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Ayşegül TOY & Adalet HAZAR & Şenol BABUŞCU

The Relationship Between Couples' Educational Pairings and Fertility: Evidence from Türkiye
Selçuk GEMİCİOĞLU & Gamze KARGIN-AKKOÇ

The Relative Development Levels of Independent Turkic States: Strengths and Weaknesses of the Countries
Aytekin ALTIPARMAK & Hayriye ATIK

Why Do Some Civilisations Collapse? An Evolutionary Game Theory Model of Societal Decline
Araş YOLUSEVER

Innovations in Monte Carlo-Based Markov Switching Tests: An Application to Türkiye's GDP Data
Anıl GÜZEL

**The Neoliberal Restructuring of Turkish Agriculture:
An Analysis of State Forms and Class Power through the Lens of Historical-Political Economy, 1960-Present**
Betül SARI-AKSAKAL

Energy Consumption in the EU: The Role of Productivity and Efficiency-Driven Technology
Mehmet Ali ÇAKIR & Mehmet Kutluhan Savaş OKTE

Digitalisation and Economic Performance: The Impact of ICT on Tourism, Exports and Investments
Cansu ÇİLİNGİR-KARA & Meliha Sena YILDIRGAN

Analysis of Firm-Specific Factors Affecting Capital Structure in Renewable Energy Firms
Yakup SÖYLEMEZ & Şenol DOĞAN

**Sustainability in the Skies:
A Tri-Dimensional Performance Evaluation of Global Airlines with Hybrid MCDM Methods**
Metecan ÇAKRAK & Gültekin ALTUNTAŞ & Yelda İNANÇ

Contextualising Subjective Well-Being Through Happiness and Life Satisfaction: A Microdata Analysis
İsmail ÇAKMAK & Selcen ÖZTÜRK & Dilek BAŞAR

Hysteresis in EU Member States: A Comprehensive Analysis Using the Fourier Approach
Yağmur SAGLAM & Sultan SALUR-KUÇUK

Financial Determinants of Tax Avoidance: Evidence from Borsa Istanbul Listed Firms
Meral GÜNDÜZ

The Effects of Geopolitical Risk on Investor Attention towards Renewable Energy: Evidence from Türkiye
Ayşegül UÇKUN-ÖZKAN & Özge KANDEMİR-KOCAASLAN

Do Sustainability Index Inclusions Impact Audit Fees? Insights from the Turkish Capital Market
Çağdaş GÜNDÜZ & Eymen GÜREL

Assessing the Effects of Political Risks on Türkiye's Trade between 1923 and 1950
İsmail ALTAY & Özgül BİLİCİ & Emel PARLAR-DAL

The Impact of Immigrants on Economic Growth Through R&D and Innovation in the EU
Zeki YILMAZ

**A Valuation of Onshore Wind Energy Investments Using a Real Options Approach:
The Case of Onshore Wind Energy in Türkiye**
Melek AKSU

**Risk Assessment in Motor Insurance Using Generalised Linear Models in Small Markets:
The Case of Bosnia and Herzegovina**
Safet KOZAREVIĆ & Slađana FILIPOVIĆ

A Qualitative Research on The Applicability of Value-Based Payment Method in The Health System of Türkiye
Merve TEKİNARSLAN & Sıdıka KAYA

Examining the Theory of Planned Behaviour in the Context of Sustainable Clothing
Nazlı DİKMEN-ÖZCAN & Beyza GÜLTEKİN

**Yeşil Örgüt Kültürü, Sürdürülebilir İş Modeli İnovasyonu ve İşletme Performansı İlişkisi:
KOBİ'ler Üzerinde Bir Araştırma**
Ayşe YAVUZ

Faiz ve Enflasyon Dinamiklerinde Yapısal Dönüşüm: Türkiye Örneğinde 2021 Sonrası Rejim Değişimi
Fatih OKUR

Türkiye'de Finansal Piyasalar Arasında Volatilité Yayılımı: TVP-VAR Modeli Uygulaması
Yüksel İLTAŞ & Adnan GÜZEL





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Content

Author(s)	Title	pp.
	Executive Summary	6
	Editörün Notu	8
<i>Research Article</i>	Impact of ESG Performance on Cost Efficiency: Evidence from the US Banking Sector Ramazan EKİNCİ	11
<i>Research Article</i>	Who Leads, Who Follows? Peer Effect on Bank Leverage Decisions in Türkiye Aysegül TOY Adalet HAZAR Şenol BABUŞCU	49
<i>Research Article</i>	The Relationship Between Couples' Educational Pairings and Fertility: Evidence from Türkiye Selçuk GEMİCİOĞLU Gamze KARGIN-AKKOÇ	67
<i>Research Article</i>	The Relative Development Levels of Independent Turkic States: Strengths and Weaknesses of the Countries Aytekin ALTIPARMAK Hayriye ATİK	91
<i>Research Article</i>	Why Do Some Civilisations Collapse? An Evolutionary Game Theory Model of Societal Decline Aras YOLUSEVER	115
<i>Research Article</i>	Innovations in Monte Carlo-Based Markov Switching Tests: An Application to Türkiye's GDP Data Anıl GÜZEL	145
<i>Research Article</i>	The Neoliberal Restructuring of Turkish Agriculture: An Analysis of State Forms and Class Power through the Lens of Historical-Political Economy, 1960-Present Betül SARI-AKSAKAL	161
<i>Research Article</i>	Energy Consumption in the EU: The Role of Productivity and Efficiency-Driven Technology Mehmet Ali ÇAKIR Mehmet Kutluğhan Savaş ÖKTE	189
<i>Research Article</i>	Digitalisation and Economic Performance: The Impact of ICT on Tourism, Exports and Investments Cansu ÇİLİNGİR-KARA Meliha Sena YILDIRGAN	207
<i>Research Article</i>	Analysis of Firm-Specific Factors Affecting Capital Structure in Renewable Energy Firms Yakup SÖYLEMEZ Şenol DOĞAN	223
<i>Research Article</i>	Sustainability in the Skies: A Tri-Dimensional Performance Evaluation of Global Airlines with Hybrid MCDM Methods Metecan ÇAKRAK Gültekin ALTUNTAŞ Yelda İNANÇ	241
<i>Research Article</i>	Contextualising Subjective Well-Being Through Happiness and Life Satisfaction: A Microdata Analysis İsmail ÇAKMAK Selcen ÖZTÜRK Dilek BAŞAR	265
<i>Research Article</i>	Hysteresis in EU Member States: A Comprehensive Analysis Using the Fourier Approach Yağmur SAĞLAM Sultan SALUR-KÜÇÜK	289

<i>Research Article</i>	Meral GÜNDÜZ	Financial Determinants of Tax Avoidance: Evidence from Borsa İstanbul Listed Firms Vergiden Kaçınmanın Finansal Belirleyicileri: Borsa İstanbul'da İşlem Gören Firmalardan Kanıtlar	301
<i>Research Article</i>	Ayşegül UÇKUN-ÖZKAN Özge KANDEMİR-KOCAASLAN	The Effects of Geopolitical Risk on Investor Attention towards Renewable Energy: Evidence from Türkiye Jeopolitik Risklerin Yenilenebilir Enerjiye Yönelik Yatırımcı Dikkati Üzerindeki Etkileri: Türkiye Örneği	319
<i>Research Article</i>	Çağdaş GÜNDÜZ Eymen GÜREL	Do Sustainability Index Inclusions Impact Audit Fees? Insights from the Turkish Capital Market Sürdürülebilirlik Endeksine Dahil Olmak Denetim Ücretlerini Etkiler Mi? Türk Sermaye Piyasasından Bulgular	343
<i>Research Article</i>	İsmail ALTAY Özgül BİLİCİ Emel PARLAR-DAL	Assessing the Effects of Political Risks on Türkiye's Trade between 1923 and 1950 Politik Risklerin Türkiye'nin Ticareti Üzerindeki Etkilerinin Değerlendirilmesi: 1923-1950	363
<i>Research Article</i>	Zeki YILMAZ	The Impact of Immigrants on Economic Growth Through R&D and Innovation in the EU AB'de Göçmenlerin AR-GE ve İnovasyon Yoluyla Ekonomik Büyümeye Etkisi	395
<i>Research Article</i>	Melek AKSU	A Valuation of Onshore Wind Energy Investments Using a Real Options Approach: The Case of Onshore Wind Energy in Türkiye Reel Opsiyon Yaklaşımı ile Kara Tipi Rüzgâr Enerjisi Yatırımlarının Değerlemesi: Türkiye'de Kara Tipi Rüzgâr Enerjisi Yatırımı Örneği	413
<i>Research Article</i>	Safet KOZAREVIĆ Sladana FILIPOVIĆ	Risk Assessment in Motor Insurance Using Generalised Linear Models in Small Markets: The Case of Bosnia and Herzegovina Küçük Ölçekli Pazarlarda Genelleştirilmiş Doğrusal Modeller Kullanılarak Motorlu Taşıt Sigortasında Risk Değerlendirmesi: Bosna Hersek Örneği	433
<i>Research Article</i>	Merve TEKİNARSLAN Sıdıka KAYA	A Qualitative Research on The Applicability of Value-Based Payment Method in The Health System of Türkiye Değer Bazlı Geri Ödeme Yönteminin Türkiye Sağlık Sisteminde Uygulanabilirliği Üzerine Nitel Bir Araştırma	453
<i>Research Article</i>	Nazlı DİKMEN-ÖZCAN Beyza GÜLTEKİN	Examining the Theory of Planned Behaviour in the Context of Sustainable Clothing Planlanmış Davranış Teorisinin Sürdürülebilir Giyim Ürünleri Bağlamında İncelenmesi	473
<i>Research Article</i>	Ayşe YAVUZ	Yeşil Örgüt Kültürü, Sürdürülebilir İş Modeli İnovasyonu ve İşletme Performansı İlişkisi: KOBİ'ler Üzerinde Bir Araştırma The Relationship Between Green Organisational Culture, Sustainable Business Model Innovation, and Business Performance: A Study for SMEs	491
<i>Research Article</i>	Fatih OKUR	Faiz ve Enflasyon Dinamiklerinde Yapısal Dönüşüm: Türkiye Örneğinde 2021 Sonrası Rejim Değişimi Structural Transformation in Interest Rate and Inflation Dynamics: The Case of Türkiye's Post-2021 Policy Regime Shift	513
<i>Research Article</i>	Yüksel İLTAŞ Adnan GÜZEL	Türkiye'de Finansal Piyasalar Arasında Volatilité Yayılmı: TVP-VAR Modeli Uygulaması Volatility Spillover Among Financial Markets in Türkiye: An Application of the TVP-VAR Model	533
	Notes for Contributors		560
	Yazarlara Duyuru		561

Executive Summary

The 69th issue (Vol. 34) of *Sosyoekonomi Journal* for the year 2026 features 25 original research articles that address various dimensions of economics, finance, public finance, environment, technology, energy, and management sciences, adopting an interdisciplinary approach. The studies in this issue shed light on current, multidimensional topics such as macroeconomic stability, green growth, sustainability, applications of artificial intelligence, financial market risks, and social dynamics, making significant contributions to the academic literature.

In the first article, Ekinci examines the impact of Environmental, Social, and Governance (ESG) performance on cost efficiency in the US banking sector using the single-stage stochastic frontier analysis (SFA) method, revealing that ESG performance, particularly its environmental and governance components, significantly and positively increases cost efficiency. The second article, authored by Toy, Hazar, and Babuşcu, analyses the role of peer effects on banks' leverage decisions in the Turkish banking sector using the Panel-Corrected Standard Errors (PCSE) method, finding that banks are influenced by their peers' financial behaviours when making leverage decisions. In the third article, Gemicioglu and Kargin-Akkoç explore the relationship between couples' educational matching and fertility outcomes in Türkiye using 2018 Türkiye Demographic and Health Survey (TDHS) data and the GPRM model, demonstrating that among homogamous couples, those with a "high-high" education level are less likely to have children compared to couples with a "low-low" match.

In the fourth article by Altıparmak and Atik, the development levels of the Independent Turkic States across 156 countries are determined using principal component and cluster analyses, emphasising that Kyrgyzstan, Türkiye, and Uzbekistan are in a similar development cluster, whereas Kazakhstan, Azerbaijan, and Turkmenistan are in different clusters. The fifth article, prepared by Yolusever, models societal collapse within the framework of evolutionary game theory (EGT) and replicator dynamics, demonstrating that resource depletion, institutional fragility, and inequality create favourable conditions for collapse. In the sixth article, Güzel applies Monte Carlo-based Markov regime-switching tests (LMC-LRT and MMC-LRT) to analyse Türkiye's quarterly GDP data (1998-2024), revealing that the MSAR model confirms structural breaks and captures two distinct economic regimes with different means and variances.

In the seventh article, Sarı-Aksakal reads the transformation of Turkish agriculture from 1960 to the present through the lens of historical political economy, arguing that neoliberal restructuring prompted by recommendations from international financial institutions has eroded food sovereignty and rendered rural production fragile and vulnerable to global crises. The eighth article, authored by Çakır and Ökte, analyses the impact of productivity and efficiency-oriented technology on energy consumption in EU countries using the AMG method, finding that multifactor productivity and efficiency-oriented innovations significantly reduce energy consumption. In the ninth article, Çilingir-Kara and Yıldırğan investigate the long- and short-term impacts of Information and Communication Technology (ICT) investments on tourism, exports, and foreign direct investments (FDI) in 12 emerging economies using the PMG-ARDL approach, reporting a statistically significant negative relationship between ICT expenditures and these three indicators in the long run.

In the tenth article of this issue, Söylemez and Doğan examine the factors affecting the capital structures of the world's 10 leading renewable energy firms through multiple linear regression analysis, finding a significant and negative relationship between firm leverage and profitability, size, asset structure, tax, and liquidity variables, thereby confirming the pecking order theory. In the eleventh article, Çakrak, Altuntaş, and İnanç evaluate the corporate sustainability performance of global airline companies using the Entropy and TOPSIS hybrid Multi-Criteria Decision Making (MCDM) framework, determining that China Southern, China Eastern, and American Airlines exhibit the highest performance. In the twelfth article prepared by Çakmak, Öztürk, and Başar, direct and indirect factors affecting subjective well-being in Türkiye are examined using pseudo-panel data and path analysis, highlighting the complex relationship between education and well-being: higher education negatively affects happiness but positively affects life satisfaction.

In the thirteenth article, Sağlam and Salur-Küçük analyse the persistence of inflation and unemployment in EU member countries using the Fourier KPSS test and ECM Bootstrap analysis, revealing that inflation is persistent in many EU countries and that the hysteresis effect in unemployment is prominent in countries such as Germany and Ireland. The fourteenth article, written by M. Gündüz, examines the impact of financial variables on tax avoidance among BIST50 index companies, establishing that deferred tax expense, capital intensity, and profitability negatively affect the effective tax rate (ETR), whereas transfer pricing positively affects it. In the fifteenth article, Uçkun-Özkan and Kandemir-Kocaaslan analyse how geopolitical risks (GPR) and global

economic uncertainties (WUI) affect investors' attention to renewable energy, focusing on Türkiye via the Google Search Volume Index.

The sixteenth article, authored by Gündüz and Gürel, investigates the impact of inclusion in the sustainability index on audit fees within the BIST 50 Index; they determine that inclusion in the index has no significant effect, but firm age, total assets, and group affiliation increase audit fees. In the seventeenth article written by Altay, Bilici, and Parlar-Dal, the effects of political risks on Türkiye's foreign trade in the early years of the Republic period (1923-1950) are evaluated with an augmented gravity model, finding that geopolitical risks negatively affect trade, but tensions in bilateral relations do not harm trade. In the eighteenth article, penned by Yılmaz, the impact of immigrants on economic growth through R&D and innovation in EU countries is analysed via the ARDL bounds test, emphasising that skilled labour contributes to these processes and positively affects economic growth.

In the nineteenth article, Aksu evaluates an onshore wind energy investment in Türkiye using traditional methods and the abandonment real option approach, demonstrating that managerial flexibility increases the investment's strategic net present value. The twentieth article, authored by Kozarević and Filipović, assesses risk in motor vehicle insurance in Bosnia and Herzegovina using Generalised Linear Models (GLM) and shows that premiums are generally underpriced compared to current market tariffs. In the twenty-first article of this issue, Tekinarslan and Kaya examine the applicability of the value-based reimbursement method in the Turkish health system through qualitative research and the Delphi technique, stating that stakeholders support this model and defining 15 core value measurement parameters.

In the twenty-second article written by Dikmen-Özcan and Gültekin, the Theory of Planned Behaviour model is extended in the context of sustainable apparel products by adding dimensions of environmental concern, price sensitivity, and love of money, revealing that attitude toward behaviour, subjective norm, environmental concern, and the wealth dimension of love of money positively affect behavioural intention. In the twenty-third article, Yavuz analyses the relationships among green organisational culture, sustainable business model innovation, and firm performance in SMEs, determining that sustainable business model innovations play a mediating role in the effect of green culture on performance. The twenty-fourth article, signed by Okur, examines regime change in interest and inflation dynamics in Türkiye during the 2015-2024 period using the ARDL model and the Toda-Yamamoto causality test, finding a directional change in the interest-inflation relationship in the post-September 2021 period, consistent with a structural transformation and the Neo-Fisher effect. In the final article of this issue, İltaş and Güzel investigate volatility spillovers among financial markets (BIST 100, USD/TRY exchange rate, gold, bonds, etc.) in Türkiye using the TVP-VAR method, reporting that the USD/TRY exchange rate, as the strongest source of volatility in the financial system, significantly affects the CDS premium, BIST 100, and bond yields.

In the complex transformation processes we are going through at the global and local levels, we carry forward our mission of applying an analytical lens to multidimensional economic and social issues with this issue. We hope that these 25 valuable studies, which blend methodological innovations and interdisciplinary perspectives, will open new research frontiers in academia and serve as a solid, data-driven reference for policymakers.

We offer our deepest gratitude to our esteemed authors who continuously elevate the scientific competence and international quality standards of *Sosyoekonomi Journal*, to our invaluable referees who enhance the academic depth of the works introduced to the literature with their rigorous and constructive evaluations, and to our editorial board who work with great devotion at every stage of the process. Hoping to meet again in our upcoming issues, where we will continue to make sense of the new dynamics of the increasingly digitalising and transforming global ecosystem, we wish all our readers productive and inspiring reading.

Dr. Emre ATSAN

Co-Editor-in-Chief

Editörün Notu

Sosyoekonomi Dergisi'nin 2026 yılına ait 69. sayısı (Cilt: 34), iktisat, finans, kamu maliyesi, çevre, teknoloji, enerji ve yönetim bilimlerinin çeşitli boyutlarını disiplinlerarası bir yaklaşımla ele alan 25 özgün araştırma makalesine ev sahipliği yapmaktadır. Bu sayıda yer alan çalışmalar, makroekonomik istikrar, yeşil büyüme, sürdürülebilirlik, yapay zekâ uygulamaları, finansal piyasa riskleri ve toplumsal dinamikler gibi güncel ve çok boyutlu konulara ışık tutarak akademik literatüre önemli katkılarda bulunmaktadır.

İlk makalede Ekinci, ABD bankacılık sektöründe Çevresel, Sosyal ve Yönetişim (ESG) performansının maliyet etkinliği üzerindeki etkisini tek aşamalı stokastik sınır analizi (SFA) yöntemiyle incelemekte; ESG performansının, özellikle çevresel ve yönetim bileşenlerinin maliyet etkinliğini anlamlı ve pozitif yönde artırdığını ortaya koymaktadır. İkinci makale, Toy, Hazar ve Babuşcu tarafından kaleme alınmış olup, Türk bankacılık sektöründe akran etkisinin banka kaldıraç kararları üzerindeki rolünü Panel-Corrected Standard Errors (PCSE) yöntemiyle analiz etmekte ve bankaların kaldıraç kararlarını alırken akranlarının finansal davranışlarından etkilendiklerini saptamaktadır. Üçüncü sıradaki makalede Gemicioğlu ve Kargın-Akkoç, Türkiye'de çiftlerin eğitimsel eşleşmeleri ile doğurganlık sonuçları arasındaki ilişkiyi 2018 Türkiye Nüfus ve Sağlık Araştırması (TNSA) verileri ve GPRM modeliyle irdeleyerek, homogamik çiftler içinde eğitim düzeyi "yüksek-yüksek" olanların "düşük-düşük" eşleşmeye sahip çiftlere kıyasla daha az çocuk sahibi olmaya meyilli olduğunu göstermektedir.

Altıparmak ve Atik tarafından yazılan dördüncü makalede, Bağımsız Türk Devletlerinin 156 ülke arasındaki kalkınma düzeyleri temel bileşenler ve kümeleme analizleriyle belirlenmekte; Kırgızistan, Türkiye ve Özbekistan'ın benzer bir gelişme kümesinde yer aldığı, Kazakistan ile Azerbaycan ve Türkmenistan'ın ise farklı kümelerle dahil olduğu vurgulanmaktadır. Beşinci makale, Yolusever tarafından hazırlanmış olup, evrimsel oyun teorisi (EOT) ve çoğaltıcı dinamikler çerçevesinde toplumsal çöküş kavramını modellemekte; kaynakların tükenmesi, kurumların kırılganlığı ve eşitsizliğin çöküşe elverişli koşullar yarattığını saptamaktadır. Altıncı makalede Güzel, Türkiye'nin çeyreklik GSYİH verilerini (1998-2024) analiz etmek için Monte Carlo tabanlı Markov rejim değişimi testlerini (LMC-LRT ve MMC-LRT) uygulamakta; MSAR modelinin yapısal kırılmaları doğruladığını ve ortalamaları ile varyansları farklılık gösteren iki ayrı ekonomik rejimi yakaladığını ortaya koymaktadır.

Yedinci makalede Sarı-Aksakal, Türkiye tarımının 1960'tan günümüze kadarki dönüşümünü tarihsel-siyasal iktisat merceğinden okumakta; uluslararası finans kuruluşlarının telkinleriyle tetiklenen neoliberal yeniden yapılandırmanın gıda egemenliğini aşındırıp kırsal üretimi küresel krizlere açık ve kırılgan hale getirdiğini belirtmektedir. Sekizinci sırada yer alan makale, Çakır ve Ökte tarafından kaleme alınmış olup AB ülkelerinde üretkenlik ve verimlilik odaklı teknolojinin enerji tüketimine etkisini AMG yöntemiyle analiz etmektedir; çok faktörlü verimliliğin ve verimlilik odaklı inovasyonların enerji tüketimini önemli ölçüde azalttığını saptamaktadır. Dokuzuncu makalede Çilingir-Kara ve Yıldız, 12 gelişmekte olan ekonomide Bilgi ve İletişim Teknolojileri (BİT) yatırımlarının turizm, ihracat ve doğrudan yabancı yatırımlar (DYY) üzerindeki uzun ve kısa vadeli etkilerini PMG-ARDL yaklaşımıyla incelemekte; BİT harcamalarının bu üç göstergelye uzun vadede istatistiksel olarak anlamlı negatif bir ilişki içinde olduğunu raporlamaktadır.

Bu sayının onuncu makalesinde Söylemez ve Doğan, dünyanın önde gelen 10 yenilenebilir enerji firmasının sermaye yapılarına etki eden faktörleri çoklu doğrusal regresyon analizi ile incelemekte; firma kaldıraç ile kârlılık, büyüklük, varlık yapısı, vergi ve likidite değişkenleri arasında anlamlı ve negatif bir ilişki bularak finansal hiyerarşi teorisini doğrulamaktadır. On birinci makalede Çakrak, Altuntaş ve İnanc, küresel hava yolu işletmelerinin kurumsal sürdürülebilirlik performansını Entropi ve TOPSIS melez Çok Kriterli Karar Verme (ÇKKV) çerçevesiyle değerlendirecek en yüksek performansı China Southern, China Eastern ve American Airlines'ın sergilediğini saptamaktadır. Çakmak, Öztürk ve Başar tarafından hazırlanan on ikinci makalede, Türkiye'de öznal iyi oluş üzerinde doğrudan ve dolaylı etkili faktörler pseudo-panel veri ve path analiziyle incelenmekte; yükseköğrenimin mutluluğu olumsuz, yaşam memnuniyetini ise olumlu yönde etkilediği bulgulanarak eğitim ile iyi oluş arasındaki karmaşık yapıya dikkat çekilmektedir.

On üçüncü makalede Sağlam ve Salur-Küçük, AB üyesi ülkelerde enflasyon ve işsizliğin kalıcılığını Fourier KPSS testi ve ECM Bootstrap analiziyle incelemekte; birçok AB ülkesinde enflasyonun kalıcı olduğunu, Almanya ve İrlanda gibi ülkelerde ise işsizlikte histerezis etkisinin belirgin olduğunu ortaya koymaktadır. On dördüncü makale M. Gündüz tarafından yazılmış olup, BIST50 endeksindeki şirketlerde finansal değişkenlerin vergiden kaçınma üzerindeki etkisini incelemekte; ertelenmiş vergi giderinin, sermaye yoğunluğunun ve kârlılığın etkin vergi oranını (ETR) negatif, transfer fiyatlandırmasının ise pozitif yönde etkilediğini saptamaktadır. On beşinci makalede Uçkun-Özkan ve Kandemir-Kocaaslan, jeopolitik risklerin (GPR) ve küresel belirsizliklerin

(WUI) yatırımcıların yenilenebilir enerjiye olan dikkatini Google Arama Hacmi Endeksi üzerinden Türkiye odaklı olarak nasıl etkilediğini analiz etmektedir.

On altıncı makale Ç. Gündüz ve Gürel tarafından kaleme alınmış olup, BIST 50 Endeksi'nde sürdürülebilirlik endeksinde dahil olmanın denetim ücretleri üzerindeki etkisini incelemek; endekse dahil olmanın anlamlı bir etkisi olmadığını, ancak firma yaşı, toplam varlıklar ve grup bağlantısının denetim ücretlerini artırdığını tespit etmektedir. On yedinci sırada yer alan Altay, Bilici ve Parlar-Dal tarafından yazılan makalede, Cumhuriyet döneminin ilk yıllarında (1923-1950) politik risklerin Türkiye'nin dış ticareti üzerindeki etkileri genişletilmiş çekim modeliyle değerlendirilmekte; jeopolitik risklerin ticareti olumsuz etkilediği ancak ikili ilişkilerdeki gerginliklerin ticarete zarar vermediği saptanmaktadır. Yılmaz tarafından kaleme alınan on sekizinci makalede, AB ülkelerinde göçmenlerin AR-GE ve inovasyon yoluyla ekonomik büyümeye etkileri ARDL sınır testiyle analiz edilmekte ve nitelikli işgücünün süreçlere katkı sağlayarak ekonomik büyümeyi olumlu etkilediği vurgulanmaktadır.

On dokuzuncu makalede Aksu, Türkiye'de bir kara tipi rüzgâr enerjisi yatırımını geleneksel yöntemler ve terk etme reel opsiyon yaklaşımı kullanarak değerlemekte; yönetsel esnekliğin yatırımın stratejik net bugünkü değerini nasıl artırdığını saptamaktadır. Yirminci sıradaki makale, Kozarević ve Filipović tarafından kaleme alınmış olup Bosna-Hersek'te motorlu taşıt sigortasında risk değerlendirmesini Genelleştirilmiş Doğrusal Modeller (GLM) kullanarak yapmaktadır ve mevcut piyasa tarifelerine göre primlerin genellikle düşük fiyatlandırıldığını göstermektedir. Bu sayının yirmi birinci makalesinde Tekinarslan ve Kaya, Türkiye sağlık sisteminde değer bazlı geri ödeme yönteminin uygulanabilirliğini nitel araştırma ve Delphi tekniğiyle incelemek; paydaşların bu modeli desteklediğini belirterek 15 temel değer ölçüm parametresi tanımlamaktadır.

Dikmen-Özcan ve Gültekin tarafından yazılan yirmi ikinci makalede, Planlanmış Davranış Teorisi modeli sürdürülebilir giyim ürünleri bağlamında çevresel kaygı, fiyat duyarlılığı ve para sevgisi boyutları eklenerek genişletilmekte; davranışa yönelik tutum, öznel norm, çevresel kaygı ve para sevgisinin zenginlik boyutunun davranışsal niyeti olumlu etkilediği ortaya konmaktadır. Yirmi üçüncü makalede Yavuz, KOBİ'lerde yeşil örgüt kültürü, sürdürülebilir iş modeli inovasyonu ve işletme performansı arasındaki ilişkileri analiz etmekte; yeşil kültürün performans üzerindeki etkisinde sürdürülebilir iş modeli inovasyonlarının aracı rol oynadığını belirlemektedir. Yirmi dördüncü sıradaki Okur imzalı makale, Türkiye'de 2015-2024 döneminde faiz ve enflasyon dinamiklerindeki rejim değişimini ARDL modeli ve Toda-Yamamoto nedensellik testiyle inceleyerek, 2021 Eylül sonrası dönemde faiz-enflasyon ilişkisinde bir yön değişimi yaşandığını ve bunun Neo-Fisher etkisiyle uyumlu yapısal bir dönüşüm olduğunu saptamaktadır. Bu sayının son makalesinde İltaş ve Güzel, Türkiye'de finansal piyasalar (BIST 100, USD/TL kuru, altın, tahvil vb.) arasındaki volatilité yayılımını TVP-VAR yöntemiyle incelemek; USD/TL kurunun finansal sistemdeki en güçlü volatilité kaynağı olarak CDS primini, BIST 100 ve tahvil faizini belirgin biçimde etkilediğini raporlamaktadır.

Küresel ve yerel düzeyde içinden geçtiğimiz karmaşık dönüşüm süreçlerinde, çok boyutlu ekonomik ve toplumsal meselelere analitik bir mercek tutma misyonumuzu bu sayımızla bir adım daha ileri taşıyoruz. Metodolojik yenilikleri ve disiplinlerarası bakış açılarını harmanlayan bu 25 kıymetli çalışmanın akademi dünyasında yeni araştırma sınırlarına kapı aralmasını ve politika yapıcılar için sağlam, veriye dayalı bir referans kaynağı olmasını umut ediyoruz.

Sosyoekonomi Dergisi'nin bilimsel yetkinliğini ve uluslararası standartlardaki kalitesini her geçen gün daha da yukarı taşıyan değerli yazarlarımıza, titiz ve yapıcı değerlendirmeleriyle literatüre kazandırılan eserlerin akademik derinliğini artıran kıymetli hakemlerimize ve sürecin her aşamasında büyük bir özveriyle çalışan yayın kurulumuza en derin şükranlarımızı sunarız. Giderek dijitalleşen ve dönüşen küresel ekosistemin yeni dinamiklerini anlamlandırmaya devam edeceğimiz gelecek sayılarımızda yeniden buluşmak ümidiyle, tüm okurlarımıza verimli ve ilham verici okumalar dileriz.

Dr. Emre ATSAN

Yayın Kurulu Başkan Yardımcısı

Impact of ESG Performance on Cost Efficiency: Evidence from the US Banking Sector

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ESG Performansının Maliyet Etkinliği Üzerindeki Etkisi: ABD Bankacılık Sektöründen Kanıtlar

Abstract

This paper examines the impact of Environmental, Social, and Governance (ESG) performance on the cost efficiency of U.S. banks from 2016 to 2023 using a one-step stochastic frontier analysis (SFA). The results reveal that ESG performance enhances cost efficiency, with environmental and governance components having significant positive effects, while the social component shows mixed results. An endogenous SFA model further confirms that all ESG dimensions positively affect efficiency, even after accounting for endogeneity. This paper contributes to the literature by providing recent evidence on the U.S. banking system, addressing endogeneity, and offering practical insights for bank managers and policymakers seeking to improve efficiency through ESG integration.

Keywords : Cost Efficiency, ESG, Stochastic Frontier Analysis (SFA).

JEL Classification Codes : D20, G21, P34.

Öz

Bu çalışma, 2016-2023 dönemi için ABD bankalarında Çevresel, Sosyal ve Yönetişim (ESG) performansının maliyet etkinliği üzerindeki etkisini tek aşamalı stokastik sınır analizi (SFA) yöntemiyle incelemektedir. Bulgular, ESG performansının maliyet etkinliğini artırdığını; çevresel ve yönetim bileşenlerinin anlamlı ve pozitif etkiler yarattığını; sosyal bileşenin ise karışık sonuçlar sunduğunu ortaya koymaktadır. Ayrıca, içsellik sorununu dikkate alan endojen SFA modeli, tüm ESG bileşenlerinin etkinlik üzerinde pozitif etkisini doğrulamaktadır. Çalışma, ABD bankacılık sistemine yönelik güncel kanıtlar sunarak ve içsellik sorununu ele alarak literatüre katkı sağlamakta; ayrıca, banka yöneticileri ile politika yapıcılara, ESG entegrasyonunun maliyet etkinliğini artırmadaki rolüne ilişkin pratik öneriler sunmaktadır.

Anahtar Sözcükler : Maliyet Etkinliği, ESG, Stokastik Sınır Analizi (SFA).

1. Introduction

As global awareness of climate change, social inequality, and corporate governance rises, consumers are demanding greater responsibility from businesses, including banks. This shift, accelerated by challenges like the COVID-19 pandemic, has led consumers to prioritise environmental, social, and governance (ESG) values over traditional factors like service quality and product offerings. Today, consumers are closely examining how financial institutions align with their values, particularly in sustainability and ethical governance. Major banks, such as JPMorgan Chase and Bank of America, are setting sustainability goals, signalling that ESG is now a core priority rather than just a marketing tool. To meet the changing demands of consumers, banks are investing in renewable energy initiatives, issuing green bonds, and offering investment options aligned with ESG principles. By adopting these values, banks and financial institutions not only meet consumer expectations but also help address critical global issues such as climate change and social inequality.

ESG has become a fundamental element for companies aiming to generate long-term value (Cek & Eyupoglu, 2020; Velte, 2017). The assumption is that companies that prioritise long-term sustainability and growth are more likely to attract long-term investors. Therefore, the market plays a significant role in motivating companies to adopt ESG practices (Eliwa et al., 2019). Companies that emphasise ESG are seen as more attractive investment opportunities, particularly for investors focused on sustainable and long-term growth (Aslan-Çetin et al., 2024; Buallay, 2019). Therefore, investors are increasingly considering ESG factors in their decision-making processes (Azmi et al., 2021). However, the degree to which ESG factors influence investor preferences remains subject to debate. While studies such as Buallay (2019) and Gül & Altuntaş (2024) find that strong ESG performance attracts long-term investors and reduces market volatility, others argue that investor responses vary significantly across regions and sectors (Friede et al., 2015). In particular, ESG preferences are often contingent upon institutional contexts, regulatory frameworks, and cultural norms (Kotsantonis et al., 2016). Therefore, understanding how ESG influences investor behaviour in the banking sector requires further contextualised and sector-specific research, which this study aims to contribute to. In addition, ESG serves as an important risk management tool, allowing companies to detect and address potential problems before they escalate (Chen et al., 2023). Companies with a strong focus on ESG tend to see higher returns and less stock price volatility (Gül & Altuntaş, 2024). Additionally, ESG performance can reduce the cost of equity (Chen et al., 2023), helping companies manage operational and market risks by leveraging ESG factors (Chen et al., 2023).

Financial markets today are undergoing a transformation that emphasises not only short-term profitability but also long-term sustainability. ESG criteria lie at the core of this transformation. The banking sector is also affected by this transformation, and the impact of ESG practices on corporate performance is being increasingly studied. The transformation of the financial system towards sustainability makes it imperative for the banking sector to align with ESG criteria. The banking industry affects the economy as a whole by providing

credit and contributing to its stability. As banks play a central role in the financial system, they are essential to achieving sustainable development goals. The adoption of ESG standards is essential not only for ethical considerations but also for their profound impact on financial outcomes, risk strategies, and competitive advantage. Growing regulatory requirements, investor demands, and evolving market conditions have recently brought ESG performance and its financial implications to the forefront of academic research (Gangi et al., 2020; Martiny et al., 2024).

Although numerous studies have examined the relationship between ESG performance and firm-level financial outcomes, the literature on banks, especially regarding cost efficiency, remains limited. For instance, while studies like Fatemi et al. (2018) and Nizam et al. (2019) suggest that ESG practices enhance operational efficiency and reduce capital costs, other works (e.g., Wang et al., 2023; Bagh et al., 2024) highlight the diminishing returns and potential cost burdens of extensive ESG investments. This inconsistency reflects a lack of consensus, particularly on the optimal level and allocation of ESG resources in the banking sector.

Moreover, much of the existing research applies two-step estimation methods (e.g., Battese & Coelli, 1995), which may introduce endogeneity bias by treating ESG as an exogenous factor. However, as noted by Azmi et al. (2021) and Gangi et al. (2019), ESG decisions are often endogenous to bank performance and strategic priorities. Hence, there is a need for empirical approaches that simultaneously account for ESG and efficiency dynamics, such as the endogenous stochastic frontier model of Karakaplan and Kutlu (2017), which remains underutilised in banking studies. Therefore, this study adopts a one-step SFA approach that simultaneously accounts for inefficiency and endogeneity, offering a more robust efficiency estimation framework. In addition, while most studies (e.g., Liang et al., 2024; Algeri et al., 2025) investigate the impact of ESG scores on the cost efficiency of European banks using a parametric SFA approach, this paper extends the geographical scope to U.S. commercial banks.

Furthermore, many prior studies focus on aggregate ESG scores without disaggregating the specific roles of environmental, social, and governance pillars, even though these dimensions may have divergent impacts on efficiency. For example, while environmental initiatives often bring long-term cost savings (e.g., through energy efficiency), social programs may involve short-term labour or compliance costs that dilute their immediate benefits (Clark et al., 2015; Chiaramonte et al., 2022).

Therefore, this study contributes to the literature by offering a more nuanced, dimension-specific analysis of ESG and cost efficiency, using recent data (2016-2023) and addressing potential endogeneity. In doing so, it not only fills a methodological gap but also provides clarity on the heterogeneous effects of ESG subcomponents in the U.S. banking sector.

ESG factors are among the key criteria considered by investors and regulators. The banking sector has seen significant attention to ESG, with banks incorporating these factors into their strategies due to their impact on long-term sustainability and profitability (Citterio & King, 2023). Depending on their investment strategies, banks support green infrastructure such as water systems, waste management, and renewable energy projects (Barua, 2020). They also set up funds, such as the Climate Change Risk Fund, to address environmental concerns. This highlights the significant role of banks in fulfilling their primary social responsibility, as neglecting this duty could have severe consequences for society as a whole (Dikau & Volz, 2021). Despite the normative emphasis on social responsibility, there remains a lack of clarity about the mechanisms by which banks' ESG activities translate into tangible societal benefits. Barua (2020) and Citterio & King (2023) suggest that green infrastructure financing contributes to long-term sustainability. Yet, there is limited empirical evidence linking these projects to concrete efficiency or stability outcomes at the bank level. This study contributes to filling this gap by investigating how ESG implementation, particularly in environmental and governance dimensions, affects banks' cost efficiency. This crucial intermediate outcome links ESG efforts with broader developmental goals. The importance of sustainability in financial markets is increasingly growing.

Banks that adopt ESG principles in their operations stand to gain several benefits, including reduced risks, improved reputation, and increased stakeholder trust (Chiamonte et al., 2022; Gangi et al., 2022). By integrating ESG values into their business models, banks can also identify new growth prospects and enhance their financial performance (Arun et al., 2022; El Khoury et al., 2023). Recently, regulators have placed greater focus on ESG issues, prompting many countries to implement mandatory ESG reporting requirements for banks. This trend is anticipated to persist as ESG continues to grow in importance within the banking sector (Arun et al., 2022; El Khoury et al., 2023). On the other hand, excessive investment in ESG activities may negatively impact bank value by diminishing returns to scale as more ESG initiatives are implemented, especially after high net present value activities have been exhausted (McWilliams & Siegel, 2001; Marom, 2006; Haans et al., 2016; Wang et al., 2023). Shareholders may also face indirect costs of ESG efforts, such as lower returns due to higher expenses or workforce-related changes. As a result, the net positive impact of ESG spending may be substantially reduced once it exceeds a certain threshold (Bagh et al., 2024). Azmi et al. (2021) argue that while low-level ESG activities have a positive effect on bank value, high-level ESG activities show diminishing returns. For banks investing heavily in ESG initiatives, the associated costs may reduce the overall value, despite potential benefits.

As environmental and social concerns rise, financial institutions are increasingly likely to implement sustainable investment methods. This shift raises questions about how these strategies affect bank cost efficiency and, more importantly, the role of bank stability in this relationship. In recent years, sustainable investment practices have received more attention for their potential impact on bank cost efficiency. But the impact of ESG policies on bank cost efficiency is still debated (Gangi et al., 2019). Traditionally, banks have focused

on optimising costs through lending processes, risk management, and operational expenditures. However, in recent years, ESG factors have become a critical element impacting banks' cost structures. Banks that embrace ESG principles can achieve long-term financial sustainability by lowering capital costs, improving operational efficiency, and establishing robust risk management frameworks. From a theoretical perspective, banks that prioritise ESG practices may experience lower capital costs and improved operational efficiency in the long run (Friede et al., 2015). This is largely because strong ESG performance helps reduce reputational risks, thereby lowering borrowing costs (Nizam et al., 2019), while sustainable business models enable more efficient cost management. Banks also implement cost-effective strategies to create value for their stakeholders (Azmi et al., 2021). Effective ESG risk management enhances credit risk management, ultimately supporting financial stability (Nitescu & Cristea, 2020). However, it is acknowledged that ESG investments often entail high initial costs and may negatively affect profitability in the short term (Clark et al., 2015). However, it is also noted that ESG investments incur high short-term costs, which may temporarily reduce cost efficiency (Clark et al., 2015). In particular, initiatives such as green finance projects, carbon-neutral operations, and social responsibility programs may require high upfront costs and suppress short-term profitability. Nevertheless, in the long run, ESG practices can support cost efficiency by optimising operational processes (Fatemi et al., 2018). Yet, the empirical literature remains divided on the actual cost-efficiency gains from ESG integration. While Fatemi et al. (2018) document long-run cost advantages through operational improvements, Clark et al. (2015) caution that the short-run trade-offs, such as compliance costs, technology investments, and personnel training, may outweigh immediate benefits. This ambivalence necessitates a more granular analysis, particularly for banks that are uniquely exposed to regulatory pressures, credit risks, and reputational concerns. This paper addresses this research gap by employing a stochastic frontier framework that distinguishes cost efficiency outcomes while accounting for endogeneity in ESG engagement. ESG-driven policies play a key role in reducing financial risks for banks while also enhancing cost efficiency.

In recent years, sustainable investment has grown as investors become more aware of its long-term environmental and social effects. At the same time, banks have faced increasing pressure to enhance stability and reduce costs, especially after the 2008 financial crisis. Therefore, examining the effects of sustainable investment on cost efficiency while accounting for banking stability is crucial. However, the link between cost efficiency and sustainable investment is not straightforward and requires deeper analysis. According to Fontaine & Sylvestre (2017), in the short term, the financial burden of implementing sustainable practices may outweigh the advantages, potentially raising banks' operational expenses. Nevertheless, long-term advantages such as greater customer loyalty and lower risk exposure could ultimately offset these initial costs. In essence, sustainable investment can improve cost efficiency, but its adoption should involve a thorough analysis of both financial drawbacks and expected gains. For instance, Fontaine & Sylvestre (2017) note that adopting ESG-aligned financial practices in European banks may entail short-term costs that may outweigh the expected benefits.

This study analyses the influence of ESG on bank cost efficiency using a one-step stochastic frontier analysis (SFA, henceforth) model. Although numerous studies have explored the relationships between ESG and financial performance, most fall short of explicitly addressing endogeneity or disaggregating ESG dimensions. This study addresses these critical gaps by employing a one-step SFA framework that controls for simultaneity bias and enables a dimension-specific assessment of ESG's impact on bank cost efficiency. Following Wang and Schmidt (2002), environmental variables are directly incorporated into the inefficiency component of the model to avoid the endogeneity bias associated with two-stage approaches. For the robustness analysis, in addition to the overall ESG score, we separately examine the effects of each ESG component, environmental, social, and governance, on bank efficiency to determine which component plays a more prominent role.

This study extends and complements prior literature by addressing several methodological and empirical limitations observed in earlier works. While prior research has explored ESG impacts on various performance metrics, such as profitability, stock returns, or credit ratings, the relationship between ESG and cost efficiency, especially in the U.S. banking context, has received comparatively less attention (Gangi et al., 2019; Azmi et al., 2021). The U.S. banking sector is selected as the empirical setting for this study due to its systemic importance in the global financial system, its regulatory transformation following the 2008 crisis, and its leading role in ESG adoption. Furthermore, the majority of existing research relies on two-step estimation techniques that treat ESG variables as exogenous, overlooking potential simultaneity bias (Gangi et al., 2019; Azmi et al., 2021). Additionally, few studies disaggregate ESG into its environmental, social, and governance components, despite the possibility that these dimensions exert heterogeneous effects on efficiency. To address these gaps, this study investigates the relationship between ESG performance and cost efficiency in U.S. commercial banks between 2016 and 2023, employing a one-step endogenous SFA model. The following research questions guide the analysis:

- (1) Does ESG performance enhance the cost efficiency of U.S. banks?
- (2) Do the environmental, social, and governance dimensions of ESG exert differential effects on efficiency?
- (3) Is the ESG-efficiency relationship robust when endogeneity is explicitly modelled?

The study's theoretical framework is grounded in stakeholder theory and the resource-based view (RBV). From a stakeholder perspective, responsiveness to social and environmental expectations fosters long-term sustainability by strengthening stakeholder relationships and reputational capital (Freeman, 1984; Shah et al., 2019). Concurrently, the RBV conceptualises ESG capabilities as strategic resources that are difficult to imitate and deeply embedded in organisational routines, yielding operational advantages and cost reductions (Barney, 1991; Zhou et al., 2022). In light of the theoretical background and the gaps identified in the existing literature, this study primarily aims to investigate the effect of ESG performance on the cost efficiency of U.S. commercial banks. More specifically, it

seeks to explore whether banks with higher ESG performance demonstrate superior cost efficiency compared to their peers. In addition to examining the overall ESG score, this study also evaluates the distinct impacts of each ESG pillar, Environmental (E), Social (S), and Governance (G), on cost efficiency, as existing literature suggests that these dimensions may exert heterogeneous effects. Furthermore, considering the potential endogeneity between ESG performance and bank efficiency, the study tests whether the positive association between ESG and cost efficiency remains robust when endogeneity is explicitly addressed. Based on these questions, the study proposes the following hypotheses:

Hypothesis 1: Higher overall ESG performance is associated with greater cost efficiency in U.S. commercial banks.

Hypothesis 2: The environmental and governance components of ESG have a stronger positive effect on cost efficiency than the social component.

Hypothesis 3: The relationship between ESG performance and cost efficiency remains statistically significant when endogeneity is addressed using an endogenous stochastic frontier model.

This study makes important contributions to the existing literature. First, despite its significance from both policy and research perspectives, the impact of ESG on the cost efficiency of U.S. banks has been examined in only a few studies. To address this gap, this study investigates the effects of ESG investment on bank cost efficiency for U.S. banks. Second, it examines the cost efficiency of U.S. commercial banks across the three ESG dimensions (E, S, and G), providing better insight into which dimension most effectively improves cost efficiency when banks perform ESG activities. Third, unlike the data used in previous studies focusing on the U.S. banking sector, this study utilises more recent data spanning from 2016 to 2023. This allows for a more up-to-date investigation of U.S. banks' cost efficiency and its determinants. Fourth, unlike most studies, this study uses the endogenous stochastic frontier model of Karakaplan & Kutlu (2017) to address the potential endogeneity between ESG and cost efficiency. In contrast to prior studies that rely heavily on two-step models and aggregated ESG indices, this study contributes to the academic debate by offering a unified estimation framework that accounts for endogeneity and allows dimension-specific analysis. This methodological refinement enables a more accurate understanding of ESG's impact on cost efficiency in the banking sector.

The main results of this paper, based on a sample of 253 commercial banks over the 2016-2023 period, can be summarized as follows: (i) The overall mean cost efficiency of the U.S. banking industry is 42%, indicating a significant level of inefficiency in the sector, (ii) The analysis reveals a notable positive relationship between ESG performance and cost efficiency, suggesting that banks prioritizing ESG concerns exhibit higher cost efficiency compared to others, (iii) For robustness testing, when analyzing ESG sub-components separately, the environmental (E) and governance (G) pillars are positively correlated with efficiency, and the effect of the environmental (E) pillar (coefficient: -0.001) is stronger than

that of the governance (G) pillar (coefficient: -0.0008), (iv) However, the results are mixed regarding the impact of the social (S) pillar on bank cost efficiency. While the effect of the social (S) pillar is positive, it is insignificant in the exogenous model of Battese & Coelli (1995) but becomes significant at the 10% level in the endogenous model of Karakaplan & Kutlu (2017).

The rest of the paper is structured as follows: Section 2 presents a review of the relevant literature; Section 3 outlines the methodology and dataset; Section 4 discusses the empirical results and analysis; and Section 5 concludes the study.

2. Literature Review

While numerous studies have examined the effect of ESG on firm and bank performance, research specifically focusing on ESG and bank efficiency remains scarce. To our knowledge, only a few studies address this issue, yet findings remain mixed. On one hand, studies such as Alam et al. (2021) and Cao et al. (2024) suggest that higher ESG scores may lead to improved bank efficiency through enhanced risk management and stakeholder trust. On the other hand, Forgione et al. (2020) and Fontaine & Sylvestre (2017) highlight potential short-term inefficiencies arising from ESG investments, especially when the associated costs outweigh immediate financial returns. Moreover, Alam et al. (2021) observed a nonlinear relationship where banks with exceptionally high ESG scores exhibited improved efficiency, whereas moderate ESG adopters experienced declining performance. This suggests that ESG's efficiency effects are contingent upon the degree of implementation and the bank's strategic orientation.

Several studies suggest that integrating sustainability into investment strategies may lead to improved cost efficiency, particularly over the long term, through risk reduction and enhanced customer satisfaction. For example, when Algeri et al. (2025) studied European banks, they found that banks with better sustainability ratings also achieved better efficiency. This supports the idea that sustainable investments lead to improved cost efficiency. A study by Alam et al. (2021) examined how ESG performance affects bank efficiency globally. The research utilised data from 578 banks spanning 57 countries between 2011 and 2019. Their findings indicated that while higher ESG performance generally corresponded with lower efficiency, the relationship was nonlinear: banks with significantly high ESG scores experienced efficiency gains. The authors suggest that one underlying factor in this relationship is that high ESG performance tends to reduce bank loans and other earning assets, thereby impacting efficiency. Chang et al. (2021) conducted a study of 145 Asian-listed banks from 2015 to 2018, covering both developed and developing economies. Applying the SFA method, their findings revealed that environmental factors enhanced banks' cost efficiency only in developed Asian countries. However, governance had a negative impact on cost efficiency in developed economies, whereas it had a positive impact in developing economies. The study also suggests that socially responsible practices and strong governance contributed to greater cost efficiency for banks in developing countries, likely driven by improved reputations and increased consumer confidence. Alam et al.

(2022) analysed the influence of ESG initiatives on the efficiency of both traditional and Islamic banks. Their findings indicated that ESG activities positively affected the efficiency of traditional banks, whereas the impact on Islamic banks was not statistically significant. However, ESG efforts still played a role in enhancing overall efficiency in both banking models. Likewise, Cao et al. (2024) examined how ESG factors influence the profit efficiency of Chinese banks using an SFA model. Their study revealed that greater ESG contribute positively to bank efficiency. Specifically, the research highlighted that investments in environmental and governance aspects improve efficiency, whereas social factors tend to have a negative effect.

The existing literature predominantly examines the impact of overall ESG scores on bank efficiency. At the same time, studies that disaggregate and analyse the individual effects of the environmental, social, and governance (E, S, and G) components remain relatively scarce. However, such disaggregation is crucial, as each dimension may exert a distinct influence on bank efficiency. Recognising these heterogeneous effects not only enriches the empirical understanding of ESG-performance linkages but also strengthens the relevance of policy recommendations by enabling more targeted and dimension-specific strategies to enhance bank efficiency. For instance, the environmental dimension has been found to positively contribute to cost efficiency across various contexts. Zhou et al. (2022) and Chang et al. (2021) demonstrate that green investments, emissions reduction efforts, and innovation-oriented environmental policies can generate long-term operational savings and mitigate regulatory risks. These effects tend to be more pronounced in developed economies, where regulatory frameworks actively incentivise environmental performance. Despite these promising findings, evidence specifically focusing on U.S. banks remains limited, leaving an important empirical gap. The social dimension, encompassing workforce welfare, human rights, and community engagement, shows more ambiguous or inconsistent effects on efficiency. Studies such as Alam et al. (2022) and Cao et al. (2024) indicate that while social initiatives may enhance reputation and stakeholder trust, they often lack immediate financial returns, resulting in statistically insignificant or even negative associations with cost efficiency. These mixed findings may be attributed to measurement challenges and the long-term nature of social benefits. In contrast, the governance pillar is more consistently associated with improved efficiency outcomes. Strong governance practices, including shareholder rights, board independence, and the integration of CSR strategies, can reduce agency costs, enhance transparency, and better align managerial actions with long-term organisational goals. This view is supported by Mar Miralles-Quiros et al. (2019) and Shah et al. (2019), who find that governance scores are particularly predictive of efficiency gains.

Previous studies have examined the role of ESG factors in explaining bank cost efficiency, using both parametric and nonparametric methods (Shah et al., 2019; Forgione et al., 2020; Belasri et al., 2020; Fukuyama and Tan, 2021; López-Penabad et al., 2022; Shaddady and Alnori, 2024). Shah et al. (2019) analysed a sample of 248 banks, including 33 sustainable banks from 14 countries, between 2010 and 2018. Their findings indicate that sustainable banks are more efficient, as shown by the Data Envelopment Analysis (DEA), and more productive, as measured by the Malmquist Productivity Index, than non-

sustainable banks. Forgione et al. (2020) examined the relationship between bank profit efficiency and corporate social responsibility (CSR, henceforth), using data from 131 large commercial banks across 22 countries from 2013 to 2017, with CSR measured through Refinitiv ESG scores. They employed a one-step SFA method to analyse banks' efficiency and found that CSR initiatives, including social and environmental actions, negatively affected bank performance. This result aligns with the agency theory, suggesting that shareholders bear the costs of CSR activities. The authors also proposed that these findings might differ in countries with strong stakeholder protection or in common-law jurisdictions. Using a dynamic network framework in DEA, Belasri et al. (2020) examined how CSR influences banking efficiency. Their research, covering 184 banks from 41 countries between 2009 and 2015, demonstrated that CSR has a positive impact on bank efficiency. However, this effect was evident only in developed economies, countries with strong investor protection mechanisms, and those with a high degree of stakeholder orientation. Similarly, Fukuyama & Tan (2021) applied an output-oriented DEA approach to assess the efficiency of Chinese banks from 2007 to 2017, focusing on the connection between technical efficiency (TE) and CSR. Their analysis confirmed a statistically significant and positive link between green credit initiatives and TE. In another study, López-Penabad et al. (2022) examined the influence of corporate social performance (CSP) on banking efficiency using data from 108 European banks across 21 nations from 2011 to 2019. Their research identified an inverse U-shaped relationship between ESG engagement and efficiency, suggesting that banks with either very high or very low ESG investments are the most efficient. This trend was consistent in the social and governance dimensions, but did not hold for environmental factors. Shaddady & Alnori (2024) examined a sample of publicly listed Saudi Arabian banks between 2016 and 2021. Their analysis, using the DEA technique, revealed that banks' efficiency scores, when adjusted for ESG factors, were higher than those calculated without incorporating ESG considerations.

Taken together, the reviewed literature highlights both the potential and the limitations of ESG practices in improving bank efficiency. While many studies suggest that ESG engagement can enhance cost efficiency through better risk management, reputational gains, and stakeholder trust, the empirical results are mixed and often context-dependent. This underscores the need for a more rigorous and context-specific analysis, particularly in the U.S. banking sector. Furthermore, the divergence in methodological approaches, especially the limited use of models that address endogeneity, suggests that previous findings may not fully capture the causal effects of ESG on efficiency. Building on stakeholder theory and the resource-based view, the present study conceptualises ESG performance not only as a reputational mechanism but also as a strategic capability that can influence cost efficiency through operational optimisation and long-term value creation. Accordingly, this study proposes an integrated analytical framework that evaluates both the overall and dimension-specific impacts of ESG on cost efficiency, while correcting for potential endogeneity using a one-step stochastic frontier model.

While the existing literature provides valuable insights into the relationship between ESG and bank efficiency, several methodological and empirical limitations can be identified,

which also inform the design of the present study. First, there is substantial heterogeneity in research methods, with studies employing various efficiency estimation techniques ranging from non-parametric approaches like DEA (e.g., Shah et al., 2019; Fukuyama & Tan, 2021) to parametric models such as SFA (e.g., Chang et al., 2021; Forgione et al., 2020). These methodological differences may partially explain the mixed findings: DEA does not account for statistical noise, whereas traditional two-stage SFA models may suffer from endogeneity bias due to the separation of efficiency estimation from environmental factors. This highlights the need for an integrated, one-step estimation framework that can simultaneously account for ESG effects and unobserved heterogeneity, such as the endogenous SFA approach used in this study.

Second, although many studies report a positive relationship between ESG (or CSR) and bank efficiency, there is no consensus on the direction or magnitude of the effect. For instance, Forgione et al. (2020) find a negative impact of ESG activities, consistent with agency theory, while López-Penabad et al. (2022) and Alam et al. (2021) identify nonlinear relationships, suggesting that ESG investments may be efficiency-enhancing only beyond a certain threshold. Similarly, Chang et al. (2021) report region- and dimension-specific effects, including positive environmental impacts in developed countries and mixed governance effects across regions. These inconsistencies highlight the importance of disaggregating ESG into its components, as the effects of the environmental, social, and governance pillars may differ in direction and statistical significance. This study addresses this issue by examining each dimension separately, thereby offering a more granular understanding of ESG's role in bank efficiency.

Third, few studies explicitly address potential endogeneity between ESG performance and cost efficiency. ESG engagement may be both a cause and a consequence of improved bank efficiency, making it essential to adopt estimation techniques that correct for simultaneity bias. The use of the endogenous stochastic frontier model in this study enables more reliable estimation of the causal impact of ESG variables. Furthermore, most prior research focuses on non-U.S. banking contexts or utilises data from earlier time periods, limiting the generalizability of findings to the current U.S. banking landscape, which has experienced significant regulatory and market changes in recent years. To fill this gap, our study employs recent data (2016-2023) from U.S. commercial banks and a robust methodological framework that accounts for the complex relationship between ESG and efficiency.

This study analyses the effect of ESG on bank cost efficiency by adopting a theoretical framework based on stakeholder theory and the resource-based view (RBV). According to stakeholder theory, responsiveness to stakeholder expectations enhances long-term sustainable performance (Freeman, 1984). Indeed, Alam et al. (2021) and Shah et al. (2019) show that strong social responsibility practices improve customer trust and positively affect bank efficiency, aligning with the stakeholder approach centred on social capital and stakeholder relationships. On the other hand, RBV suggests that organisational resources such as ESG, which are difficult to replicate, can provide a competitive advantage (Barney,

1991). In this context, studies such as Fatemi et al. (2018) and Zhou et al. (2022) demonstrate that environmental investments enhance bank cost efficiency through energy savings and long-term operational gains, highlighting ESG as a strategic resource. Furthermore, research by Mar Miralles-Quiros et al. (2019) and Chiaramonte et al. (2022) shows that governance quality directly contributes to efficiency by promoting transparency and effective risk control. Therefore, this study's theoretical framework captures how ESG affects bank cost efficiency holistically through both external stakeholder engagement (stakeholder theory) and internal organisational capabilities (RBV).

3. Methodology and Data

3.1. One-Step SFA Model

This study employs the SFA approach, originally introduced by Aigner et al. (1977), to estimate the cost frontier and cost efficiency. Specifically, cost efficiency measures the degree of deviation from the 'best practice' frontier, given a certain level of output and a set of input prices. The cost frontier is estimated using an SFA model that separates the error term into a random noise component and an inefficiency component.

$$TC_{it} = f(w_{it}, y_{it}, z_{it}) + v_{it} + u_{it} \quad (1)$$

where TC_{it} is the total cost of the i -th bank in period t , w_{it} is the input price of bank i in period t , y_{it} is the output level of bank i in period t , and z_{it} stands for a set of quasi-input. The error term v_{it} reflects measurement errors and other random factors, and is assumed to be independently and identically distributed with a zero mean and a variance of σ , following a symmetric normal distribution, $N(0, \sigma_v^2)$. The second error term, u_{it} accounts for the bank's cost inefficiency and is assumed to follow a non-negative truncated distribution (asymmetric) with mean $\mu = E\delta$ and variance σ_u^2 ; that is, $u \sim \text{iid } N^+(E\delta, \sigma_u^2)$.

To estimate efficiency scores, a multi-product translog cost function based on the intermediation approach is used, following previous studies (Hao & Chou, 2005; Fenn et al., 2008). The translog functional form is preferred because it relaxes the constant substitution elasticity condition in the Cobb-Douglas production function (Kneller & Stevens, 2003; Kumbhakar & Wang, 2006), making it more flexible compared to the Cobb-Douglas functional form. Due to its flexibility and certain advantages over the Cobb-Douglas specification, the translog function is widely preferred in efficiency analyses of the banking sector (Kumbhakar & Lovell, 2003; Weill, 2013).

The translog cost function is defined as follows:

$$\begin{aligned} \ln \frac{TC_{it}}{w_{3,it}} = & \alpha_0 + \sum_{k=1}^2 \beta_k \ln(y_{k,it}) + \sum_{j=1}^2 \alpha_j \ln \left(\frac{w_{j,it}}{w_{3,it}} \right) + \frac{1}{2} \sum_{k=1}^2 \sum_{m=1}^2 \beta_{km} \ln(y_{k,it}) \ln(y_{m,it}) \\ & + \frac{1}{2} \sum_{j=1}^2 \sum_{l=1}^2 \alpha_{jl} \ln \left(\frac{w_{j,it}}{w_{3,it}} \right) \ln \left(\frac{w_{l,it}}{w_{3,it}} \right) + \sum_{k=1}^2 \sum_{j=1}^2 \delta_{kj} \ln(y_{k,it}) \ln \left(\frac{w_{j,it}}{w_{3,it}} \right) + \theta_1 T \end{aligned}$$

$$\begin{aligned}
 & + \frac{1}{2} \theta_1 T^2 + \sum_{k=1}^2 \rho_k T \ln(y_{k,it}) + \sum_{j=1}^2 \omega_j T \ln\left(\frac{w_{j,it}}{w_{3,it}}\right) + \varphi_1 \ln EQ + \frac{1}{2} \varphi_2 (\ln EQ)^2 \\
 & \sum_{k=1}^2 \vartheta_k \ln(y_{k,it}) \ln EQ + \sum_{j=1}^2 \tau_j \ln\left(\frac{w_{j,it}}{w_{3,it}}\right) \ln EQ + \sigma T \ln EQ + v_{it} + u_{it}
 \end{aligned} \tag{2}$$

where TC represents the bank's total costs (total interest + non-interest expenses), y_k ($k = 1, 2$) represents the outputs, and w_j ($j = 1, 2, 3$) denotes input prices. For the definition of inputs and outputs in the SFA model, the intermediation approach of Sealey & Lindley (1977) is used. In line with the approaches of Pessarossi & Weill (2015) and Sakouvogui (2020), this study identifies two output and three input price variables. The outputs are total loans (y_1) and investments (y_2). The input prices include: the cost of labour (w_1), determined by dividing personnel expenses by the number of employees; the cost of physical capital (w_2), measured as the ratio of other operating expenses to fixed assets; and the cost of borrowed funds (w_3), calculated by dividing interest expenses by total deposits. The time trend variable (T) is included to capture the impact of technology on the cost frontier. Following Berger & Mester (1997), we specify equity-to-total assets (EQ) as a quasi-fixed input to control for differences in risk preferences. To eliminate heteroskedasticity, total cost and input prices are normalised by the price of funds (w_3) before taking logarithms, as proposed by Allen and Rai (1996), Berger and Mester (1997), and Kraft et al. (2006).

In line with economic theory, the model imposes symmetry and linear homogeneity constraints on all quadratic terms to guarantee a well-specified cost frontier. The translog cost function becomes linear homogeneous in input price and symmetric in second-order coefficients when the following conditions hold:

$$\begin{aligned}
 & \sum_j^3 a_j = 1, \sum_{j=1}^3 a_{jl} = 0, \sum_{k=1}^3 \delta_{kj} = 0 \text{ (linear homogeneous condition)} \\
 & \alpha_{jl} = \alpha_{lj}, \beta_{km} = \beta_{mk} \text{ (symmetry condition)}
 \end{aligned} \tag{3}$$

In the two-stage methodology, inefficiency scores are first estimated and then regressed on a set of explanatory variables in the second stage. However, Wang & Schmidt (2002) challenge this approach, arguing that the inefficiency term may not be independently and identically distributed across banks and could be influenced by specific covariates. As a result, the first-stage efficiency estimates may be biased and inconsistent. To address this limitation, Kumbhakar et al. (1991) and, subsequently, Battese & Coelli (1995) proposed a one-step panel-data framework that jointly estimates inefficiency and its determinants. In this study, the Battese & Coelli (1995) model (hereafter, BC95) is preferred for its methodological advantages. The BC95 model accounts for environmental variables affecting banks and investigates their influence on inefficiency within a one-stage estimation framework, thus eliminating many of the biases associated with the two-stage approach. According to the BC95, the inefficiency term is specified as a function of a set of explanatory variables z_{it} and an unknown parameter vector γ to be estimated. The inefficiency effects are therefore defined as follows:

$$u_{it} = \gamma z_{it} + w_{it} \quad (4)$$

where w_{it} represents the error term with a zero mean and constant variance σ^2 . Based on Equation (2), inefficiency effects can be defined as follows:

$$u_{it} = \delta_0 + \delta_1 ESG + \delta_2 CAP + \delta_3 LTA + \delta_4 LTD + \delta_5 LNTA + \delta_6 ROA + \delta_7 NPL + \delta_8 NIM + \delta_9 GDP + \delta_{10} INF + w_{it} \quad (5)$$

In addition to ESG and its sub-components, this study follows the existing literature (Dietsch & Lozano-Vivas, 2000; Maudos et al., 2002; Kasman & Yildirim, 2006; Pasiouras et al., 2009) by controlling for differences in bank inefficiency. To this end, the model incorporates several bank-specific variables, including the capital adequacy ratio (CAP), liquidity risk (LTA), financial intermediation (LTD), size (LNTA), return on assets (ROA), credit risk (NPL), and net interest margin (NIM). Moreover, macroeconomic indicators such as the GDP growth rate (GDP) and the inflation rate (INF) are also included.

Cost efficiency is measured as the ratio of a bank's minimum estimated cost to its actual cost of production (Coelli et al., 2005). Thus, the cost efficiency score (CE) for bank i in year t is calculated as follows:

$$CE_{it} = \frac{\exp[\hat{f}(p_{it}, y_{it}, v_{it})]}{\exp[\hat{f}(p_{it}, y_{it}, v_{it})] \times \exp(\hat{u}_{it})} = \exp(-\hat{u}_{it}) \quad (6)$$

3.2. Data Sources and Variable Settings

In this paper, we select U.S. banks from 2016 to 2023 as the sample for our analysis. The bank-level data are obtained from the Banker database¹, while the macroeconomic variables are sourced from the World Development Indicators. After excluding banks with (a) missing data for more than two consecutive years, (b) observations with negative or zero values for outputs and input prices, (c) reporting errors, inconsistencies, or missing values, and (d) unavailable ESG data, an unbalanced panel of 1,690 observations is used, covering 253 commercial banks over the period 2016-2023.

The U.S. banking sector was selected for its pivotal role in the global financial system, particularly during the 2008 global financial crisis. As the origin point of systemic risk transmission, the U.S. banking industry has since undergone significant regulatory, structural, and strategic transformations, many of which are closely tied to ESG considerations. Given its size, international exposure, and leadership in financial innovation, analysing the U.S. context provides insights with global relevance and serves as a benchmark for understanding ESG-efficiency dynamics in large-scale, complex financial markets.

Empirical studies (Sealey & Lindley, 1977; Berger & Humphrey, 1997; Berger et al., 2000) typically use two main approaches to determine the bank cost frontier variables: the production approach, which views banks as service providers managing deposits and loans,

¹ The Banker database is a leading source of banking data, covering over 5,000 banks in more than 190 countries.

and the intermediation approach, which treats banks as intermediaries converting deposits and borrowed funds into loans and assets. The choice of approach depends on data availability and research objectives (Delis & Tsionas, 2009). In this study, the intermediation approach is used, consistent with the methodology followed by Berger (2007) and similar empirical works. All monetary values are inflation-adjusted to constant 2015 USD. Table 1 presents the set of frontier variables and inefficiency determinants, providing their detailed descriptions and data sources.

Table: 1
List of Variables

Variable	Symbol	Description	Source
Stochastic frontier function			
Total cost	TC	Interest expense + non- interest expense	The Banker
Total loans	y_1	Sum of all loan accounts - non-performing loans	The Banker
Total investments	y_2	Sum of total securities, equity investments and other investments	The Banker
Price of labor	w_1	Personnel Expenses/ Employees	The Banker
Price of capital	w_2	Other Operating Expenses/Fixed Assets	The Banker
Price of borrowed funds	w_3	Total Interest Expenses/Total Deposits	The Banker
Inefficiency determinants			
Capital adequacy ratio	CAP	Total Equity / Total Assets	The Banker
Liquidity risk	LTA	Total loans / Total assets	The Banker
Financial intermediation	LTD	Total loans / Total deposits.	The Banker
Size	LNTA	Logarithm of total assets	The Banker
Return on asset	ROA	Net Income/Total Assets	The Banker
Credit risk	NPL	Nonperforming loans/ Total loans	The Banker
Net interest margin	NIM	(Interest Income –Interest Expenses)/Interest-Bearing Assets	The Banker
Economic growth rate	GDP	Annual economic growth rate	World Bank
Inflation	INF	Annual inflation rate	World Bank
Environment pillar	E	Analyses the performance of a bank in terms of emissions, innovation, and resource use.	Datastream
Social pillar	S	Analyses the performance of a bank in terms of workforce, human rights, community engagement, and product responsibility.	Datastream
Governance pillar	G	Analyses the performance of a bank in terms of management, shareholder relations, and CSR strategy.	Datastream
Overall ESG score	ESG	A composite index measuring a bank's environmental performance within its Environmental, Social, and Governance (ESG) profile.	Datastream

Table: 2
Descriptive Statistics of Stochastic Frontier Variables and Inefficiency Determinants

Variable	Mean	Std. dev.	Min	Max
Stochastic frontier function				
TC	16095,61	84700,53	97,622	1167016,66
y_1	235748,1	1000137,71	2571,410	9472920,04
y_2	198859,9	1204099,46	275,305	13250799,17
Price of labour (w_1) %	85,7	25,5	34,5	256,0
Price of capital (w_2) %	74,1	101,7	4,5	2069,5
Price of borrowed funds (w_3) %	0,8	0,7	0,02	5,9
Inefficiency determinants				
CAP	0,110	0,024	0,041	0,256
LTA	0,687	0,120	0,120	0,920
LTD	0,864	0,172	0,153	1,667
LNTA	11,063	1,501	8,300	17,220
ROA	1,259	0,526	-6,490	7,830
NPL	0,012	0,042	2,40E-05	1,000
NIM	3,450	0,760	0,220	11,040
GDP	2,628	2,007	-2,163	6,055
INF	3,472	2,236	1,233	8,002
E	27,631	17,282	14,40	96,980
S	33,918	16,242	2,500	93,940
G	49,281	19,580	2,900	94,740
ESG	34,943	12,855	5,380	81,560

Note: All values are in thousands of US\$.

Table 2 provides the summary statistics for the SFA frontier variables and all bank efficiency determinants used in this analysis. We observe high variability among the banks in the dataset across input and output variables.

The average total cost is 16095,61, with a notably high standard deviation of 84700,53. The minimum total cost is 97,622, whereas the maximum is 1167016,66, highlighting substantial cost differences among banks in the sector. Regarding input prices, labour has the highest average value at 0,857, suggesting that labour is the most significant input variable in banking operations. Its standard deviation is 0,25, with a minimum of 0,34 and a maximum of 2,56, indicating relatively low variability. In contrast, the price of capital exhibits the highest coefficient of dispersion among input prices, with an average of 0,741 and a standard deviation of 1,017. Meanwhile, the price of funds has the lowest variability over the years, with an average of 0,008 and a standard deviation of 0,007. Regarding output variables, total loans exhibit considerable variation. The minimum loan is 2571,41, while the maximum reaches 9472920,04. The average loan is 235748,1, with a high standard deviation of 1000137,71, indicating significant differences in loan distributions among banks. Similarly, investments, another output variable, have an average of 235748,1 and a high standard deviation of 1204099,46, suggesting substantial variability in investment levels across banks. These findings indicate that both loan and investment distributions are highly heterogeneous within the banking sector. Input and output variables indicate significant variation in bank size and reflect heterogeneity in the U.S. banking sector. Considering bank-specific control variables, bank size (LNTA), with a mean of 11,063 and a standard deviation of 1,501, exhibits the greatest variation among the included banks, further confirming their heterogeneity. On the other hand, the capital ratio (CAP), with a mean of 0,110 and a standard deviation of 0,024, exhibits lower variability within the sample over the years.

In Table 2, we can see the average score of environmental (E) pillar is 27,631, the maximum value is 96,980, minimum value is 14,340, and standard deviation is 17,282, showing that banks have significant differences in the implementation of environmental activities; in the social (S) pillar, the average score is 33,918, the maximum value is 93,940, minimum value is 2,500, and standard deviation is 16,242, which shows that the implementation of social activities by banks is also very different; in terms of governance (G) pillar, the average score is 49,281, the maximum value is 94,740, minimum value is 2,900, and standard deviation is 19,580, which shows that the differences are also obvious. Regarding the overall ESG score, the average is 34,943, the maximum is 81,560, and the minimum is 5,380. The standard deviation also indicates significant variability in the overall score. From the descriptive statistics of the above ESG-related variables, we conclude that there are considerable differences in the scores of various banks, especially in the governance (G) pillar, where the difference is the largest among the three dimensions.

3.2.1. Definition of ESG Variables

ESG scores are composite measures that combine three main components: E, S, and G (Chang et al., 2014; Chiaramonte et al., 2022; Sassen et al., 2016). A higher score indicates better ESG performance. According to Albuquerque et al. (2020) and Broadstock et al. (2021), a higher ESG score indicates greater transparency and, therefore, lower risk, which gives depositors greater confidence in the bank's reputation and ability to take on risk (Azmi et al., 2021). Therefore, this variable is expected to be negatively (positively) correlated with cost inefficiency (efficiency).

The E, S, and G pillars reflect different aspects of a company's sustainability performance. The E pillar evaluates the company's resource use, emissions, and environmental innovation and accounted for 14,4% of ESG, based on the weighted-average relative rating across the three environmental categories from the Environmental Information Report. It includes resource use (2,4%), emissions (2,4%), and innovation (9,6%), as well as related policies on energy efficiency, green buildings, waste recycling rates, environmental R&D spending, and renewable energy products. The S pillar measures job satisfaction, diversity, workplace health, and human rights and accounted for 49.6% of ESG, representing the weighted average of the bank's relative ratings based on four social category scores from the Social Information Report. It includes labour (19,2%), human rights (9,6%), community (12,0%), and product responsibility (8,8%), related to gender pay gap percentages, human rights policies, crisis management systems, product responsibility controls, and customer satisfaction. The G pillar assesses the company's compliance with best practices, the equal treatment of shareholders, and the incorporation of non-financial objectives into strategic and managerial decisions. The G pillar accounted for 36% of ESG, representing a weighted-average relative rating of banks based on scores for three governance categories from the Governance Information Report: management (24.0%), shareholders (7.2%), and CSR strategy (4.8%). The information on ESG factors is sourced directly from Thomson Reuters' Datastream, which aligns with our particular area of focus.

3.2.2. Control Variables

To ensure that the ESG variable does not capture the effects of other factors influencing efficiency, we include a range of control variables identified in previous studies (Shen et al., 2016; Wu et al., 2017). These variables are categorised into two groups: one focusing on financial characteristics and the other encompassing macroeconomic factors.

Equity / Total Assets (CAP)

This ratio measures a bank's capital strength. Higher capital levels are associated with a safety net that supports banks' operations (Pasiouras, 2008; Kosmidou, 2008; Sufian, 2009). As a result, more efficient banks are likely to be better capitalised, use less leverage, have lower bankruptcy costs, and hence require less external funding (Athanasoglou et al.,

2008). Thus, this variable is expected to positively affect bank cost efficiency (Sufian, 2010a).

Loans to Asset

This ratio can be viewed as a measure of liquidity, with higher loan-to-total-asset ratios indicating a weaker liquidity position because loans are among the least liquid assets. This is particularly important because a bank with low liquidity may be forced to borrow at high interest rates in urgent situations to meet its obligations. In more severe cases, liquidity shortages can trigger bank runs, leading to failure even when the bank is solvent. Thus, a positive link between liquidity and efficiency is expected (Sufian & Habibullah, 2010; Dell'Atti et al., 2015).

Loans to Deposits

The intermediation ratio measures the depth of a bank's intermediation activities by assessing its ability to transform deposits into loans, calculated as total loans divided by total deposits. A higher ratio indicates greater intermediation, as the bank can make more loans relative to the deposits it receives. It is anticipated that this variable will have a negative impact on bank inefficiency because a larger intermediation ratio requires fewer deposits to generate loans, lowering production costs and, ultimately, increasing profits. Fries & Taci (2005) and Kořak et al. (2009) found a negative link between the intermediation ratio and bank cost inefficiencies.

Bank Size (Scale)

The size variable measures a bank's size by using the natural logarithm of its total assets (Stewart et al., 2016; Gulati & Kumar, 2017; Fernandes et al., 2018). The larger the asset size, the greater the economies of scale, and the greater the opportunities available to and profitability of the bank. The impact of bank size on efficiency has been extensively studied, with findings often indicating a positive effect on efficiency (Tecles & Tabak, 2010; Kovner et al., 2014; Stewart et al., 2016; Fernandes et al., 2018; Castro & Galán, 2019; Dutta et al., 2020; Mansour & El Moussawi, 2020; Galán & Tan, 2024). According to De Young & Nolle (1998), one possible explanation for the positive relationship between size and cost efficiency is that larger banks are better able to attract and retain highly skilled managers. However, Bonin et al. (2005) and Allen & Rai (1996) argue that increasing scale does not always lead to higher efficiency.

Return on Average Assets (ROA)

ROA is a profitability measure expected to be positively correlated with efficiency. This is primarily because banks with higher profitability are more appealing to depositors than less profitable banks, and their creditworthiness is better, which creates incentives and opportunities for banks to be efficient (Sufian & Habibullah, 2010; Avgeri et al., 2021). Several studies, such as Carbo et al. (2002), Lensink et al. (2008), Shawtari et al. (2015),

Stewart et al. (2016), Gulati & Kumar (2017), Fernandes et al. (2018), and Mansour & El Moussawi (2020), demonstrate the positive effect of ROA on bank efficiency, whereas other studies, such as Matousek & Taci (2004), find that ROA negatively affects bank efficiency.

Non-Performing Loans / Gross Loans (Credit Risk)

Previous studies (e.g., Berger & De Young, 1997; Partovi & Matousek, 2019) focus on the non-performing loans-to-total loans ratio (NPLs) as a proxy for banks' credit risk. As the share of non-performing loans rises, banks face higher costs associated with monitoring, restructuring, or liquidating these problematic loans. As a result, this variable is expected to increase cost inefficiency (Altunbas et al., 2000; Fries & Taci, 2005).

Net Interest Margin (NIM)

NIM is the ratio of net interest income to average earning assets and measures the bank's profitability relative to its total assets. Christopoulos et al. (2020) indicated that the higher the net interest margin, the more efficiently the bank generates income from its assets and the higher its net income. However, Huang et al. (2019) suggested that lowering their net interest margin by diversifying their financial products makes banks more cost-efficient. As a result, the relationship between this variable and cost inefficiency remains ambiguous.

Macroeconomic Variables

The second category comprises macroeconomic variables. The GDP growth rate captures a country's economic heterogeneity and serves as a proxy for its financial development (Wu & Shen, 2013). The INF stands for the inflation rate (Pasiouras et al. 2009).

The selection of control variables in this study is grounded in both theoretical foundations and well-established empirical evidence from the banking efficiency literature. Specifically, bank-level variables were included to account for heterogeneity in banks' operational and financial structures that could otherwise confound the relationship between ESG performance and cost efficiency. Capital adequacy (CAP) reflects the financial resilience of banks and their ability to absorb shocks, with higher capital levels generally associated with improved efficiency due to lower insolvency risk and enhanced operational stability, as emphasised by Berger & Bonaccorsi di Patti (2006) and Pasiouras (2008). The ratio of loans to total assets (LTA) captures banks' liquidity positions and reflects their ability to utilise resources effectively, as banks with higher loan volumes are often considered more efficient at converting resources into income-generating assets (Srairi, 2010; Carvallo & Kasman, 2005). Similarly, the loans-to-deposits ratio (LTD) serves as a proxy for the depth of financial intermediation, with more efficient banks typically demonstrating greater intermediation capacity and greater credit provision relative to deposit mobilisation (Kořak et al., 2009; Nguyen & Pham, 2020). Bank size, measured by the natural logarithm of total assets (LNTA), is included to account for economies of scale and potential efficiency advantages of larger institutions, consistent with Stewart et al. (2016) and

Fernandes et al. (2018). Profitability, proxied by return on assets (ROA), is another critical determinant, as more profitable banks are often better positioned to optimise operations and achieve higher efficiency levels, a relationship well documented by Sufian & Habibullah (2010) and Gulati & Kumar (2017). Credit risk, captured by the ratio of non-performing loans to total loans (NPL), is incorporated to reflect potential inefficiencies arising from poor asset quality and suboptimal lending practices, consistent with the work of Berger & DeYoung (1997). Net interest margin (NIM) reflects banks' ability to generate income from interest-bearing assets. It may have ambiguous effects on efficiency, depending on product diversification strategies, as discussed by Christopoulos et al. (2020) and Huang et al. (2019). Finally, macroeconomic variables such as GDP growth and inflation are incorporated to control for external economic conditions that influence banking operations and cost structures, as is standard practice in efficiency analyses (Pasiouras et al., 2009; Sufian & Habibullah, 2010). Together, these control variables ensure that the model adequately captures the primary bank-specific and macroeconomic factors that may affect cost efficiency, thereby allowing for a more accurate estimation of the relationship between ESG performance and bank efficiency.

4. Empirical Results and Analysis

4.1. Baseline Regression

Table 3 provides the empirical estimates of the one-step SFA models for cost efficiency (CE). Given that the efficiency scores are generated by linking the determinants to the inefficiency variance term, as shown in Section 3.1 (Equation 5), a negative parameter in the inefficiency model indicates a higher level of bank efficiency.

In Table 3, we estimated two SFA models: one with ESG and one without. In both models (Model 1 and 2), the coefficients of the variables (and their interactions) indicate the magnitude and direction of their impact on the bank's cost function. Most of the input and output coefficients in the cost frontier estimations are statistically significant, except for y_2 (investment) and EQ (equity ratio), as well as their interaction. Moreover, the cost frontier estimates in the two SFA models are consistent with the literature (e.g., Hughes & Mester, 1993; Barth et al., 2013).

The empirical results show that all normalised input prices and outputs - except for y_2 - are positive and statistically significant at the 1% level, indicating that the cost function is non-decreasing with respect to both input prices (p_s) and outputs (y_s). The positive coefficients for the inputs suggest that as input levels increase, operating costs rise. This aligns with economic theory, which holds that an increase in the price of production factors raises commercial bank costs. For the Model 1 (with-ESG), the coefficient for total loans (y_1) shows that a 1% increase in total loans results in a 0,932% increase in total costs on average. In contrast, the second output (y_2) does not have a statistically significant impact on total costs in either Model 1 or Model 2.

Table: 3
Estimation Results of Stochastic Frontier Cost Functions

Variables	Model 1 (with-ESG)			Model 2 without-ESG		
	Coefficient	SE	t-value	Coefficient	SE	t-value
Constant	0,246	0,666	0,37	0,111	0,671	0,17
$\ln y_1$	0,932***	0,232	4,02	0,948***	0,236	4,01
$\ln y_2$	-0,023	0,104	-0,23	-0,008	0,104	-0,08
$\ln(w_1/w_3)$	0,582***	0,082	7,07	0,563***	0,082	6,84
$\ln(w_2/w_3)$	0,438***	0,150	2,91	0,464***	0,151	3,06
$1/2 \ln y_1^2$	-0,123**	0,062	-1,97	-0,125**	0,063	1,98
$1/2 \ln y_2^2$	-0,016	0,020	-0,81	-0,013	0,020	-0,66
$\ln y_1 \ln y_2$	0,054*	0,030	1,82	0,053*	0,030	1,76
$1/2 \ln(w_1/w_3)^2$	0,043***	0,015	2,79	0,045***	0,015	2,92
$1/2 \ln(w_2/w_3)^2$	-0,005	0,009	-0,60	-0,004	0,009	-0,50
$\ln(w_1/w_3) \ln(w_2/w_3)$	0,031***	0,010	2,94	0,030***	0,010	2,79
$\ln y_1 \ln(w_1/w_3)$	-0,037*	0,021	-1,75	-0,034	0,021	-1,61
$\ln y_1 \ln(w_2/w_3)$	-0,026	0,018	-1,43	-0,029	0,018	-1,59
$\ln y_2 \ln(w_1/w_3)$	0,036***	0,011	3,18	0,037***	0,011	3,22
$\ln y_2 \ln(w_2/w_3)$	-0,045***	0,010	-4,37	-0,046***	0,010	-4,48
t	-0,064**	0,027	-2,39	-0,063**	0,027	-2,32
t^2	0,005***	0,001	3,81	0,005***	0,001	3,81
$t \ln y_1$	0,009**	0,004	2,14	0,008**	0,004	1,99
$t \ln y_2$	-0,008***	0,002	-3,56	-0,008***	0,002	-3,62
$t \ln(w_1/w_3)$	-0,009***	0,002	-3,48	-0,009***	0,002	-3,48
$t \ln(w_2/w_3)$	0,005***	0,001	3,02	0,005***	0,001	2,96
$\ln EQ$	-0,140	0,209	-0,67	-0,147	0,213	-0,69
$1/2 \ln(\ln EQ)^2$	-0,025	0,081	-0,31	-0,026	0,083	-0,32
$\ln EQ \ln y_1$	0,069	0,066	1,05	0,072	0,068	1,06
$\ln EQ \ln y_2$	-0,032	0,030	-1,07	-0,035	0,030	-1,15
$\ln EQ \ln(w_1/w_3)$	-0,011	0,024	-0,44	-0,013	0,024	-0,54
$\ln EQ \ln(w_2/w_3)$	0,069***	0,022	3,12	0,072***	0,022	3,26
$t \ln EQ$	-0,0006	0,005	-0,12	0,00001	0,005	0,00
Inefficient effect model						
Constant	3,042***	0,058	5,45	3,094***	0,561	5,51
CAP	-2,926***	1,074	-2,72	-2,864***	1,077	-2,66
LTA	-0,821***	0,310	-2,65	-0,868***	0,310	-2,80
LTD	-1,134***	0,158	-7,16	-1,110***	0,157	-7,04
LNTA	-0,157***	0,041	-3,82	-0,166***	0,041	-4,03
ROA	-0,107***	0,013	-8,16	-0,106***	0,013	-8,12
NPL	0,294	0,197	1,49	0,260	0,194	1,34
NIM	0,177***	0,017	10,02	0,174***	0,017	9,94
GDP	0,002	0,002	0,98	0,002	0,002	0,96
INF	0,017***	0,003	4,50	0,018***	0,003	4,56
ESG	-0,001**	0,0007	-2,53	-	-	-
σ^2	0,684			0,600		
γ	0,867			0,827		
Log likelihood function	1060,16			1056,93		
LR test	162,57			165,55		
M3T statistics	-8,521			-8,521		
M3T (p-value)	0,000			0,000		

Note: ***, **, * denote statistical significance at the 1%, 5% and 10% level, respectively.

As for input prices, the coefficient for labour cost (p_1) is positive and highly significant, indicating that a 1% increase in labour costs would raise total costs by approximately 0.582%. The coefficient for the price of physical capital (p_2) is also positive (0,438) and statistically significant; however, its lower magnitude relative to p_1 suggests that total costs are more sensitive to changes in labour costs than to changes in capital expenses.

The gamma (γ) parameter reflects the share of the total error variance that is due to inefficiency, with values ranging from 0 to 1. According to Model 1 in Table 3, γ is

approximately 0,867, indicating that inefficiency is the primary source of variation in the cost frontier model, with random error accounting for only about 13,3%.

The validity of the SFA model is tested through the presence of negative skewness in the residuals. According to the negative skewness test developed by Coelli (1995), a negative and statistically significant M3T value would lead to the rejection of the null hypothesis in favour of a negatively skewed error distribution, supporting the SFA specification over a standard regression (OLS) framework. According to the M3T test result in Table 3, the null hypothesis of symmetric error distribution is rejected in favour of the alternative hypothesis. This result further supports the presence of negative skewness in the OLS residuals. The statistical significance and validity of negative skewness confirm the appropriateness of the SFA model. Furthermore, the LR test statistic for the one-sided error is 162,57 (Table 3), which is statistically significant at the 1% level when compared to the critical value of 22,52². This result leads to the rejection of the null hypothesis, which assumes that the estimated cost model is equivalent to an ordinary least squares (OLS) model without the bank-specific inefficiency term u_i . In other words, the diagnostic test clearly confirms the existence of bank-specific inefficiencies captured by the estimated stochastic cost frontier.

4.2. Cost Efficiency Results

After estimating the BC95 model, we calculate the cost efficiency (CE) of bank i at time t by applying $\exp(-u_{it})$. The efficiency score ranges from 0 to 1, with 1 representing a fully efficient bank. Table 4 presents the mean CE scores, standard deviations, and the minimum and maximum values for U.S. banks over the period from 2016 to 2023. Overall, the average CE score of banks is approximately 42%, with its distribution varying over time. The average CE of U.S. banks increased from 0,39 (39%) in 2016 to 0,44 (44%) in 2023, reflecting an improvement of approximately 12,82%. This upward trend suggests that banks in the United States have become more efficient over time, narrowing the distance to the optimal efficiency frontier. During the period studied, CE scores showed fluctuations. Overall, CE increased from 2016 to 2019, declined in 2020 and 2021, and then recovered in 2023. The average CE was 0,39 in 2016, increased to 0,44 in 2019, but then decreased to 0,42 and 0,41 in 2020 and 2021, respectively. However, in 2023, the efficiency score increased rapidly from 0,41 to 0,44, indicating a positive trend. The standard deviation was highest at 0,16 in 2020 and lowest at 0,14 in 2019, suggesting that CE scores fluctuated more in 2020. Moreover, minimum values generally decreased over time, while maximum values remained mostly stable around 0,99, except for a significant drop to 0,92 in 2022.

The study period, however, highlights a considerable degree of inefficiency in U.S. banks' operations on average. The average CE for U.S. banks stands at 0,58 (58%). According to the parameters selected for this study, the findings indicate that U.S. banks, on average, are losing 58% of their potential output relative to the best-practice bank due to

² The critical value was obtained from Kodde and Palm (1986).

operational inefficiencies. In other words, there is substantial potential for banks to improve their operational efficiency relative to best-practice institutions. This result is consistent with Ferrara & Kounetas (2024). In their study, using the SFA approach, the authors found that the average overall CE was about 59% for 5,698 U.S. banks over the period 2010-2016. Similarly, Rezvanian et al. (2024) conducted another study that reported low CE for U.S. banks. Using DEA, they found that the average CE of 10,495 small banks operating between 2010 and 2021 was 32,93%, while their technical efficiency was 48,14%. In summary, the potentially lower CE in US banks can be attributed to a combination of structural market characteristics, a slower adoption of more efficient practices and technologies, the costs associated with a complex regulatory environment, and, for smaller institutions, challenges in achieving optimal scale and technical efficiency.

Table: 4
Cost Efficiency Summary Statistics

Year	Mean	SD	Min	Max	Obs.
2016	0,39	0,15	0,13	0,99	144
2017	0,42	0,15	0,11	0,99	201
2018	0,43	0,15	0,11	0,99	221
2019	0,44	0,14	0,11	0,99	244
2020	0,42	0,16	0,10	0,99	164
2021	0,41	0,15	0,10	0,98	247
2022	0,41	0,15	0,09	0,92	253
2023	0,44	0,15	0,14	0,99	216
Average	0,42	0,15	0,11	0,98	

4.3. Determinants of Bank Inefficiency

To examine potential drivers of bank cost inefficiency, a regression analysis is conducted using bank-level environmental factors. The regression analysis, as described in the methodology section, is carried out using the BC95 model. Within this analytical framework, bank inefficiency is specified as a function of multiple environmental variables that may impact efficiency scores.

While the SFA approach offers several advantages by separating inefficiency from statistical noise, it is not without limitations. One key concern is the distributional assumption regarding the inefficiency term, which, if misspecified, can lead to biased efficiency scores (Kumbhakar & Lovell, 2000). Another limitation is that SFA models are sensitive to the functional form used (e.g., Cobb-Douglas vs Translog), which may affect robustness. Additionally, standard SFA may suffer from endogeneity issues when inefficiency is correlated with explanatory variables, potentially distorting parameter estimates (Greene, 2005). To address these concerns, this study adopts a single-step, endogenous SFA model that jointly estimates the cost frontier and inefficiency effects, thereby reducing potential bias from two-stage approaches. Moreover, a Translog functional form is employed to capture flexible substitution effects and better accommodate scale heterogeneity across banks. These methodological choices help mitigate standard SFA limitations and enhance the robustness of the efficiency estimates.

For this study, the determinants of inefficiency are categorised into two main groups: the ESG variable and other explanatory variables. To examine the impact of ESG on cost efficiency, Table 3 reports the results of two models: Model 1 includes ESG, while Model 2 excludes it.

4.3.1. ESG and Bank Inefficiency

To determine the effects of overall ESG scores on cost inefficiency, the BC95 model was applied to US banks. The empirical results obtained with Model 1 show that the estimated coefficient on ESG scores is -0,001, with a significance level of 5% (t-value = -2,53), indicating that ESG-related activities by U.S. commercial banks can improve their cost efficiency. This aligns with the findings of Albuquerque et al. (2020) and Broadstock et al. (2021), suggesting that higher ESG scores indicate greater transparency, consequently lowering risk. This, in turn, boosts depositor confidence in the bank's reputation and risk-bearing capacity (Azmi et al., 2021). By increasing their social image and reputation through ESG, banks boost cost efficiency through two mechanisms: external and internal (Cao et al., 2024). Externally, strong ESG performance improves relationships with regulators and investors, reducing compliance and capital costs and increasing efficiency. Internally, it attracts better employees, increases staff motivation and loyalty, and enhances productivity and operational efficiency through sustainable practices. Ultimately, while initial investments in ESG may entail costs, the long-term benefits of enhanced reputation, reduced risk, and improved operational performance suggest a positive correlation between robust ESG integration and sustainable cost efficiency in the banking sector.

4.3.2. Control Variables with ESG (Model 1)

Capital Ratio (CAP)

The capital ratio (CAP), which reflects insolvency risk, is the first control variable examined for its impact on bank inefficiency. According to the inefficiency effect model, the CAP variable has a significant negative effect on cost inefficiency (-2,926), suggesting that banks with higher capitalisation are more cost-efficient than those with lower capital levels over the eight years under analysis. The positive relationship between equity and cost efficiency suggests that the level of equity during this period contributed to improving cost efficiency (Pessarossi & Weill, 2015). Additionally, since capital is more costly than debt, banks face pressure to minimise their operating costs. These findings are consistent with those of Casu & Molyneux (2003), Casu & Girardone (2004), Carvallo & Kasman (2005), Berger & Bonaccorsi di Patti (2006), and Chang & Chiu (2006).

Total Loans / Total Assets (LTA)

The ratio of total loans to total assets, an indicator of loan risk, is significant and negatively affects cost inefficiency (-0,821). This finding may be attributed to the fact that a lower liquidity position (i.e., a higher loan volume) is positively associated with cost efficiency (Srairi, 2010). For instance, Carvallo & Kasman (2005), employing an SFA on a

panel of 481 banks across Latin American countries, report a negative association between the loans-to-assets ratio and cost inefficiency. The negative (positive) link between cost inefficiency (efficiency) and loan volume is explained by the fact that banks in the United States that lend more frequently are generally more cost-efficient. In other words, banks that manage costs effectively are better positioned to grow their loan portfolios in the U.S. banking sector.

Total Loans / Total Deposits (LTD)

The financial intermediation ratio is statistically significant and negatively correlated with cost inefficiency (-1.134). The positive, statistically significant effect of the loan-to-deposit ratio indicates that banks retaining liquid assets at a minimum are more efficient, as loans generate a large source of interest income (Nguyen & Pham, 2020). In short, more efficient banks are also less liquid (Elyasiani et al., 1994; Chronopoulos et al., 2011).

Bank Size (LNTA)

As shown in Table 3, the coefficient for LNTA is statistically significant and negatively associated with cost inefficiency scores. This indicates that bank size positively influences cost efficiency, suggesting that larger banks are more efficient than their smaller counterparts. This finding is consistent with results from several applications in the banking sector (Pasiouras, 2008; Teeces & Tabak, 2010; Castro & Galan, 2019; Galán & Tan, 2024). Feng & Serletis (2010) also highlighted economies of scale in U.S. banks.

Return on Assets (ROA)

Regarding cost inefficiency, Table 3 indicates that ROA has a negative (-0,107) and significant effect on cost inefficiency, suggesting that banks with stronger financial performance operate more efficiently. This finding is consistent with the efficiency literature, which indicates that banks with higher ROA levels tend to be more cost-efficient (Fries & Taci, 2005; Hermes & Nhung, 2010; Gržeta et al., 2023).

Non-Performing Loans / Gross Loans (NPLs)

As expected, Table 3 reveals a positive impact of NPLs on bank cost inefficiency (e.g., Carvalho & Kasman, 2005; Fukuyama & Weber, 2015; Phung et al., 2022); however, the coefficient is not statistically significant. This finding aligns with Andries (2011), who found no significant association between nonperforming loans and bank efficiency.

Net Interest Margin (NIM)

Regarding the relationship between net interest margin and cost inefficiency, the empirical results show that the NIM coefficient is 0.177 and significant at the 1% level, indicating that a higher net interest margin is associated with lower cost efficiency. One possible reason for this result is that a higher interest margin signals higher credit risk.

Maudos & de Guevara (2004) and Lepetit et al. (2008) argue that banks tend to raise their net interest margins when credit risk is higher.

Macroeconomic Factors

Among the macroeconomic variables, only inflation (INF) was significant, with a negative relationship with cost efficiency. This finding is consistent with the studies of Barth et al. (2013) and Batir et al. (2017). Inflation has observable effects on the economy; for instance, during periods of higher inflation, banks often increase interest rates to maintain loan profitability. However, this can dampen economic activity, leading to reduced lending and lower profitability. On the other hand, the coefficient for the GDP growth rate is positive but not statistically significant, which runs counter to expectations. This implies that bank inefficiency is more influenced by internal, bank-specific factors rather than broader macroeconomic conditions.

4.4. Robustness Test: ESG Sub-Components and Bank Efficiency

As an initial robustness check, the BC95 model is estimated, incorporating ESG sub-components, to assess the consistency of the coefficient estimates with those of the benchmark model (Model 1). To assess the influence of specific ESG factors on bank efficiency, we replace the overall ESG score with the individual components: E, S, and G. The results in Table 5 show that the coefficient on the E pillar is negative (-0,001) and statistically significant (t-value = -2,02). This suggests that E investments enable banks to benefit from policy advantages while mitigating the risks linked to polluting loans, ultimately enhancing bank efficiency. These findings are consistent with those of Zhou et al. (2022). The second ESG component investigated in the inefficiency effect model is the S pillar. Regarding cost inefficiency, Table 5 shows a negative (-0,0009) influence of the S pillar; however, this effect is statistically insignificant (t-value = -1,45). Clearly, the S pillar does not have a strong influence on the cost of U.S. banks. One possible explanation for the relatively weaker impact of the social (S) component on cost efficiency is the difficulty in quantifying and operationalising social performance in a way that directly affects bank-level cost structures. Social indicators such as employee training, diversity policies, or community engagement often generate intangible benefits that materialise over longer periods and are not immediately reflected in short-term cost efficiency metrics. Moreover, in the banking sector, regulatory and market forces tend to prioritise governance and environmental compliance more directly, driven by financial risk and sustainability disclosures. Previous studies (e.g., Buallay, 2019; García-Sánchez et al., 2021) also suggest that social performance may exert an indirect influence on financial outcomes through reputational gains or employee satisfaction, which are difficult to isolate in efficiency analysis. It is also possible that variations in the quality and consistency of social performance disclosures across banks reduce the statistical power of the social ESG dimension. Therefore, the less significant effect of the social component may reflect a combination of measurement challenges, longer time horizons, and weaker direct financial linkages, rather than an actual lack of strategic relevance (Broadstock et al., 2021; Liang et al., 2024). Regarding the G

pillar, the results of the inefficiency effect model show that the coefficient for the G variable is -0,0008 and is significant (t-value = -2,04), indicating that higher G scores are associated with better cost efficiency for commercial banks. At the governance level, when commercial banks prioritise governance-related activities, they can improve cost efficiency, thereby enhancing their financial performance and market value. Additionally, Mar Miralles-Quiros et al. (2019) suggest that investing in governance helps commercial banks strengthen internal governance, increase transparency, and reduce agency costs, ultimately boosting profit efficiency.

The findings on ESG sub-components carry meaningful implications for both banking practitioners and policymakers. From a managerial standpoint, the significant effects of the environmental (E) and governance (G) dimensions suggest that banks can improve cost efficiency by investing in environmentally responsible operations and enhancing governance practices. These efforts may include strengthening risk oversight, increasing board independence, and integrating environmental standards into lending decisions. In contrast, the limited significance of the social (S) pillar indicates a need for clearer frameworks to link social responsibility initiatives with operational efficiency. These initiatives often generate long-term or intangible benefits, which may not be immediately reflected in cost performance. For policymakers, the results emphasise the value of supporting environmental and governance efforts through targeted regulations and tax incentives. Additionally, improving the consistency and clarity of ESG reporting, particularly for the social dimension, could help reduce measurement uncertainty and strengthen the link between ESG performance and financial outcomes. Encouraging the systematic inclusion of ESG factors in risk management and performance evaluation frameworks would support a more sustainable and efficient banking sector.

Table: 5
Empirical Results from the Inefficiency Model (ESG Sub-Components)

Variables	E		S		G	
	Parameter	t value	Parameter	t value	Parameter	t value
Frontier estimation						
Inefficient model estimation						
Constant	3,083***	5,50	3,063***	5,46	3,088***	5,55
CAP	-2,765***	-2,58	-2,865***	-2,66	-2,948***	-2,75
LTA	-0,860***	-2,78	-0,864***	-2,79	-0,822***	-2,65
LTD	-1,125***	-7,15	-1,113***	-7,05	-1,131***	-7,14
LNTA	-0,163***	-3,94	-0,161***	-3,89	-0,163***	-3,99
ROA	-0,107***	-8,22	-0,107***	-8,17	-0,105***	-8,04
NPL	0,271	1,40	0,273	1,40	0,280	1,43
NIM	0,177***	10,05	0,175***	9,96	0,176***	9,99
GDP	0,002	0,94	0,002	0,97	0,002	0,98
INF	0,017***	4,54	0,018***	4,55	0,017***	4,51
Core Variables						
E	-0,001**	-2,02				
S			-0,0009	-1,45		
G					-0,0008**	-2,04

Note: ***, **, * denote statistical significance at the 1%, 5% and 10% level, respectively.

4.5. Endogeneity Issues

The SFA (Battese & Coelli, 1995) model, estimated and discussed above, is an exogenous model that assumes the determinants of inefficiency are exogenous, thereby neglecting possible endogeneity issues. As noted above, our core aim is to analyse the link between ESG and cost efficiency while accounting for potential endogeneity in ESG. To rule out endogeneity between ESG and cost efficiency, an endogeneity test is conducted using a one-period lagged ESG variable as the instrumental variable.

Based on endogeneity tests, we used an endogenous SFA model following the methodology of Karakaplan & Kutlu (2017). The endogenous SFA model estimates endogeneity by evaluating the joint significance of the components of the η term. If η is found to be jointly significant, it indicates endogeneity in the model. Conversely, if η is not jointly significant, there is no need for a correction term, allowing for the estimation of efficiency using traditional stochastic frontier models.

Table 6 shows that the individual eta terms for overall ESG and its sub-components (E, S, and G) are statistically significant, and the eta endogeneity tests reject the null hypothesis at all conventional levels of significance (1% and 5%). This result indicates that a correction for endogeneity in both the estimated models and the inefficiency estimates is necessary.

Table: 6
Endogenous SFA Estimates

Variables	ESG		E		S		G	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Frontier analysis model								
Determinants of inefficiency (Environmental Variables)								
Constant	2,085***	0,616	2,062***	0,621	2,077***	0,620	2,058***	0,615
CAP	-2,121*	1,239	-2,110*	0,155	-2,071*	1,242	-2,081*	1,241
LTA	-0,762**	0,366	-0,768**	0,366	-0,797**	0,366	-0,719*	0,368
LTD	-1,070***	0,201	-1,040***	0,200	-1,039***	0,201	-1,092***	0,202
LNTA	-0,096**	0,046	-0,101**	0,047	-0,099**	0,047	-0,098**	0,046
ROA	-0,097***	0,015	-0,097***	0,015	-0,096***	0,015	-0,095***	0,015
NPL	0,734**	0,294	0,749**	0,298	0,739**	0,294	0,712**	0,293
NIM	0,166***	0,021	0,161***	0,021	0,161***	0,021	0,163***	0,021
GDP	0,001	0,003	0,001	0,003	0,001	0,003	0,001	0,003
INF	0,022***	0,005	0,022***	0,005	0,022***	0,005	0,022***	0,005
Core Variables								
ESG	-0,003***	0,001						
E			-0,002**	0,001				
S					-0,002*	0,001		
G							-0,002**	0,001
eta	0,002***	0,001	0,001**	0,000	0,001**	0,000	0,001***	0,000
Eta endogeneity test								
chi2 (1)	11,78		5,29		3,88		8,39	
p-Value	0001		0,021		0,049		0,004	

Note: ***, **, * denote statistical significance at the 1%, 5% and 10% level, respectively.

As shown in Table 6, overall, the coefficients for ESG and its sub-components (E, S, and G) become more significant and larger in magnitude when endogeneity is accounted for, highlighting the importance of properly addressing potential endogeneity. According to the endogenous SFA model, the sign of the ESG variable is negative (-0,003) and statistically

significant (at 1%), thereby confirming the robustness of previous findings. The result aligns with Liang et al. (2024) and Cao et al. (2024) and is also consistent with the stakeholder hypothesis: banks with a high ESG score emphasise the benefits to their stakeholders and increase operational efficiency. Moreover, when all three ESG sub-components are included, the coefficients for each sub-indicator retain their direction and significance, except for the S pillar. According to the results, the coefficient of the E pillar is -0,002 and statistically significant at the 5% significance level, confirming that the effect of the E pillar remains robust. Similarly, the coefficient for the G pillar is negative (-0,002) and statistically significant, consistent with the benchmark model (exogenous). The effect of the G pillar remains robust. Nevertheless, although the S pillar is insignificant in the benchmark model (exogenous), it becomes negative (-0,002) and statistically significant at the 5% level in the endogenous model.

Regarding the environmental factors, our results are consistent with the exogenous model. The coefficient estimates from the exogenous model in Table 3 and the endogenous model in Table 5 have the same sign for each variable and are significant at any conventional level of significance. However, regarding NPL, the results differ significantly between the endogenous and exogenous models. While the NPL is positive but statistically insignificant in the exogenous model, it becomes significant in the endogenous model when endogeneity is considered. Apart from the exogenous model, the endogenous SFA model confirms a positive and significant relationship between the NPLs and cost inefficiency. This indicates that commercial banks with higher levels of bad loans tend to be less cost-efficient. The result aligns with the expectation that an increase in NPLs leads to higher costs associated with managing these loans, thereby reducing overall bank cost efficiency (Berger & De Young, 1997; Altunbas et al., 2000).

5. Conclusion

This paper empirically analyses the influence of ESG on banks' cost efficiency using the most recent panel data of 253 listed U.S. banks from 2016 to 2023, applying a one-step stochastic cost frontier model. For robustness testing, we further assess the relationships between cost efficiency and the subcomponents of E, S, and G separately. On the other hand, because the traditional SFA model is limited in that it does not address explanatory variable endogeneity, which results in considerable bias in both parameter and efficiency estimates, we also test the possible endogeneity between ESG and cost efficiency using an endogenous SFA model (Karakaplan & Kutlu, 2017a). The findings are as follows: First, banks with stronger ESG performance tend to experience improved cost efficiency due to greater transparency and, therefore, lower risk, which gives depositors more confidence and increases operational efficiency. The analysis also reveals that banks that are more committed to ESG principles outperform less committed banks in terms of efficiency. Second, the influence of the E, S, and G subcomponents varies, where E and G pillars are found to enhance banks' cost efficiency, while the effect of the S pillar remains unclear. Third, endogeneity is found in cost efficiency and ESG; after controlling for endogeneity, the magnitude of the effects of ESG and its subcomponents (E, S, G) significantly increases.

Additionally, according to the endogenous SFA model, both ESG and its subcomponents have a positive, statistically significant impact on cost efficiency. This result robustly identifies the overall effects of sustainability factors on cost efficiency.

The findings of this study provide valuable insights and practical recommendations for both bank managers and regulatory authorities. For banking institutions, integrating ESG practices, particularly in the environmental and governance dimensions, should be treated not only as a reputational or compliance issue but also as a strategic investment that enhances cost efficiency. Banks are encouraged to allocate resources toward green technologies, sustainable lending practices, and strong internal control mechanisms. Additionally, social responsibility efforts should be aligned with core business operations and measured with more consistent metrics to increase their financial relevance. For regulators and policymakers, the results highlight the importance of promoting ESG adoption through targeted incentives. Regulatory bodies may consider offering tax advantages or capital relief to banks demonstrating strong ESG performance, particularly in governance and environmental practices. Furthermore, harmonising ESG disclosure frameworks, especially for the social component, would reduce inconsistencies in reporting and strengthen the reliability of ESG-related performance assessments. These measures would not only improve the integration of ESG in banking strategy but also support broader goals of financial stability and sustainable development.

This study contributes to the theoretical intersection of finance and sustainability by providing robust empirical evidence on the role of ESG performance in enhancing cost efficiency within the banking sector. By employing a one-step SFA that accounts for endogeneity, the study offers a methodological advancement over traditional two-stage models, generating more consistent and unbiased efficiency estimates. The findings support stakeholder theory by demonstrating that greater engagement with ESG practices, particularly in the environmental and governance dimensions, can improve operational efficiency. This challenges the conventional view of sustainability as a cost burden and instead positions ESG integration as a strategic driver of long-term financial performance. Furthermore, by disaggregating ESG into its sub-dimensions, the study reinforces its multidimensional nature. It emphasises the importance of tailored managerial strategies rather than a one-size-fits-all approach. From a finance perspective, the study extends the traditional efficiency literature by incorporating non-financial variables into firm performance analysis, offering a more holistic understanding of value creation. From a sustainability perspective, it contributes to the growing literature that seeks to quantify the financial materiality of ESG factors, particularly within the context of banking institutions, which play a critical role in the broader transition to a sustainable economy.

This research is subject to certain limitations. First, the main limitation of this research is data availability, which restricts the study period to only eight years. We had to reduce our sample size because not many banks have publicly available ESG data. Second, future studies may consider different sustainability metrics. Relying solely on the Eikon Refinitiv database may introduce selection bias; therefore, using alternative ESG indicators,

such as Bloomberg or MSCI ESG scores, could strengthen the findings. Finally, the data in this study cover U.S. banks, but future research could expand to include banks from both developed and developing economies.

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Who Leads, Who Follows? Peer Effect on Bank Leverage Decisions in Türkiye¹

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Kim Önder, Kim Takipçi? Türkiye'de Banka Kaldıraç Kararlarında Akran Etkisi²

Abstract

This study examines the role of peer effect on bank leverage decisions in the Turkish banking sector. Data from 21 deposit banks operating between 2007 and 2022 were analysed using the Panel-Corrected Standard Errors (PCSE) method. In the model, the dependent variable is the bank leverage ratio, the independent variable is peer bank leverage, and the control variables are bank size, liquidity ratio, and loss provisions/total assets ratio. The findings show that peer influence is positive and significant, indicating that their peers' financial behaviour influences banks' leverage decisions. The study aims to demonstrate that bank decisions are shaped not only by internal factors but also by sectoral interactions.

Keywords : Peer Effect, Bank Behaviour, Leverage Decisions, Banking Sector.

JEL Classification Codes : G21, G32, D85.

Öz

Bu çalışma, Türk bankacılık sektöründe akran etkisinin banka kaldıraç kararları üzerindeki rolünü incelemektedir. 2007-2022 döneminde faaliyet gösteren 21 mevduat bankasına ait veriler Panel-Corrected Standard Errors (PCSEs) yöntemiyle analiz edilmiştir. Modelde bağımlı değişken banka kaldıraç oranı, bağımsız değişken akran banka kaldıraç; kontrol değişkenler ise banka büyüklüğü, likidite oranı ve zarar karşılıkları/toplam varlıklar oranıdır. Bulgular, akran etkisinin pozitif ve anlamlı olduğunu, bankaların kaldıraç kararlarını akranlarının finansal davranışlarından etkilenecek şekilde göstermektedir. Çalışmanın motivasyonu, banka kararlarının yalnızca içsel faktörlerle değil, sektörel etkileşimlerle de şekillendiğini ortaya koymaktır.

Anahtar Sözcükler : Akran Etkisi, Banka Davranışı, Kaldıraç Kararları, Bankacılık Sektörü.

¹ This paper is a revised and expanded version of the abstract titled "Peer Dynamics Shaping Leverage Decisions in Banking - The Example of Türkiye" that was orally presented at the 4th International Banking Congress held in Bozüyük on May 16-18, 2024.

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1. Introduction

The functionality of the financial system for the sustainability of economic development has been widely discussed in the literature (Arestis & Demetriades, 1997; Ahmed, 2010; Ozili & Iorember, 2024). In this context, the finding that the financial system supports economic growth by efficiently allocating resources is prominent (King & Levine, 1993; Levine, 1996). It is stated that an efficient financial system benefits both individual and institutional investors and contributes to increased national wealth (Scholtens & Van Wensveen, 2003).

Banks, one of the main institutions of the financial system, play a critical role as intermediaries, collecting resources from segments with excess savings and transferring them to segments in need of funds. This intermediate function places banks at the centre of the system in terms of ensuring the continuity of the economic cycle. Their high leverage largely enables banks to fulfil these functions. While converting the deposits they collect into loans, banks tend to borrow much more than their shareholders' equity. While this situation supports the efficient allocation of financial resources, it also brings along systemic risks. Leverage levels have become a key factor affecting not only individual bank performance but also the stability of the entire financial system (Firestone et al., 2017). The 2008 Global Financial Crisis is considered a concrete example of this risk. During the crisis, it was observed that banks with seemingly adequate capital adequacy ratios built high-risk balance sheets through excessive borrowing, thereby deepening the crisis (D'Hulster, 2009; Acosta-Smith et al., 2020). The tendency of banks to borrow to maintain their leverage levels during periods of rising asset prices is considered a dynamic that increases systemic fragility (Baglioni et al., 2013). Since risk-weighted capital adequacy ratios are susceptible to manipulation, the leverage ratio serves as a safeguard to compensate for this shortcoming (Blum, 2008; Kiema & Jokivuolle, 2014). Within the scope of Basel III regulations, a minimum leverage ratio of 3% was implemented; this ratio was considered a measure to increase the system's resilience in cases where risk-weighted regulations are insufficient (Türküner, 2016). The leverage ratio can be used as a prudential tool at both the micro level (e.g., disciplining banks' lending behaviour) and the macro level (e.g., limiting credit growth and supporting economic stability). Consequently, it plays a role in ensuring financial stability and preventing systemic risks that could spread throughout the economy. Ultimately, it is emphasised that credit cycles can be effective in reducing behaviours or mechanisms that amplify the current economic cycle, or in other words, in balancing variables or policies that move in the same direction as economic cycles (D'Hulster, 2009).

Avgouleas (2015) argues that the leverage ratio strengthens financial stability by limiting not only individual bank risks but also systemic debt accumulation. Similarly, Barth and Miller (2018) argue that increases in the leverage ratio can reduce the frequency and severity of crises, thereby mitigating the negative effects on economic contraction. In the same study, it is argued that increasing the leverage ratio from 4% to 15% may result in significant reductions in crisis costs. Although the leverage ratio is an effective regulatory tool, its failure to account for differences in risk nature is considered an important limitation.

Fender and Lewrick (2015) emphasise the leverage ratio's role in limiting the accumulation of cyclical and structural risk and argue that it provides net economic benefits when kept between 4% and 5%. Grill, Lang and Smith (2016), on the other hand, argue that the leverage ratio may encourage banks' risk-taking behaviour in some cases, but high capital buffers can offset this negative effect. In this context, the question of what the optimal leverage ratio should be remains a subject of debate in the literature. Begenau and Landvoigt (2022) and Egan et al. (2017) argue that certain leverage levels can have positive effects on economic welfare, while Barth and Miller (2018) state that increasing the leverage ratio may reduce crisis risk but could also negatively affect real investment and growth by increasing capital costs.

This study aims to determine whether a peer effect exists in the leverage decisions of deposit banks in Türkiye. In this context, 21 Turkish deposit banks were examined for the period 2007-2022. Using panel data analysis, the dependent variable is the bank leverage ratio, while the independent variables are peer bank leverage, bank size, liquidity ratio, and risk (loss provisions/total assets). Although the bank leverage ratio has been a heavily debated topic in the literature, the peer effect dimension has not been studied, particularly in the Turkish context. This study is expected to fill this gap in the literature and to provide concrete data for policy recommendations to regulators and decision-makers.

2. Conceptual Framework

In recent years, it has been widely accepted that decision-making processes in financial markets are influenced by both behavioural factors and rational approaches (Doğan, 2016; Umapathy, 2024). In this context, peer effect is defined as individuals or institutions shaping their own behaviour by observing the decisions of other actors operating under similar conditions (Lahno & Serra-Garcia, 2015). Not only in daily decisions but also in financial decisions, a person's choices are influenced by those around them. In this context, individuals influenced by others in their financial behaviour make decisions based on others' choices. In addition, this influence is considered an important factor for companies, as studies show that peer influence is present in their financial management. For example, Adhikari and Agrawal (2018) show that companies' distribution policies, such as dividends and share buybacks, are significantly influenced by peers' policies in the same sector. Especially in sectors such as banking, where information asymmetry is high, decision-making processes are complex and external risks are intense, the peer effect becomes more evident.

The theoretical foundations of peer effects are primarily associated with social learning theory (Bandura, 1977). According to this theory, individuals learn from their environment through observation, and the actions of other actors serve as a reference point, especially in conditions of uncertainty. Conlisk (1980) interpreted this behaviour as a strategy to avoid the costs of acquiring information and making decisions, and stated that individuals or firms prefer to imitate successful peers rather than engage in trial-and-error. Manski (1993) argues that firms tend to adopt the strategies of peer firms that they observe

in their environment, especially during periods of high uncertainty. Additionally, Lieberman and Asaba (2006) examined why firms imitate each other. They reviewed the existing literature and proposed two different theoretical frameworks. The first is the information-based theory, and the other is the rivalry-based theory. The information-based theory suggests that firms follow other firms that are believed to possess superior knowledge. According to this theory, managers, especially during periods of high uncertainty, cannot clearly establish cause-and-effect relationships when making decisions and therefore take their peers' decisions as information signals. Within this theory, there are two mechanisms within economic approaches: information cascades/social learning and reputation-based imitation. The organisational sociology and ecology approaches in information-based theory state that, according to mimetic isomorphism (DiMaggio & Powell, 1983), organisations in uncertain environments are influenced by and emulate their more successful peers, thereby reducing their knowledge costs. According to legitimacy theory, companies that reach a critical mass in new industries help the sector gain legitimacy. This situation facilitates access to financing and encourages new entrants by increasing the workforce's attractiveness. Lieberman and Asaba (2006) propose the second main theory in the peer literature for firms: the Rivalry-Based Theory, which argues that firms imitate their competitors to maintain competitive equality or limit competition. These theories can be divided into two main groups: strategies aimed at limiting competition and strategies aimed at maximising risk. Following the leader is a prerequisite, and similar investments are made with peers to avoid falling behind. Imitating peers can involve negative aspects such as aggressive competition and excessive investment risks. For example, Posen and Martignoni (2018) similarly state that following peers' actions can lead to poor performance and the risk of worse performance. In this context, it is noted that while peer influence has positive aspects, it also poses negative aspects for companies.

The mechanism of peer effects in financial decisions is generally explained by three main channels: (i) interpreting the behaviour of other actors as a signal in markets with high information asymmetry (Lieber & Skimmyhorn, 2018), (ii) avoiding decision-making costs and saving time (Conlisk, 1980), and (iii) trying to conform to social norms or behavioural similarity (Bursztyn et al., 2014). These mechanisms lead bank managers to consider the preferences of similarly situated banks when making strategic and risky financial decisions, such as leverage.

For financial institutions, the peer effect manifests itself in many areas, such as loan portfolios (Wang et al., 2021), capital structures (Leary & Roberts, 2014), risk-taking behaviour (Wang et al., 2023), corporate cash policies (Chen et al., 2019), and corporate social responsibility. Especially in times of crisis or in highly competitive sectors, this effect becomes stronger (Xu & Wu, 2022; Warninda & Maryani, 2022). In this context, firms' excessive imitation of peers in the aftermath of financial crises has become a phenomenon that warrants careful examination, as it may increase systemic risk and spread poor decisions.

Although the impact of peer effect on leverage decisions is a relatively new area in the literature, it has received increasing attention. Lee et al. (2017) find that financial institutions are significantly influenced by the leverage levels of other firms in the industry when determining their leverage structures. Similarly, He and Wang (2020) find that leverage levels of Chinese firms are positively correlated with those of their industry peers. However, such studies are generally concentrated in non-financial sectors and evidence on the banking sector is limited.

This study examines the determinants of peer effects on bank-specific financial decision-making by analysing the extent to which bank managers are influenced by other banks' behaviour when setting leverage ratios. In addition to being the first study to empirically test social learning theory in the context of bank leverage decisions in the Turkish banking sector, the study has the potential to offer new regulatory perspectives to the Turkish financial system and policymakers, as well as to policymakers in similar countries that consider the behavioural dynamics between banks.

In the remainder of the study, theoretical and empirical literature on the subject will be reviewed, followed by a description of the data set and methodology, and the empirical findings will be presented.

3. Literature Review

The basis of the peer effect is individuals' observation and imitation of other actors in decision-making through social learning. Conlisk (1980) argued that individuals avoid the costs of acquiring knowledge by imitating successful actors, thereby reducing decision-making costs. Therefore, with this approach, he pioneered the adaptation of social learning to economic decisions. Kaustia and Knüpfer (2012) found that investors continue to enter the stock market in line with their peers' preferences, even when stock returns are negative, demonstrating that peer influence can also fuel irrational behaviour. In this regard, it presents evidence that peers' presence serves as a mechanism that reveals investors' psychological motivations beyond financial decisions, showing that investors do not behave rationally but instead reference their peers' preferences. Bursztyn et al. (2014) found that the concepts of social learning and social benefit can influence investment decisions, revealing that social learning has a decisive impact not only on individuals but also on market dynamics. Lahno & Serra-Garcia (2015) show that individuals take their peers' decisions into account based on their preferences and profit concerns. This can be seen as a step towards linking peer influence on modern behavioural economics and decision theory literature. It reveals that individuals do not merely imitate their peers' behaviour in their decision-making processes but also take these interactions into account while balancing their own benefit expectations and preferences. In line with this perspective, various studies have documented that the peer effect is also effective at the firm level. Peer effects are influential factors in many firms' strategic decisions, including cash holdings, capital structure, investment, dividend distribution, and stock splits. From the perspective of peer effects and financial leverage, Leary and Roberts (2014) argue that small, new, and unsuccessful firms imitate the capital

structures of larger and more successful firms. He and Wang (2020), in their study of Chinese firms, find that firms' leverage levels are positively associated with those of their peers. Francis et al. (2016) show that firms in both developed and developing countries take into account the leverage decisions of their sectoral peers. Kaustia and Rantala (2015) find that firms' stock split decisions are influenced by peers', while Ren et al. (2022) find that successful IPOs can shape price and credit conditions in the industry, especially among firms operating in an intensely competitive environment. Jinkrawee et al. (2023) find that firms may exhibit cash-holding behaviour similar to that of their peers during crises. Chen et al. (2019) find that peer effects are determinants of cash policies in US manufacturing firms. Zhuang et al. (2022) find that firms with low cash reserves increase their cash levels in parallel with the increase in liquidity of their peers. These findings support the impact of information and rivalry-based mechanisms. In addition, Gao et al. (2011), who evaluate financial leverage decisions across geographical and competitive differences, find a 'local peer effect' that varies by firm location. The literature also emphasises that the peer effect is stronger in sectors with high levels of asymmetric information and intense competition (Ren et al., 2022; Warninda & Maryani, 2022).

Horvath (2020) argues that central banks shape their decisions on monetary policy transparency in line with other central banks' practices; thus, the peer effect also affects regulatory decisions. This type of effect may become even more sensitive, especially in times of crisis and put the stability of the financial system at risk.

Studies specific to the banking sector reveal the effects of peer effects on systemic risk and financial stability. Wang et al. (2021) showed that loan portfolios of Chinese commercial banks exhibit a peer effect, which can increase the risk of systemic bankruptcy, while Margaretic et al. (2021) found that small and foreign banks are more sensitive to the lending/borrowing decisions of large banks. Wang et al. (2023) emphasise that peer banks' risk levels shape bank risks and that this effect varies with market conditions. Parallel to the findings of Lee et al. (2017), who found that the leverage decisions of financial institutions are subject to peer effects more intensely than non-financial firms and that this effect is determinant in decision-making processes, Warninda and Maryani (2022) found that the financial leverage decisions of Islamic banks in Indonesia during the global financial crisis were strongly affected by the leverage structures of peer banks.

In addition to financial issues in the limited literature on peer effect in the banking sector; Malik et al. (2019) found that corporate social responsibility expenditures of banks in Bangladesh increased due to peer pressure, while Gangopadhyay and Nilakantan (2021), who addressed the issue in terms of its effects on information technology and corporate behaviours, found the existence of social learning processes and peer effect in the information technology investments of banks in Jordan; and found that the investment decision of one bank triggers other banks to make similar decisions.

The summarised literature reveals that the peer effect is a powerful mechanism that affects not only individual behaviour but also strategic decisions at the corporate and sectoral

level. Especially in the financial field, the peer effect plays a critical role in capital structure and risk management decisions. However, studies on the peer effect on bank leverage decisions are quite limited. In this context, the study offers several contributions: While peer effects on individual and firm decisions are frequently discussed in the literature, studies examining peer effects on bank decisions are limited. It offers originality by being among the very few studies in the literature to link bank leverage decisions to peer influence directly. Furthermore, literature has generally examined developed countries. It is the first study to analyse peer influence in the financial sector using Türkiye as an example, a developing country, and it is also distinctive in that it examines peer influence on bank leverage decisions, which are important for financial stability. At the micro level, it shows that bank leverage decisions are shaped by peer influence, while at the macro level, the findings offer policy implications for financial stability and regulatory authorities. In this context, the results will not only offer practical recommendations for bank managers to consider peer dynamics in their strategic decision-making processes, but will also yield insights for regulatory and supervisory authorities in their assessment of the issue.

4. Data and Methodology

This study aims to determine whether a peer effect exists among Turkish deposit banks and, if so, to quantify its magnitude, thereby providing decision-makers with important data on this subject. Annual financial data for 21 deposit banks for the period 2007-2022 were obtained from the Turkish Banks Association (TBB) database. All banks included in the analysis are deposit banks, established in Türkiye, have more than one branch, and have regularly provided data throughout the analysis period. Single-branch banks create significant deviations in this type of analysis. Development and investment banks were excluded from the scope due to their different resource structure. Banks headquartered in foreign countries and operating only as branches in Türkiye were not included in the sample because they only have branch characteristics. The banks covered in the analysis are presented in Table 1.

Table: 1
Turkish Deposit Banks Subject to Analysis

Code	Bank Name	Type	Code	Bank Name	Type	Code	Bank Name	Type
1	Akbank	Private	8	QNB Finansbank	Foreign	15	Türk Ekonomi Bank	Private
2	Alternatifbank	Private	9	HSBC Bank	Foreign	16	Türkiye Cumhuriyeti Ziraat Banka	Public
3	Anadolubank	Private	10	ICBC Türkiye Bank	Foreign	17	Türkiye Garanti Bank	Private
4	Arap Türk Bank	Foreign	11	ING Bank	Foreign	18	Türkiye Halk Bank	Public
5	Burgan Bank	Foreign	12	Şekerbank	Private	19	Türkiye İş Bank	Private
6	Denizbank	Foreign	13	Turkish Bank	Private	20	Türkiye Vakıflar Bank	Public
7	Fibabanka	Private	14	Turkland Bank	Foreign	21	Yapı ve Kredi Bank	Private

In the study, since the data set's structure is suitable for the panel format, the econometric model adopted the Panel-Corrected Standard Errors (PCSEs) method, a robust panel method, as the appropriate approach. The primary reason for using the PCSEs method in econometric analyses in this study is that preliminary tests of the panel data set revealed cross-sectional dependence, heteroscedasticity, and autocorrelation. First, the results of the

Pesaran (2004) CD test and the Breusch-Pagan LM test indicated significant cross-sectional dependence among the countries in the panel. This indicates that shocks arising from economic, financial, or structural similarities between countries affect one another and that the error terms are mutually dependent. If traditional panel data methods do not account for such dependencies, the estimated standard errors may become systematically biased and inconsistent. Furthermore, the results of the Breusch-Pagan/White test and the Wooldridge autocorrelation test indicate the presence of heteroscedasticity (varying variance) in the error terms and autocorrelation over time. Heteroscedasticity can lead to incorrect coefficient standard errors when error variances differ across countries. Autocorrelation, on the other hand, arises from the dependence of error terms within the same country over time and also undermines the reliability of standard errors. The PCSEs method developed by Beck and Katz (1995) is an estimation approach that corrects standard errors by simultaneously addressing these three issues (cross-sectional dependence, heteroscedasticity, and autocorrelation). One of the most important advantages of the method is that it produces efficient and robust results, especially in panel data settings where the time dimension (T) is long relative to the cross-sectional dimension (N). PCSEs provide more accurate standard error estimates compared to the Feasible Generalised Least Squares (FGLS) approach and eliminate the problem of overly optimistic (downward-biased) standard errors. The choice of the PCSEs method in this study contributed to the accurate determination of the statistical significance of the obtained coefficients, enhanced the reliability of the policy implications, and strengthened the predictive power of the model. Thus, the influence of peers' leverage ratios on banks could be more accurately presented. Econometric analyses were performed using Eviews and Stata 17. The variables used in this study were determined based on the literature and are shown in Table 2.

Table: 2
Definitions of Variables

Variable	Definitions
Dependent variable	
Bank Leverage Ratio	[1-(Equity / Total Assets)]
Independent variables	
Peer Leverage	[Peer Bank Leverage Ratios]
Control variables	
Bank size	[Logarithm of Total Assets]
Liquidity	[Liquid assets / Total Assets]
Risk	[Loss provisions / Total Assets]

Using the dependent and independent variables introduced in Table 2 and based on studies in the literature (Dang & Nguyen, 2021; Lee et al., 2017; Lucky & Nwosi, 2015; Warninda & Maryani, 2022; Yudaruddin, 2017), the model equation (1) was established. This model was estimated using panel data (i indicates the bank, t indicates the time). Thus, both interbank differences and changes over time can be considered. The dependent variable in the equation, $LEV_{i,t}$, represents the leverage ratio of banks in each period. β_0 ; The constant term indicates the leverage level outside the explanatory variables in the model. $PELEV_{i,t}$; expresses the leverage ratio of peer banks. The β_1 coefficient measures the existence and direction of the peer effect. $\sum CONT$ encompasses control variables at the bank level, such

as liquidity, bank size, and loss provisions. Finally, the error term $e_{i,t}$ represents other random factors not included in the model that may affect the bank's leverage ratio.

$$\text{Model: } LEV_{i,t} = \beta_0 + \beta_1 PELEV_{i,t} + \sum CONT + e_{i,t} \quad (1)$$

The peer bank calculation for each bank in the model was performed using the following formula: for each bank, the average of the other banks was computed, excluding the bank itself, and this value was modelled as the “peer average.” This calculation is expressed as in Equation (2):

$$y_i = (1 / (n - 1)) \times \sum x_j, j \neq i \quad (2)$$

In the panel analysis conducted, descriptive statistics were first calculated. Subsequently, the correlation between variables was examined. The ADF test was used to test the unit root levels of the variables. The hypothesis established for this purpose is as follows.

H_0 : The series are unit roots (non-stationary).

H_1 : It is a stationary series.

Decision criterion: H_0 is rejected when $p < 0.05$ (Dickey & Fuller, 1979).

After determining the stationarity levels of the series in the next stage, cross-sectional dependence was examined. The Breusch-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM, and Pesaran CD tests were used for cross-sectional dependence. The hypothesis tested is as follows.

H_0 : There is no cross-sectional dependence.

H_1 : There is cross-sectional dependence.

Decision criterion: H_0 is rejected when $p < 0.05$ (Yerdelen-Tatoğlu, 2020).

The basic hypothesis established for regression analysis and to be tested in the study is as follows:

H_0 : Peer banks do not influence a bank's leverage decisions. ($\beta_1 = 0$).

H_1 : Peer banks have an impact on a bank's leverage decisions. ($\beta_1 \neq 0$).

Decision criterion: H_0 is rejected when $p < 0.05$ (Greene, 2002).

Finally, after determining the necessary method, panel regression analysis was performed. The test method used for this purpose is robust least squares.

5. Findings

Descriptive statistics values calculated for all variables used in the analysis are shown in Table 3. The number of observations, based on variables derived from 16 years of data from 21 deposit banks, is 336. As seen in Table 3, while the average leverage ratio of the 21 banks examined within the scope of the analysis is approximately 87,33%, the peer leverage ratios of the banks are similarly 87,23%. The average similarity levels of peer banks in the capital structure are remarkable. Similarly, the peer leverage standard deviation is low, and even here the peer effect is noticeable.

Table: 3
Descriptive Test Statistics

Variables	Mean	SD	Medyan	Min	Max	N
LEV	87.333	10.04	88.880	15.071	100.000	336
PELEV	87.229	3.551	89.185	78.736	92.154	336
SIZE	4.730	0.661	4.615	4.015	7.026	336
LIK	26.296	4.538	27.535	17.056	34.092	336
LP/TA	1.141	0.384	1.021	0.678	2.061	336

To investigate multicollinearity in the analysis, a correlation analysis was utilised, and the correlation coefficients between the independent and control variables are presented in Table 4. There is a negative relationship between LEV and LIK, ZARKŞ/TV (-0.207, i.e., 21%, and -0.012, i.e., 0.1%), while there is a positive relationship between PELEV (21%) and SIZE (0.3%). However, the correlations among the independent variables are not strong. This situation increases the reliability and interpretability of the model coefficients.

Table: 4
Correlation Analysis

	LEV	PELEV	LIK	SIZE	LP/TA
LEV	1				
PELEV	0.207	1			
LIK	-0.187	-0.569	1		
SIZE	0.003	0.006	-0.003	1	
LP/TA	-0.012	-0.05	-0.468	-0.163	1

The stationarity of all variables used in the study was tested using the Augmented Dickey-Fuller (ADF) unit root test. Since non-stationary series can lead to incorrect regression results, the series was tested for stationarity before analysis. The ADF test was preferred because it can account for different model specifications, including trend and constant terms, and is widely used in the literature. The unit root test results are presented in Table 5. According to the results, the variables are not stationary at the level but are stationary at the first difference, meaning they do not have a unit root.

Table: 5
ADF Unit Root Test Findings

	At level	LEV	PELEV	LIK	SIZE	LP/TA
Constant	t-stat.	0.089	0.495	0.495**	0.999	0.099*
Constant and Trending	t-stat.	0.2304	0.718	0.065	0.842	0.183
Without Constant and No Trend	t-stat.	0.578	0.933	0.032**	0.245	0.380
	First Difference	d(LEV)	d(PELEV)	d(LIK)	d(SIZE)	d(LP/TA)
Constant	t-stat.	0.041***	0.013***	0.010***	0.000***	0.005***
Constant and Trending	t-stat.	0.176*	0.043**	0.047**	0.000***	0.032**
Without Constant and No Trend	t-stat.	0.003***	0.002***	0.000***	0.000***	0.000***

Note 1: *, **, *** represent 10%, 5% and 1% significance levels, respectively.

Panel data models generally assume that the error terms are independent across units, but in some cases, errors can also be correlated across the cross-sectional dimension. Therefore, in this study, the presence of cross-sectional dependence on variables was tested using 4 methods. In this study, Breusch-Pagan LM (Breusch & Pagan, 1980), Pesaran scaled LM (Pesaran, 2004), Bias-corrected scaled LM (Pesaran, 2008), and Pesaran CD (Pesaran, 2004) methods were used, respectively.

Cross-sectional dependence findings are presented in Table 6. According to the cross-sectional dependence test results, there is cross-sectional dependence in all variables. Therefore, second-generation methods were used.

Table: 6
Cross-Sectional Dependency Findings

	LEV	PELEV	LIK	SIZE	LP/TA
Breusch-Pagan LM	907.215*	3149.189*	3327.026*	3359.375*	3304.172*
Pesaran scaled LM	32.996*	142.393*	151.071*	152.650*	149.955*
Bias-corrected scaled LM	32.296*	141.6931*	150.371*	151.950*	149.255*
Pesaran CD	15.334*	56.092*	57.680*	57.960*	57.477*

Note 2: Degrees of freedom for all variables are 210.

As the tests conducted in the study revealed horizontal section dependence, the Panel-Corrected Standard Errors (PCSEs) method, which is one of the Robust Panel methods, was applied as the appropriate test. PCSEs are a technique developed to correct for dependency. This method recalculates standard errors to account for dependence among observation units. This allows for more accurate standard errors by accounting for the dependence among error terms, thereby making the results more reliable. Using such correction methods is important for obtaining accurate results in panel data analysis. The test results are presented in Table 7. According to the model's probability results, the model is significant at the 5% level. Here, the LEV variable is the dependent variable, while the other variables are independent and control variables. According to the results, all variables in the model, except the LP/TA variable, are significant. Accordingly, the LEV variable is positively affected by the PELEV variable. The coefficient is 0.1669 and is statistically significant at the 1% level. This result indicates that banks' leverage ratios are positively influenced by their peers' leverage decisions, suggesting a strong, statistically significant peer effect. According to the regression results, based on equation (5) in the basic hypothesis established for this study, the H_0 hypothesis was rejected and H_1 was accepted. Therefore, there is a peer effect in the leverage decisions of 21 Turkish deposit banks. Accordingly, a one-unit increase in peer

leverage ratios affects a bank's leverage ratio by approximately 17%. In the functioning of the financial system, bank leverage ratios are important factors that determine how much banks can increase their loans and how these decisions affect the riskiness of the banking sector (Christensen et al., 2011). In this sense, when peers increase their leverage, other banks may be influenced to imitate them, thereby increasing the sector's riskiness. Conversely, if a bank acts prudently by reducing its leverage ratio and its peers follow suit, reducing their leverage ratios as well, this can reduce the sector's riskiness because lower leverage indicates a more prudent, capital-intensive structure. The SIZE variable is also positively correlated with the LEV variable. The coefficient is 0.4492, which is statistically significant at the 10% level. This finding indicates that larger banks tend to use higher leverage. As banks grow larger, they tend to use more leverage. A negative relationship has been observed between the SIZE and LIK variables. The coefficient is -0.1610 and is statistically significant at the 1% level. This finding indicates that as liquidity ratios increase in Turkish banks, leverage levels decrease, meaning that banks with higher liquidity levels have lower debt levels. On the other hand, the relationship between the LP/TA variable, the last control variable in the model, and the LEV variable is not statistically significant. According to the analysis, the coefficient for the LP/TA variable is -0.9097, but it is not significant ($p=0.114$). As a result, this variable, used as a risk indicator, cannot statistically explain banks' leverage decisions.

Table: 7
Model Results

Variable	Coefficient	Std. Error	z-Statistic	Prob.
PELEV	0.166886	0.065767	2.537530	0.0112
LIK	-0.161034	0.058405	-2.757176	0.0058
SIZE	0.449206	0.266469	1.685769	0.0918
LP/TA	-0.909750	0.575633	-1.580435	0.1140
C	77.47886	7.470664	10.37108	0.0000
	Robust Statistics			
R-squared	0.075746	Adjusted R-squared		0.064577
Rw-squared	0.152671	Adjust Rw-squared		0.152671
Akaike info criterion	391.4598	Schwarz criterion		412.9697
Deviance	3575.173	Scale		3.051747
Rn-squared statistic	47.32361	Prob (Rn-squared stat.)		0.000000
	Non-robust Statistics			
Mean dependent var	87.33345	S.D. dependent var		10.04049
S.E. of regression	10.02681	Sum squared resid		33277.74

6. Conclusion and Recommendations

This study aims to determine whether peer influence affects leverage ratio decisions of Turkish deposit banks, identify its level if present, and provide decision-makers with important data on this subject. Within this scope, findings were obtained by applying the Panel-Corrected Standard Errors method to data from 21 deposit banks spanning 2007-2022. When the analysis results were examined, significant results were obtained for all variables except the LP/TA variable.

There is a positive relationship at the 5% significance level between the LEV and PELEV variables, which are the focus of the study. According to this result, banks are

affected by their peers' leverage decisions, and the effect is positive. It is seen that as their peers increase their leverage ratios, banks also increase their own leverage ratios. Similarly, Lee et al. (2017), Warninda and Maryani (2022), among the studies encountered in the literature on this subject, concluded that banks are influenced by their peers when making leverage decisions. Similarly, although a positive effect has been identified, the studies in question used different samples.

Leverage in banking is an indicator that shows the extent to which banks borrow relative to their equity capital. Although an increase in this ratio increases financial risk, it also indicates that banks' lending capacity has increased. In other words, it indicates how much they have increased their lending capacity or invested in the deposits and other liabilities they have collected. Banks' leverage decisions are determined not only by individual risk optimisation but also by competitive pressure, information signals, and market norms. In other words, when one bank shows a tendency to borrow more, other banks tend to adopt similar strategies. Therefore, based on this study's findings, the peer effect is one channel through which systemic risk spreads in the banking system. The fact that the peer leverage ratio is significant and positive indicates that banks align their leverage decisions not only with their own financial conditions but also with the decisions of other banks in the sector. This is both an important finding for financial stability and a critical warning for policymakers. It indicates that banks shape their borrowing and risk-taking behaviour not only independently but also by taking other actors in the sector into account. These findings reveal that bank leverage decisions are significantly related not only to internal factors but also to the leverage levels of other banks in the sector. However, this effect should not lead to decisions made solely by following others; it may be more appropriate for managers to base their decisions on analyses of fundamental indicators, such as their own bank's risk profile, liquidity position, and capital adequacy, when determining leverage levels. Internal mechanisms should require justification for decisions based on industry trends. At the macro level, to ensure financial stability, policymakers should take measures not only targeting individual banks but also addressing leverage trends across the entire sector. Positive peer effects can be a good indicator when the economy is doing well, but can lead to problematic outcomes during times of crisis. In this context, macro-prudential indicators that track leverage concentrations should be developed; behavioural synchronisations should be monitored, particularly during crisis periods, using early warning mechanisms. In the banking sector, the likelihood of risk contagion triggered by peer effects in financial institutions is high. Therefore, managers must carefully evaluate and manage both internal and peer-influenced decisions within their own scope of responsibility. In developing countries such as Türkiye, banks account for a large share of the financial system in terms of asset size. Given their importance in fund transfers and their fragile structure, the tendency toward peer effects in banks should be monitored.

The finding of a negative relationship between leverage and liquidity suggests that banks with high leverage may be more vulnerable to liquidity constraints. From a liquidity perspective, high liquidity tends to reduce risk-taking and encourage prudent balance sheet management. From the perspective of bank managers, liquidity management is critical not

only for payment capacity but also for creating sustainable leverage strategies. In line with this finding, it is recommended that banks align their liquidity strategies with their risk management policies in an integrated manner. For policymakers, counterbalancing measures such as targeted liquidity buffers for highly leveraged banks could be considered. Particularly within the macroprudential framework, developing regulations that monitor the leverage-liquidity balance and include preventive liquidity buffers for stress periods would be beneficial.

As banks grow larger, they tend to increase their leverage ratios. This can be explained by the fact that, as banks grow, they want to increase their borrowing. At the same time, bank size affects the leverage ratio. This is because large banks have greater opportunities to benefit from leverage, as they are well-known in the market (Gropp & Heider, 2010). Small banks incur higher borrowing costs than large banks do. Larger banks generally exhibit less volatility in their annual returns. This reduces the financial risks associated with them and, consequently, increases their ability to maintain a higher financial leverage ratio than smaller banks (AL-Shatnawi et al., 2021). As understood, high leverage indicates that the bank has grown by borrowing more, thus increasing its risk, while low leverage indicates a more cautious, capital-intensive structure. Like literature, this study also reveals that as bank size increases, leverage ratios rise, and that there is a positive interaction between the peer effect and financial leverage. The findings of this study regarding the relationship between liquidity and leverage are consistent with those in the literature by George (2015), Dinlersoz et al. (2019), Chatterjee and Eyigungor (2023), and Cincinelli et al. (2024). These studies also reveal a similarly positive relationship. Furthermore, similar results have been observed in studies on Turkish banking (Caglayan and Sak, 2010; Avcı and Çatak, 2016). The positive correlation between bank leverage and size in the study indicates that large banks tend to have higher debt levels in their capital structures, and that potential systemic risks may become more pronounced in them. From the perspective of bank managers, this result points to the need for more careful management of the risks associated with increasing leverage levels as size increases. It would be appropriate for large banks to develop stronger risk control mechanisms not only to leverage their scale advantages, but also to address potential loss scenarios arising from leverage. For supervisory and regulatory authorities, this finding raises the need for differentiated leverage limits or scale-based macroprudential policies for large banks. In particular, the excessive borrowing tendencies of systemically important banks should be regularly monitored, and, where necessary, the existing size-sensitive additional capital requirements should be reviewed with this perspective in mind.

Another finding of the study is that no statistically significant relationship was observed between the Loss Allowances/Total Assets variable, a measure of credit risk (Lucky & Nwosi, 2015), and the Leverage variable. This result may indicate that banks do not base their leverage decisions directly on credit risk indicators or that this relationship was not apparent during the sample period. Furthermore, leverage levels may be more influenced by factors such as market conditions, peer behaviour, and liquidity. This situation

indicates that credit risk policy tools may not be sufficient on their own to guide leverage decisions.

This study is one of the first to examine peer effects in the Turkish banking sector and aims to contribute to the limited international literature on this topic. When the findings are compared, the result that banks are affected by their peers' leverage decisions is consistent with Lee et al. (2017), Warninda and Maryani (2022), confirming the existence of a peer effect in banks' leverage decisions. In this context, it provides important data for strategic decision-making by managers of Turkish deposit banks. It also provides critical information for relevant regulatory decisions and supervisory processes, including oversight and supervision mechanisms. In conclusion, the development of policy frameworks by regulatory authorities that take into account the dynamic structures, including peer effects, in bank behaviour will contribute to the sector becoming more resilient and stable. Future studies investigating whether banks are influenced by their peers in their financial decisions could provide additional insights for both bank managers and policymakers regarding financial strategies.

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The Relationship Between Couples' Educational Pairings and Fertility: Evidence from Türkiye

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Çiftlerin Eğitimsel Eşleşmeleri ve Doğurganlık Arasındaki İlişki: Türkiye Örneğinden Bulgular

Abstract

This study aims to examine the relationship between couples' educational pairings and fertility outcomes by using 2018 Türkiye Demographic and Health Survey (TDHS) data and the GPRM model. Our findings show that couples' educational pairings are closely associated with fertility outcomes. The fertility outcomes differ significantly across the subcategories of educational homogamy, hypergamy, and hypogamy. For homogamous couples, we find that those with medium-medium and high-high educational pairings are less likely to have children than those with low-low educational pairings. Additionally, it is revealed that hypergamous and hypogamous couples with high-medium educational pairings have lower fertility outcomes compared to homogamous couples with low-low educational pairings.

Keywords : Educational Pairings, Family Type, Fertility.

JEL Classification Codes : J12, J13.

Öz

Bu çalışmada 2018 Türkiye Nüfus ve Sağlık Araştırması (TNSA) verileri ve GPRM modeli kullanılarak Türkiye'de çiftlerin eğitimsel eşleşmeleri ile doğurganlık sonuçları arasındaki ilişkinin incelenmesi amaçlanmaktadır. Bulgular, çiftlerin eğitimsel eşleşmelerinin doğurganlık sonuçlarıyla yakından ilişkili olduğunu göstermektedir. Eğitimsel homogami, hipergami ve hipogami alt kategorilerinde doğurganlık sonuçları önemli ölçüde değişkenlik göstermektedir. Homogamik çiftler içinde orta-orta ve yüksek-yüksek eğitimsel eşleşmeye sahip çiftlerin, düşük-düşük eğitimsel eşleşmeye sahip çiftlerden daha az çocuk sahibi olmaya meyilli olduğu bulunmuştur. Buna ilaveten, düşük-düşük eğitimsel eşleşmesine sahip homogamik çiftlere kıyasla yüksek-orta eğitimsel eşleşmesine sahip hipergamik ve hipogamik çiftlerin daha düşük doğurganlık sonuçlarına sahip olduğu ortaya çıkmıştır.

Anahtar Sözcükler : Eğitim Eşleşmesi, Aile Tipi, Doğurganlık.

1. Introduction

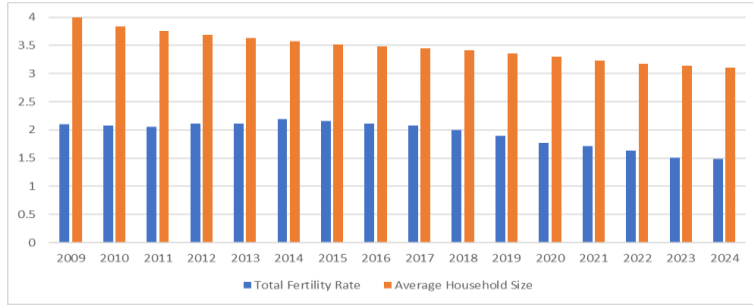
The rapid ageing of the population is a global challenge that has reduced economic performance and led to an expansion of social policies in most countries. However, some developing countries still benefit from a favourable demographic window of opportunity, a consequence of their historically high fertility rates. The demographic window of opportunity is a special case of a country's population pyramid in which a country has an advantageous period during which it can leapfrog in economic development. Developing countries experience an unusual period when the proportion of working-age adults reaches a maximum, thereby facilitating economic and social investment (Bloom et al., 2003). This period is called a demographic window of opportunity for two reasons. First, it provides significant economic advantages, and second, it is available for only a short period. The population pyramid and the concept of a demographic window of opportunity, which imply a relationship between population growth and age distribution driven by changes in economic behaviour and labour force participation that vary with age, highlight the economic importance of fertility and mortality rates.

Türkiye has a relatively young and crowded population at Europe's elbow. The Turkish economy, a typical developing country, has experienced a demographic window of opportunity for a few decades. While Türkiye experienced a slight increase in the fertility rate until the 1950s, it has been steadily declining since the second half of the 20th century. The fertility rate dropped from a record high of 6.8 in 1950 to 4.1 in 1980 (Gökburun, 2020). A look at the situation in Türkiye over the last 40 years reveals that fertility rates have been on a downward trend. Türkiye's fertility rate, which halved between the early 1960s and the mid-1980s, stagnated in the 1990s. However, fertility then entered another period of decline, with a 15% decrease over the five years between 1998 and 2003. Figure 1 shows that total fertility rates started to decrease sharply after 2014. The dramatic decline over the last decade led to the fertility rate reaching 1.48 in 2024, down from 2.2 in 2014, a 0.72-point drop. Very low fertility rates characterise this period in Türkiye. Rindfuss et al. (2016) argue that there are two groups in advanced economies: one with a relatively higher fertility rate (1.9) and the other with a lower rate (1.3). The trend in the fertility rate of the Turkish population suggests that Türkiye will gradually join the lower-fertility group.

In the last decade, family formation has changed greatly in Turkish society. Acar's (2022) measurements show that the age of marriage increased to 25.1 for women and 27 for men in 2020. According to TURKSTAT Marriage and Divorce Statistics, the average ages of marriage for women and men are 25.8 and 28.3, respectively (TURKSTAT, 2025). Also, Acar (2022) states that the total fertility rate fell to 1.77 in 2020, well below the replacement level. This trend led to the closure of the demographic window of opportunity in Türkiye, and the population pyramid began to resemble that of a country with a stable population. With rapid decreases in fertility rates in the last decade, the population pyramid of Türkiye takes the form of a tower that has steep sides from the bottom to the top (Gökburun, 2020). Figure 1 also presents the average household size from 2009 in Türkiye. Household size

decreases from 4 people to 3.1 people on average during this period. In a nutshell, households become one-child families in this period.

Figure: 1
Total Fertility Rates and Average Household Size in Türkiye



Source: TURKSTAT Birth Statistics, 2025.

Moreover, average educational attainment and duration have gradually increased in Türkiye. The proportion of higher education graduates for the population aged 25 and over increased from approximately 10% in 2008 to 25.3% in 2024 (TURKSTAT, 2025). The average duration of education increased from 8.3 to 10.2 years for men, and from 6.4 to 8.8 years for women (TURKSTAT, 2025). It is well known that increasing duration and level of education are among the reasons why people delay marriage and having children. However, in recent years, some studies have focused on the effect of couples' educational pairings on fertility rather than the effect of education on fertility. The literature demonstrates that educational pairings of couples act as intermediaries in the relationship between fertility and education. This role of educational pairings becomes more evident as the level of education increases. Broadly speaking, there are three theoretical approaches to exploring the relationship between decision-making of fertility and educational pairings. The first of these is the New Home Economics Theory of Becker, which began with Becker's work in 1960. It is proposed that sophisticated gender roles in the family increase fertility. If men play the breadwinner role while women specialise in unpaid work and childcare, fertility rises. According to this approach, hypergamous couples in which men have a high level of education have the highest number of children. The second theoretical approach to fertility and education focuses on the family's joint resources. Because educated partners can gain more resources in the labour market, the family's joint resources expand. This approach shows a positive relationship between the partner's educational level and fertility. The third one is about the opportunity cost of having a child. According to Craig & Mullan (2011), childbearing puts mothers at risk of job loss, employment breaks, reduced earnings, and wage penalties. Precarious employment and unemployment delay childbearing (Busetta et al., 2019). In this approach, educational pairings have complex effects on fertility, depending on the labour market conditions of the partner. Micro-level economic uncertainties discourage individuals from starting a family and having children. Economic uncertainty is an individual risk factor, but it is mainly determined by the individual's labour market

conditions and past work experience. Factors such as job-loss risk, short-term contracts, and insecure employment contribute to economic uncertainty for individuals (Mills & Blossfeld, 2012). Economic uncertainty and its primary determinant, unemployment, have income and substitution effects on fertility, and which of these is dominant depends on the individual's likelihood of returning to the labour force and the conditions they will face upon return (Busetta et al., 2019). This study is not only based on New Home Economics theory but also draws on explanatory factors from other theoretical perspectives, such as economic welfare, employment status, and literacy.

This study aims to comprehensively analyse the relationship between couples' educational pairings and fertility outcomes using the 2018 Türkiye Demographic and Health Survey (TDHS) with the Generalised Poisson Regression Model (GPRM). Furthermore, we aim to present policy recommendations grounded in the relationship between couples' educational pairings and fertility to prevent the closure of the demographic opportunity window in Türkiye. The difference between this study and the relevant literature, which includes Bagavos (2017), Nitsche et al. (2021), Da Silva et al. (2022), and Tian et al. (2023), is that it examines whether fertility outcomes are linked to couples' educational pairings within specific subgroups of such pairings. Acar (2022) is the most recent study on the relationship between fertility and education in Türkiye and is the closest to this study. It reports that educational matching among couples influences fertility and that the most significant difference is observed when both the woman and the couple have a university education. However, Acar (2022) examines educational matching using only descriptive methods. This study, unlike Acar (2022), uses microeconomic methods and repeats the analysis across broader demographic subgroups to examine how the effects vary across these subgroups. To achieve this aim, couples were divided into nine educational pairing categories and examined for their association with fertility. This study contributes to the literature by analysing the relationship between couples' educational pairings and fertility outcomes within subcategories of educational pairings. This topic has received limited attention in previous Turkish studies.

The remainder of this study is formed as follows: the next section presents a brief review of the literature. The third section describes the methodology and data used in the study. The fourth section provides the findings. The last section discusses the results and offers policy recommendations.

2. Theoretical Background

There is extensive literature on the relationship between fertility and education, as well as other determinants, stemming from Becker's (1960) seminal work. Becker (1960) provides an economic framework for analysing fertility and family-size decisions. Becker (1960) and Becker (1993) reveal that childbearing is directly related to income. According to them, forgone earnings from motherhood and lower specialisation in paid work are important factors in the effects of income on family-size decisions. In the final step, Becker (1993) and subsequent literature highlight that when parenthood results in temporary or

permanent leave from the workforce, the opportunity costs of income and job loss increase as women's educational levels rise. The theoretical framework of Becker's works links income and family size through education. In sum, it is possible to say that women's education level is an important factor in shaping fertility and has been characterised as a main determinant of economic well-being (Thomas et al., 2017).

Many factors affect childbearing, including cultural, demographic, socioeconomic, ecological, and health and psychological factors (Piotrowski & Tong, 2016; Hashemzadeh et al., 2021). At the same time, fertility depends on restrictions on family size and labour-market compliance (Goldscheider et al., 2015). In the last decades of the twentieth century, the changing social structure of societies strengthened the substitutability of labour-market roles and motherhood for women. It weakened the relationship between marriage and parenthood (Rindfuss et al., 2003). Macro policies and labour market conditions determine the decision to have children (Matysiak & Weziak-Bialowska, 2016). More specifically, labour market conditions such as precarious employment or unemployment, and low wages, are important determinants (Modena & Sabatini, 2012; Goldstein et al., 2013), as are motherhood wage penalties (Budig & Hodges, 2010). Economic insecurity is associated with the possibility of being childless and not realising fertility intentions (Berrington & Pattaro, 2014). The findings on the relation between the individual's unemployment experience and fertility behaviour are inconclusive by gender. While unemployment has causal effects on women's first births, it has no statistical effects on men's (Andersen & Özcan, 2021). The mechanism that creates a negative relationship between labour market tightness and parenthood stems from the effects of education on women's labour market positions. The relevant literature has found that the coefficient for unemployment often changes sign across different education groups (Andersen & Özcan, 2021) and across individuals' well-being (Vignoli et al., 2020). Only when subjective well-being is low do uncertain conditions reduce fertility. At the same time, Kreyenfeld & Andersson (2014) find that fertility tends to be lower during periods of unemployment among highly educated women and men, but not among their less educated counterparts.

An empirical literature on fertility that focuses on the effects of education provides a wide range of evidence. Sobotka (2015) demonstrates the negative effects of higher education on fertility in Austria and the Czech Republic. So, Wood et al. (2014) find that childlessness is more common among highly educated women in 14 low-fertility countries, although the relationship differs strongly across countries and over time. Also, the fertility tempo is negatively associated with women's education in most countries. In Central and Eastern European countries, a negative relationship between fertility and women's education is observed in the second and third births. So, Winkler-Dworak & Toulemon (2007) report, based on a nonlinear analysis, that this relation is U-shaped in France. Consequently, higher levels of education are associated with higher rates of childlessness, lower fertility rates, and smaller family sizes (Martin, 2000; Miettinen et al., 2015).

On the other hand, Nitsche et al. (2021) state that relevant literature on the relationship between fertility and education has focused much less on low-educated parents.

These parents may find fewer opportunities in the labour market, and they mostly take low-skilled positions in manufacturing. Women with low education or migrant backgrounds are more likely to adopt childbearing strategies as an alternative to labour market participation (Wood & Neels, 2017). Also, it is interesting that, as a result of labour market conditions, low-educated people tend to drift towards extremes, such as remaining childless or having many children (Jalovaara et al., 2022). Finally, it must be noted that the effects of education are asymmetric in developed countries. When women's education has a negative effect on fertility, the effects of men's education are positive or negligible (Osiewalska, 2015).

The relevant literature suggests a strong relationship between fertility and women's and men's education, but this relationship is complex in detail. Another important question is whether parents' educational levels are more important or whether the difference in educational levels between couples matters. Education has a negative effect on the likelihood of achieving the desired number of children; however, when analysed in more detail, this relationship between education and fertility is mediated by educational pairings (Berrington & Pattaro, 2014). The educational pairing of couples is a powerful factor in fertility. Theoretically, couples can be classified based on differences in their parents' educational levels. Firstly, families can be divided into symmetrical and asymmetrical types (Young & Wilmott, 2013). Another modern classification consists of three classes: educational homogamy, hypergamy, and hypogamy. If couples have the same education level or the educational levels of couples are different, the families are classified as educational homogamy or heterogamy, respectively. In addition, if the educational level of women is higher than that of men in educational heterogamy, the family are classified as educational hypergamy; otherwise, as educational hypogamy. In this regard, throughout the 20th century, there has been a noticeable increase in the prevalence of both educational homogamy and women who "partner down" in terms of their education (Schwartz & Mare, 2005; Blossfeld, 2009).

Theoretically, expectations are that homogamous couples could have higher fertility rates because they share similar values and goals (Thomson, 1990; Corijn et al., 1996). For example, Huber & Fieder (2011) show that childlessness is lower in educational homogamy than in other educational pairings. However, homogamous couples do not necessarily exhibit higher fertility levels across all educational levels. The interaction between educational pairings and the number of children has different functions at each education level. Becker (1993) theoretically explains this by using the labour market approach. If income loss caused by motherhood is important for the family, the income of women in highly educated homogamous couples is higher than the income of women in less educated homogamous couples, and this leads to a decrease in fertility. Some empirical studies provide support for the labour market approach. Bagavos (2017) provides strong insights into the mediating role of education level in the Greek case. According to the results, the possibility of having a child before 30 is highest for low-educated homogamous couples and lowest for highly educated homogamous couples. Moreover, the duration between the first and second child is longest in highly educated homogamous couples.

On the other hand, the idea is that labour market conditions that women need to cope with improve with higher education. Compliance with the labour market conditions is better for highly educated and career women. Thus, it is possible to say that highly educated couples could have higher fertility (Dribe & Stanfors, 2010). Homogamous couples with low education levels postponed becoming parents in Europe. Consequently, the total number of children remains low in low-educated homogamous families in Europe (Osiewalska, 2015). In addition, Nitsche et al. (2021) find that highly educated homogamous couples delay the first, second, and third child compared to hypogamous and hypergamous couples.

If we need to review the fertility studies in Türkiye, there is limited literature on the relationship between fertility and education. There are some common facts in Turkish literature. The primary data source is the Türkiye Demographic and Health Survey conducted by the Hacettepe University Institute of Population Studies (HUIPS). Second, the studies present trends of fertility in time and across some groups of society. The studies in Turkish literature calculate fertility rates and the number of children at different educational levels. However, none of them extends the analysis to examine the mediating roles of income or cohort in the fertility-education relationship, or investigates the effects of educational pairings on fertility in detail.

Finally, the literature shows that women's educational attainment is negatively associated with fertility in Türkiye, where the total fertility rate has been declining over the long term. In an early study, Selim & Üçdoğruk (2005) found that both the educational levels of women and men in couples are negatively associated with the total number of children. It also claims that the main determinant of a child's education is the educational level of parents. In a detailed study examining parental education and child demand, Eryurt & Akadlı-Ergöçmen (2016) found that the father's education is more important for the first child, whereas the mother's family's educational level is more important for the second and subsequent children. Also, Akça & Ela (2012), in a study presenting descriptive statistics on fertility in Türkiye using the TDHS datasets from 2008 and 2013, show that fertility rates across all groups have declined. Some studies show a strong relationship between employment and fertility in Türkiye. For instance, Abbasoğlu-Özgören et al. (2018) found that when there is a two-way negative association between fertility and employment, the risk of entering employment is reduced by fertility. Gemicioğlu et al. (2019) confirm the robust finding of a negative relationship between fertility and education. Acar (2022) provides statistics on having children and the educational pairing of couples from the 2018 TDHS data. According to the results, as women's educational level increases, the number of children decreases, and among homogamous couples, more educated women have fewer children. It shows that hypergamous couples, in which men are more educated, but those with secondary education or less have the highest fertility rate.

3. Data and Methodology

3.1. Data

This study utilises data from TDHS collected by the Hacettepe University Institute of Population Studies for 2018. TDHS is conducted every 5 years. It includes information on topics such as women’s basic characteristics, marriage, fertility and fertility preferences, family planning, maternal health and care, child health, nutritional status of children and women, miscarriages and stillbirths, early childhood development, and women’s empowerment. It is based on a representative sample of women aged 15-49. 7,346 women were interviewed in 2018. In TDHS, women currently in a union or living with a man were asked to report the total number of children ever born to them and the education level of their partners. Also, in 2018, TDHS included a question about the respondent's ex-husband's education level. Thus, the TDHS dataset allows us to investigate the relationship between couples’ educational pairings and fertility outcomes.

We exclude women and their husbands under 25 from the sample, as they may not have completed their education. In addition, women and men with more than one spouse are also excluded from the sample. Therefore, our sample comprises 3,860 married couples aged 25-49.

Table 1 shows the distributions of married couples aged 25-49 by the educational pairings.

Table: 1
Distributions of Married Couples Aged 25-49 by the Educational Pairings

Educational pairings	(% of total)
Homogamy	61.6%
Heterogamy	38.4%
Hypergamy	26.4%
Hypogamy	12.0%

Source: Authors’ own calculation based on 2018 TDHS.

Couples in which both partners have the same level of education are referred to as educational homogamy. Conversely, couples in which the partners have different levels of education are known as educational heterogamy. Therefore, there are two logically distinct subtypes of educational heterogamy: educational hypergamy and hypogamy. The phenomenon of educational hypergamy occurs when men are more highly educated than women, whereas educational hypogamy occurs when men are less educated than women. As shown in Table 1, 62% of women have the same educational attainment as their husbands, and 38% have either lower or higher educational attainment. Furthermore, compared to their husbands, 26% of women have lower levels of education, while 12% have higher levels. In this regard, educational homogamy is more common than educational heterogamy among married couples aged 25-49 in Türkiye.

Table 2 indicates the distributions of married couples aged 25-49 by subcategories of educational pairings. This study categorises individuals by educational attainment as

follows: those with no education or primary education are classified as having low educational attainment, those with secondary education are classified as having medium educational attainment, and those with tertiary education are classified as having high educational attainment. We divide each homogamous, hypergamous, and hypogamous couple into three subcategories. As illustrated in Table 2, homogamous couples comprise low-low, medium-medium, and high-high educational pairings. Hypergamous and hypogamous couples include medium-low, high-low, and high-medium educational pairings.

Table: 2
Distributions of Married Couples Aged 25-49 by Subcategories of Educational Pairings

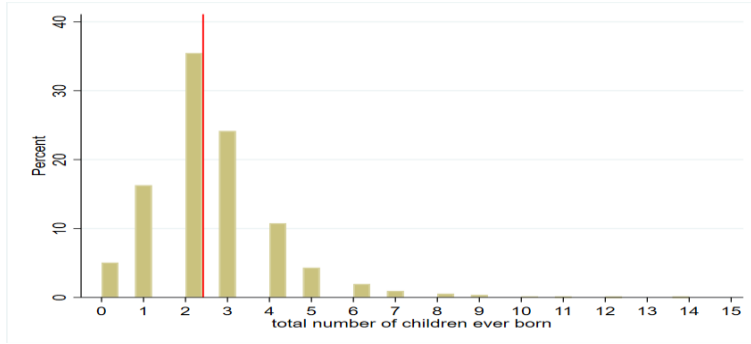
Couples' educational levels	Homogamy		
	Woman	Man	(% of total)
	Low	Low	44.6%
	Medium	Medium	33.1%
	High	High	22.3%
	Heterogamy		
	Hypergamy		
	Man	Woman	(% of total)
	Medium	Low	70.5%
	High	Low	7.6%
	High	Medium	21.9%
	Hypogamy		
	Woman	Man	(% of total)
	Medium	Low	57.5%
	High	Low	5.3%
	High	Medium	37.2%

Source: Authors' own calculation based on 2018 TDHS.

Table 2 shows that homogamous couples with low, medium, and high educational levels are 45%, 33%, and 22%, respectively. The majority of hypergamous and hypogamous couples, around 71% and 58%, are medium-low educational pairings, respectively. For these two types of couples, the shares in high-medium educational pairings are about 22% and 37%, while the shares in high-low educational pairings are only 8% and 5%, respectively. In this regard, high-low educational pairings are rare in both types of couples, whereas medium-low educational pairings are quite common, especially among hypergamous couples. In addition, high- and medium-level educational pairings are more prevalent among hypogamous couples than among hypergamous couples.

Figure 2 indicates the total number of children ever born for married couples aged 25-49 in 2018 in Türkiye. The mean total number of children ever born is 2.42 for married couples aged 25-49, indicated by the red vertical line. Furthermore, among these couples, about 35% have 2 children, and 25% have 3 children.

Figure: 2
Total Number of Children Ever Born for Married Couples Aged 25-49



Source: Authors' own calculation based on 2018 TDHS.

Table 3 presents the mean number of children ever born by educational pairings for married couples aged 25-49.

Table: 3
Mean Number of Children Ever Born by Educational Pairings

Educational Pairings	Mean number of children ever born
Homogamy	2.41
Low-Low	3.24
Medium-Medium	2.00
High-High	1.35
Heterogamy	2.46
Hypergamy	2.44
Medium-Low	2.85
High-Low	2.77
High-Medium	1.97
Hypogamy	2.00
Medium-Low	2.28
High-Low	2.29
High-Medium	1.52

Source: Authors' own calculation based on 2018 TDHS.

As can be seen in Table 3, the mean number of children ever born for homogamous couples is 2.41. However, the mean number of children ever born has substantial heterogeneity across subcategories of educational homogamy. The mean number of children ever born of low-low, medium-medium, and high-high educational pairings is 3.24, 2.00, and 1.35, respectively. Accordingly, the mean number of children ever born decreases markedly (to about 2) as educational level increases for couples with the same level of education. In addition, in all subcategories of educational pairings, high-high and low-low educational pairings for homogamous couples have the lowest and highest fertility outcomes.

The mean number of children ever born for heterogamous couples is 2.46, almost the same as that of homogamous couples. However, the fertility outcomes vary for hypergamous and hypogamous couples. The mean number of children ever born by hypergamous and

hypogamous couples is 2.44 and 2.00, respectively. In this respect, fertility outcomes of hypergamous couples are higher than those of homogamous couples. Conversely, fertility outcomes of hypogamous couples remain below those of homogamous couples.

Furthermore, fertility outcomes exhibit considerable variability between and within hypergamous and hypogamous couples. Within hypergamous couples, fertility outcomes for medium-low and high-low educational pairings are comparable at 2.85 and 2.77, respectively, whereas those for high-medium educational pairings are notably lower at 1.97. A similar trend was observed within hypogamous couples in terms of fertility outcomes. For hypogamous couples, the fertility outcomes of medium-low and high-low educational pairings are nearly identical, with values of 2.28 and 2.29, respectively. However, in these types of couples, high-medium educational pairings have a much lower fertility outcomes with a value of 1.52.

Table 3 also indicates that in all the same subcategories of educational pairings, the mean number of children ever born to hypergamous couples exceeds that of hypogamous couples. More specifically, in comparison to hypogamous couples, hypergamous couples had higher fertility outcomes in medium-low, high-low, and high-medium educational pairings by 0.57, 0.48, and 0.45, respectively. In other words, in all the subcategories of educational pairings, fertility outcomes in couples where men are more educated than women are always higher than in couples where women are more educated than men.

3.2. Methodology

Count data models are used for fertility analysis when the dependent variable takes non-negative integer values, such as the number of children ever born. One of these models is the Poisson regression model (PRM), which assumes equidispersion, meaning the conditional mean and variance are equal or nearly equal (Hilbe, 2014). However, the assumption of equidispersion is rarely met in fertility analysis. If the assumption is not met in fertility analyses, PRM estimations indicate that only the standard errors are affected, and the coefficients remain unaffected (Harris et al., 2012). Put simply, while the model produces reliable coefficients, inferences based on the estimated standard errors are no longer accurate. To overcome this problem, Winkelmann & Zimmermann (1994) developed GPRM. GPRM adjusts to account for overdispersion, in which the variance of the model is greater than the conditional mean, and underdispersion, in which the variance of the model is less than the conditional mean, as well as equidispersion. Therefore, we prefer to use GPRM in fertility analysis, recognising the possibility of encountering equidispersion, overdispersion, or underdispersion.

Harris et al. (2012) parametrise the generalised Poisson probability function based on Consul (1989) and Famoye (1993) as follows:

$$f(y_i, \theta_i, \delta) = \frac{\theta_i [\theta_i + \delta y_i]^{y_i - 1} e^{-\theta_i - \delta y_i}}{y_i!}, y_i = 0, 1, 2, \dots \quad (1)$$

The mean and variance of the generalised Poisson random variable Y_i are given

$$\mu_i = E(y_i) = \frac{\theta_i}{1-\delta}, \quad Var(y_i) = \frac{\theta_i}{(1-\delta)^3} = \frac{1}{(1-\delta)^2} E(y_i) = \varphi E(y_i)$$

The role of a dispersion factor is played by the term $\varphi = \frac{1}{(1-\delta)^2}$. If $\delta = 0$, then there is equidispersion and the generalised Poisson distribution is reduced to the usual Poisson distribution with parameter θ_i . In addition, if $\delta > 0$ the model has an overdispersion, and if $\delta < 0$ the model has an underdispersion.

To reveal the relationship between educational pairings of couples and fertility outcomes, we estimated the following equation with GPRM:

$$\ln(numtotchild_i) = \beta_0 + \beta_1 educational\_pairings_i + X'_i \beta_2 \quad (2)$$

In equation 2, $\ln(numtotchild_i)$ is the dependent variable that defines the natural logarithm of the number of children ever born of a couple i . β_0 is a constant term. *Educational pairings_i* is our main independent variable that indicates the pairings of the educational levels of a couple i . We use a broad definition of the educational pairings variable to clarify the relationship between couples' educational pairings and fertility. We divide each educational homogamy, hypergamy, and hypogamy, which are three basic educational pairings, into three subcategories, so that the educational pairing variable consists of nine subcategories. More precisely, the subcategories of educational homogamy are low-low, medium-medium, and high-high, while the subcategories of educational hypergamy and hypogamy are medium-low, high-low, and high-medium. In addition, β_1 is the coefficient of the educational pairing's variable, X'_i is a vector that includes control variables, and β_2 is the coefficient of the control variables.

Interpretation of GPRM coefficients is generally not favoured because it indicates the change in the natural logarithm of the response for a one-unit change in the predictor. We therefore prefer to interpret the GPRM coefficients in terms of the incidence rate ratio (IRR), which is the ratio of the count rates between two adjacent ascending response levels. To get IRRs for each predictor, we exponentiate GPRM coefficients. In this context, if we exponentiate both sides of equation 2, we get equation 3.

$$e^{\ln(numtotchild_i)} = e^{\beta_0 + \beta_1 educational\_pairings_i + X'_i \beta_2}$$

$$numtotchild_i = e^{\beta_0 + \beta_1 educational\_pairings_i + X'_i \beta_2} \quad (3)$$

For example, the IRR for β_1 is obtained with equation 4.

$$IRR_{\beta_1} = \frac{e^{\beta_0 + \beta_1 (=1) + X'_i \beta_2}}{e^{\beta_0 + \beta_1 (=0) + X'_i \beta_2}} = e^{\beta_1 (=1)} \quad (4)$$

For the reference category, IRR equals 1. $IRR < 1$ indicates that the other category has lower fertility outcomes than the reference category, while $IRR > 1$ shows that the other category has higher fertility outcomes than the reference category.

For the IRR for β_1 , we can also interpret it in percentage terms, as in equation 5.

$$IRR_{\beta_1}(\%) = [IRR_{\beta_1} - 1] \times 100 \quad (5)$$

Table 4 gives the summary statistics of the control variables used in the fertility analysis.

Table: 4
Summary Statistics of Control Variables

Control variables	Type	Mean	Std. Dev.
<i>Women's Characteristics</i>			
Age	Continuous	35.613	6.148
Age square	Continuous	1306.083	443.751
Employment status	Dichotomous		
No (ref)		0.692	
Yes		0.308	
Native language	Categorical		
Turkish (ref)		0.790	
Kurdish		0.160	
Arabic		0.024	
Others		0.026	
<i>Women's Parental Characteristics</i>			
Mother literate	Categorical		
No (ref)		0.451	
Yes		0.545	
Don't know		0.004	
Father literate	Categorical		
No (ref)		0.116	
Yes		0.873	
Don't know		0.011	
<i>Couples' Characteristics</i>			
Age difference	Continuous	3.411	3.571
Wealth index	Categorical		
Poorest (ref)		0.143	
Poorer		0.185	
Middle		0.206	
Richer		0.224	
Richest		0.242	
Type of residential place	Dichotomous		
Urban (ref)		0.786	
Rural		0.214	
Region	Categorical		
West (ref)		0.439	
South		0.121	
Central		0.220	
North		0.052	
East		0.168	
Total sample size		3860	

Source: Authors' own calculations based on 2018 TDHS.

In this study, we categorise the control variables into three groups: characteristics of women and couples and women's parental characteristics. Women's characteristics include age and its square, employment status, and native language variables. A substantial body of research indicates that there is a considerable relationship between a woman's age and fertility, and as a woman's age increases, her fertility tends to decline (ESHRE, 2005; Chua

et al., 2020; Delbaere et al., 2020; Beaujouan & Toulemon, 2021). In addition, women are more likely to have children at younger ages (HUIPS, 2018). Thus, an inverted U-shaped relationship is expected between a woman's age and fertility. The existence of the relationship is evidenced by the coefficients of the age and age-square variables being positive and negative, respectively, and being statistically significant.

The general view on the relationship between women's employment and fertility is that women's employment is associated negatively with fertility outcomes. However, in recent years, the emergence of complementary factors between fertility and women's work careers, such as family policy (e.g., increased accessibility of institutionalised childcare), cooperative fathers, favourable social norms, and flexible labour markets (e.g., growth in part-time work), has weakened the negative relationship between fertility and employment (Doepke et al., 2023). From a feminist perspective, the adverse effect of women's employment on fertility may be primarily attributed to existing gender structures within society and the resultant power dynamics within marital relationships (Bernhardt, 1993).

The native language of women is classified into four categories: Turkish, Kurdish, Arabic, and others. Arabs and Kurds have social norms that favour higher fertility, such as pressurising women to have children, the desire of husbands and family elders for male children, and the legal and religious prohibition of abortion (Karakaya et al., 2017). Thus, we expect that women whose native languages are Kurdish and Arabic will have higher fertility outcomes than those whose native language is Turkish.

Women's parental characteristics include the mother's and father's educational levels. The educational status of parents is one of the determinants of the number of children, and parental education is crucial in reducing fertility (Josipovic, 2007; Chen, 2022). Furthermore, Chen (2022) asserts that maternal education is a stronger determinant of fertility than paternal education. In this regard, we expect women whose fathers, especially mothers, are literate to have lower fertility than women whose fathers and mothers are illiterate.

Characteristics of couples include age difference, wealth index, type of residence place, and region variables. Some studies argue that the age of a male partner also affects fertility (Jimbo et al., 2022). In addition, among married couples, the age difference between men and women is generally small. For example, women are on average 2-3 years younger than their partners in most Western countries (Poppel et al., 2001; Dribe & Nystedt, 2017). When couples are close in age, using both women's and men's ages as independent variables simultaneously in econometric analysis can lead to multicollinearity. We therefore use the age difference variable, which represents the difference in age between men and women. In addition, in patriarchal societies such as Türkiye, as the age gap widens in favour of the male partner, it is expected that fertility will be higher due to the bargaining power of the male partner within the household.

The wealth index is constructed from household durable goods, such as televisions and cars, and from their living conditions. This index, which can also serve as a proxy for household income, comprises 5 categories: poorest, poorer, middle, richer, and richest. As income levels rise, individuals tend to invest more in their children's education rather than increase the number of children; in other words, they make a trade-off between the quantity and quality of children (Becker & Lewis, 1973). In this regard, fertility is expected to be negatively affected by higher welfare levels among couples.

The place of residence is considered rural or urban. Fertility outcomes are high in rural areas and low in urban areas (Akça & Ela, 2012; Fiori et al., 2014). The disparity in fertility outcomes between rural and urban areas can be attributed to environmental, economic, and social factors, as well as the demographic composition of specific population segments (Adhikari et al., 2024). From an economic perspective, 84.1% of households living in rural areas of Türkiye are among the poorest in terms of wealth (HUIPS, 2018). Moreover, in rural areas, where women work as unpaid family workers, there is less conflict between fertility and employment (Akça & Ela, 2012). As rural people work mainly in agriculture, households tend to meet their labour needs through their children. From a social point of view, households in rural areas are more likely to have a patriarchal family structure that attaches more importance to fertility than households in urban areas. In addition, the educational attainment of individuals residing in rural areas is lower than that of those residing in urban areas (HUIPS, 2018). All of these lead to higher fertility among couples in rural areas than among those in urban areas.

We have divided Türkiye into 5 main regions: west, east, north, south, and central. Compared with the rest of Türkiye, the eastern and southern regions exhibit higher fertility rates (Selim & Üçdoğruk, 2005; Akça & Ela, 2012; HUIPS, 2018). This phenomenon can be attributed to the comparatively lower level of socio-economic development observed in these regions.

4. Findings

Table 5 presents GPRM estimates of the relationship between couples' educational pairings and fertility outcomes.

Table: 5
GRPM Estimation Results

Variables	Coefficients	IRRs
Educational pairings (ref: homogamy: low-low)		
medium-medium	-0.125*** (0.025)	0.883*** (0.022)
high-high	-0.435*** (0.035)	0.647*** (0.023)
hypergamy		
medium-low	-0.043 (0.023)	0.958 (0.022)
high-low	-0.052 (0.043)	0.950 (0.041)
high-medium	-0.202*** (0.036)	0.817*** (0.030)

hypogamy		
medium-low	-0.148***	0.862***
	(0.031)	(0.027)
high-low	-0.045	0.956
	(0.142)	(0.136)
high-medium	-0.300***	0.741***
	(0.051)	(0.038)
<i>Women's Characteristics</i>		
Age	0.132***	1.141***
	(0.015)	(0.017)
Age square	-0.001***	0.999***
	(0.000)	(0.000)
Employed (ref: no)		
yes	-0.083***	0.920***
	(0.019)	(0.017)
Native Language (ref: Turkish)		
Kurdish	0.253***	1.288***
	(0.025)	(0.032)
Arabic	0.424***	1.529***
	(0.055)	(0.084)
Others	0.115**	1.121**
	(0.051)	(0.057)
<i>Women's Parental Characteristics</i>		
Mother literate (ref: no)		
yes	-0.046***	0.955***
	(0.018)	(0.017)
don't know	-0.003	0.997
	(0.106)	(0.106)
Father literate (ref: no)		
yes	-0.023	0.978
	(0.025)	(0.024)
don't know	-0.055	0.946
	(0.072)	(0.068)
<i>Couples Characteristics</i>		
Age difference	0.022***	1.022***
	(0.002)	(0.002)
Wealth index (ref: poorest)		
poorer	-0.077***	0.926***
	(0.028)	(0.025)
middle	-0.154***	0.857***
	(0.031)	(0.026)
richer	-0.188***	0.829***
	(0.033)	(0.027)
richest	-0.265***	0.767***
	(0.037)	(0.029)
Residence place (ref: urban)		
rural	0.001	1.001
	(0.023)	(0.023)
Region (ref: west)		
south	0.088***	1.092***
	(0.028)	(0.031)
central	0.132***	1.141***
	(0.022)	(0.025)
north	0.052**	1.053**
	(0.026)	(0.028)
east	0.260***	1.297***
	(0.028)	(0.036)
Constant	-1.967***	0.140
	(0.276)	0.039
δ	-0.386***	
	(0.017)	
LR test ($\delta = 0$)	816.78***	
	(0.000)	
Log pseudolikelihood	-5707.196	
Pseudo R^2	0.161	
N	3860	

Notes: ** $p < 0.05$, *** $p < 0.01$. Standard errors in the second row. For the LR test only, the second row gives the p-value.

As shown in Table 5, the LR test statistic is 816.78, and the null hypothesis ($\delta = 0$) is rejected at the 1% significance level. Accordingly, the dispersion parameter is found to be significantly different from zero. In addition, the dispersion parameter is -0.386, indicating that the model is underdispersed. Thus, the preference for GPRM over PRM is supported by the findings.

The findings show that couples' educational pairings are closely associated with fertility outcomes. The fertility outcomes differ significantly across some subcategories of educational homogamy, hypergamy, and hypogamy. For homogamous couples, we find that couples with medium-medium and high-high educational pairings are less likely to have children than those with low-low educational pairings. More specifically, the fertility outcomes of medium and highly educated homogamous couples are lower at 11.7% and 35.3% compared to those of low-educated homogamous couples. These findings are consistent with Bagavos (2017), who found that higher education levels are associated with lower fertility in homogamous couples. Conversely, the findings contradict several studies (Dribe & Stanford, 2010; Osiewalska, 2015).

When fertility outcomes are considered for heterogamous couples, findings show that hypergamous and hypogamous couples with high-medium educational pairings and hypogamous couples with medium-low educational pairings have lower fertility outcomes in comparison to homogamous couples with low-low educational pairings. Compared to homogamous couples with low-low educational pairings, fertility outcomes are lower: 18.3% and 25.9% for hypergamous and hypogamous couples, respectively, and 13.8% for hypogamous couples with medium-low educational pairings. These findings support the notion that hypogamous couples have lower fertility than homogamous couples, in line with empirical studies in the relevant literature (Thomson, 1990; Corijn et al., 1996; Bueno & Garcia-Roman, 2021; Nitche et al., 2021).

The relationship between control variables and fertility is theoretically as expected. The coefficient signs for women's age and its square are significantly positive and negative, respectively, indicating an inverted U-shaped relationship between fertility and women's age. Fertility outcomes of employed women are found to be 8% lower than those of non-employed women. Women's native language is also associated with fertility. The fertility outcomes of women whose native language is Arabic, Kurdish, or other languages are 1.53, 1.29, and 1.21 times those of women whose native language is Turkish, respectively.

Maternal literacy, rather than paternal literacy, is associated with fertility, and women whose mothers are literate have approximately 5% lower fertility outcomes. For each year the age difference between men and women increases in favour of men, fertility outcomes increase by 2.2%. Couples' wealth level plays a key role in fertility outcomes, and as wealth rises, fertility outcomes decline. Fertility outcomes are 23.3% lower among the richest couples than among the poorest. We also find that the geographical region is associated with fertility outcomes, whereas the couples' residence place is not. Fertility outcomes in the east,

centre, south, and north of Türkiye are approximately 1.30, 1.14, 1.09, and 1.05 times more than in the west of Türkiye, respectively.

5. Discussion and Conclusions

In this study, we focus on the relationship between couples' educational pairings and fertility outcomes in Türkiye. The rationale for this focus is that homogamous couples, where both partners have the same level of education, and heterogamous couples, where the partners have different levels of education, exhibit mostly heterogeneity in fertility trends. We offer a comprehensive fertility analysis with nine subcategories, dividing each of the three main educational pairings, homogamy, hypergamy, and hypogamy, into three subcategories. This study contributes to the existing Turkish literature by being among the pioneering studies on the relationship between couples' educational pairings and fertility outcomes. Our findings show that couples' educational pairings play a significant role in fertility outcomes. More specifically, fertility outcomes for couples with the same and different levels of education vary dramatically in subcategories. The top three subcategories with the highest fertility outcomes are the low-low subcategory among homogamous couples and the medium-low subcategory among hypergamous and hypogamous couples, respectively. In addition, the first three subcategories with the lowest fertility outcomes are the high-high subcategory among homogamous couples and the high-medium subcategory among hypogamous and hypergamous couples, respectively. The high-high subcategory of homogamy has the lowest fertility compared to the low-low subcategory, which serves as the reference group. Furthermore, our results indicate that our model satisfies the underdispersion assumption. This suggests that the GPRM, which considers all three assumptions of equidispersion, overdispersion, and underdispersion, is more appropriate than the standard Poisson and Negative Binomial Regression models, which are used under the assumptions of equidispersion and overdispersion, respectively.

Türkiye is a country in which gender roles are dominant. In Türkiye, men spend more time in the labour market as they assume the role of the breadwinner, while women spend more time on household chores, such as housework and caring for children and the elderly. While this situation limits women's participation in education and the labour force, it leads to a decrease in the age at which women marry and have their first child, thus raising their fertility. From this point of view, it is expected that low-educated couples with the same level of education are relatively more likely to have children. Higher educational attainment among women increases the probability of labour force participation and employment. In Türkiye, the employment of highly educated women leads them to devote a significant portion of their time to the labour market, resulting in relatively low fertility. The fact that highly educated working women have highly educated husbands may lead to greater consensus between couples and further reduce the number of children. At the same time, because highly educated working women will have bargaining power over their partners with lower levels of education, the number of children may also be relatively low. In a situation where the male partner is more educated, the opposite effect is observed.

To combat rapidly declining fertility rates worldwide, almost all countries are implementing fertility-promotion policies. Pronatalist policies include legal arrangements to protect the position of women who give birth in the labour market, cash and in-kind benefits to reduce the financial burden of having a child, and labour market support. One of the oldest of these is paid parental leave. Among these leaves, referred to as family-related leave in the literature, maternity leave is the leave taken by working women after the birth of their child, while paternity leave is the leave taken by working men immediately after the birth of their child. Parental leave is leave taken by working parents in addition to maternity and paternity leave to fulfil care responsibilities in the first years of their children's lives (Hofman et al., 2020). In Türkiye, numerous regulations have been in place for many years to ensure that women maintain their position in the labour market during childbearing. In general, 16 weeks of maternity leave are granted to working women. After this period, hourly breastfeeding leave (and allowance) is provided for one year for women returning to work, and up to two years of unpaid leave is provided for women working in the public sector who wish to take it. In the private sector, this period is six months. To increase fertility and improve the disadvantaged position of private-sector employees, this period should be equalised. There are legal provisions that prevent mothers from losing their current jobs after exercising these rights.

In addition to these, numerous incentive mechanisms are implemented to encourage parents' fertility. Among the benefits presented in Dağlıoğlu & Bektaş (2022), Multiple Birth Assistance, Family Assistance Allowance for civil servants, and child benefits provided by employers under collective labour agreements are included. Accordingly, the Ministry of Family and Social Services provides a lump-sum cash support (increasing with the number of children) in the form of a maternity allowance to insured women in Türkiye upon having a child. Although the scope of this support is broad enough to cover all citizens, the amount of support is currently only 1.7% of the minimum wage for the first child. The Turkish government announced a new program to subsidise marriage and fertility at the beginning of 2025. With this new program, total support will reach 29.4% of the minimum wage with three (four) children beginning this year. On the other hand, working women can also receive maternity benefits from their organisations. In the private sector, the amount and scope of support vary, but, for example, for civil servants, the maternity allowance is 5% of the minimum wage. In addition, there are other supports, such as maternity expense reimbursement and a breastfeeding allowance. To summarise, the low level of cash benefits related to childbirth is far from encouraging fertility. Moreover, it can be argued that social policies such as maternity and breastfeeding leave and nursery allowances may be more important for educated women in the labour market, which may be related to the fertility outcomes of couples in educational matches with high levels of education.

More specifically, policymakers aiming to increase fertility should develop policies targeting couples with the lowest fertility outcomes in educational pairings. Couples with the fewest children are those in the high-high subcategory, where both partners have the same educational level, and in the high-medium subcategory, where the female partner is much more educated than the male partner. The main traits of these couples are high levels

of education, with the female partner's education higher than the male's. From the perspective of increasing the likelihood that highly educated couples enter the labour market, it is crucial to recognise flexible working opportunities, provide childcare support for dual-earner families, and extend maternity and breastfeeding leave periods to boost the fertility rates of couples with low fertility. Moreover, given that low education levels are often associated with low income, to improve fertility outcomes for couples with relatively high fertility levels in other educational pairings, cash child benefits should be increased significantly to offset the rising costs of raising children in recent years. These payments should also rise substantially in proportion to the number of children.

The dataset used in the study covers only one year of fertility outcomes. In fact, some women have not yet completed their fertility process. For instance, a woman who gave birth to her first child at the age of 30 in 2018 could still have more children in subsequent years. Consequently, our data provides a snapshot of the relationship between couples' educational pairings and fertility outcomes. If a dataset were available that tracked the same women from the start to the end of their fertility process, it would be possible to make more comprehensive inferences about the relationship between couples' educational pairing and fertility outcomes. This is the study's most significant limitation.

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The Relative Development Levels of Independent Turkic States: Strengths and Weaknesses of the Countries

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Bağımsız Türk Devletlerinin Göreli Gelişme Düzeyleri: Ülkelerin Güçlü ve Zayıf Yönleri

Abstract

In this article, the development levels of Türkiye, Azerbaijan, Turkmenistan, Kazakhstan, Uzbekistan, and Kyrgyzstan among world countries have been determined. In the study, which used 47 development indicators from 156 countries, principal components analysis and cluster analysis were utilised. Kyrgyzstan, Türkiye, and Uzbekistan, which exhibit development similar to that of most countries in Asia and the Arabian Peninsula, have been placed in a cluster of 31 countries. Kazakhstan, unlike the other Turkic states, is part of a cluster of 45 countries, while Azerbaijan and Turkmenistan are part of a cluster of 47 countries.

Keywords : Independent Turkic States, Economic Development, Principal Components Analysis, Cluster Analysis, Global Economy.

JEL Classification Codes : O57, O1, C38.

Öz

Bu makalede Türkiye, Azerbaycan, Türkmenistan, Kazakistan, Özbekistan ve Kırgızistan'ın dünya ülkeleri arasındaki kalkınma düzeylerinin belirlenmesi amaçlanmıştır. 156 ülkeye ait 47 kalkınma göstergesinin kullanıldığı çalışmada, temel bileşenler analizi ve kümeleme analizlerinden yararlanılmıştır. Kırgızistan, Türkiye ve Özbekistan, Asya kıtasında ve Arap Yarımadası'nda bulunan ülkelerle benzer bir gelişme sergileyerek 31 ülkeden oluşan bir kümede yer almıştır. Kazakistan, diğer Türk devletlerinden ayrı olarak 45 ülkenin oluşturduğu bir kümede yer alırken, Azerbaycan ve Türkmenistan ise 47 ülkenin oluşturduğu bir kümede yer almıştır.

Anahtar Sözcükler : Bağımsız Türk Devletleri, Ekonomik Kalkınma, Temel Bileşenler Analizi, Kümeleme Analizi, Küresel Ekonomi.

1. Introduction

The Independent Turkic States consist of Türkiye, the Turkish Republic of Northern Cyprus, Azerbaijan, Turkmenistan, Kazakhstan, Uzbekistan, and Kyrgyzstan. The Independent Turkic States possess significant potential in their rich underground and above-ground resources, fertile agricultural lands, populations, and educated workforce. This potential will also positively impact the positions and development levels of Turkic states in the global economy, given the cooperation agreements signed in recent years.

The Turkic States, primarily by setting special development goals aligned with the United Nations Sustainable Development Goals, have established various development plans and strategies to achieve them. For example, Kazakhstan has set several goals to be achieved by 2030 and has prepared a document called the "Kazakhstan 2030 Development Strategy." Kazakhstan also has a "2050 Strategy" that covers a longer term. Similarly, Kyrgyzstan adopted the "Kyrgyzstan 2018-2040 National Strategy" in 2018.

The strategies adopted by the Independent Turkic States and the progress they have made within the United Nations Sustainable Development Goals have been addressed and analysed in various studies. In the studies, analyses have generally focused on a small number of macroeconomic variables, such as per capita income, foreign trade indicators, savings, and investments. The relative development levels of the Independent Turkic States in the world economy have not been revealed through analyses involving large numbers of countries and multiple variables. Therefore, this article examines the relative development levels of the Turkic states in the global economy using a large number of socioeconomic variables.

The article has two main objectives. The first of these is to determine the development rankings of the Independent Turkic States, outside the Turkish Republic of Northern Cyprus, among 156 countries for each of the principal components representing the 47 variables. These rankings will determine the strengths and weaknesses of the Turkic states in terms of the principal components and the variables they represent. The Turkish Republic of Northern Cyprus could not be included in the empirical analyses because data were unavailable for many variables. The second aim of the article is to identify, when all the principal components are considered, which countries the Independent Turkic States are at the same level of development with, in other words, to reveal the clusters of countries that share a similar level of development.

In connection with these purposes, this article will address two research questions. These can be expressed as follows:

- i) What are the strengths and weaknesses of Turkic states within the framework of the groups of variables considered?
- ii) Which countries in the world do the independent Turkic states exhibit a similar level of development to?

Using World Bank 2022 data, principal component analysis and cluster analysis were applied. The article makes two significant contributions to the literature. The first of these is determining the performance of Turkic states among 156 countries for each principal component. Such a finding, in terms of principal components, will enable the identification of the areas in which each Turkic state is successful or unsuccessful across groups of variables. In other words, the strengths and weaknesses of Turkic states will be determined. Thus, countries will be able to identify and develop policies in areas where they are relatively weak compared to other countries worldwide. The second contribution of the article is to identify the groups of countries (clusters) that exhibit a level of development similar to that of the Turkic states. This result will also show which development group each Turkic state belongs to.

The article consists of the following sections: The first section contains the introduction. The second section concerns the measurement of economic development. The third section addresses the economic and demographic indicators of the Independent Turkic States. In the fourth section, a literature review examines studies that examine the economic development and potential of the Independent Turkic States. The fifth section explains the variables used in the empirical analysis and the countries included. The statistical methods used in the empirical analysis are explained in the sixth section. In the seventh section, analysis and empirical findings are discussed, while the eighth section consists of the "conclusion".

2. Measuring Economic Development

The emergence of development differences between countries and regions has made it necessary to quantify development. The phenomenon of development has been measured in the literature, sometimes with socioeconomic variables grouped under different categories and sometimes with indices created using these indicators. The introduction to the studies conducted on this subject and the development indicators used will also explain the rationale for selecting the variables used in the empirical analysis.

2.1. Measuring Development with Socioeconomic Variables

The level of economic development has been measured in some studies using various socioeconomic variables. Here, the studies that have received the most citations on this topic will be discussed. One of the first studies on measuring the level of Economic Development was conducted by Adelman & Morris (1967: 133). Adelman and Morris argued that development could be measured with 37 variables grouped into three categories: economic, political, and sociocultural.

Another economist who attempts to measure economic development with quantitative data is Ahluwalia. The author measured the relationship between income distribution and economic development using ten variables grouped into five categories. These variables are: per capita gross national product, growth rate, literacy rate, primary

school enrollment rate, secondary school enrollment rate, the share of the agricultural sector in GDP, the urban population ratio, total population, population growth rate, and the share of public revenues in GDP (Ahluwalia, 1976: 314).

Hicks and Streeten conducted another study on the relative development of world countries. The authors have categorised the development indicators into two groups: economic and social. Economic indicators are the number of newspapers read, the number of cars, the number of radio receivers, and energy consumption per capita. Social indicators, on the other hand, include life expectancy, per capita calorie consumption, fertility rate, primary school enrollment ratio, literacy rate, number of persons per room, and the proportion of settlements without access to drinking water (Hicks & Streeten, 1979: 570).

The World Bank, in its World Development Report, considers gross national income per capita a development indicator and groups countries by this indicator into low-income, lower-middle-income, upper-middle-income, and high-income countries.

Another study on this subject was conducted by Saraçoğlu in 1992. In analyses involving 30 variables and 111 countries, it was examined whether countries developed in parallel with the World Bank's income classification (Saraçoğlu, 1992: 20).

Felipe and Resende, in their article involving 35 countries, examined the economic development levels of the countries in 1970 and 1990 using 39 variables and multivariate statistical analysis methods (Felipe & Resende, 1996: 194).

2.2. Measuring Economic Development with Indices

Economic development has also been measured using indices rather than single indicators. Countries' positions on specific issues are measured using indices developed for those issues. Only the most commonly used indices will be explained here. The first of these indices is the "Standard of Living Index," conducted by the United Nations Research Institute for Social Development in 1960. In the index, basic needs are divided into two groups: "physical needs" and "cultural needs".

To highlight differences in development across countries, the United Nations Development Programme publishes the Human Development Index. Another specific index is the mother's index, which is prepared annually by the international organisation called "Save the Children" to show the welfare status of mothers in countries around the world. The World Competitiveness Index, prepared by the World Economic Forum, measures countries' competitiveness. The United Nations Committee prepares the Economic Vulnerability Index for Development Policy and measures countries' resilience to external shocks. Another index related to world economies is the globalisation index prepared by the Swedish Institute of International Affairs.

3. Demographic and Economic Indicators of Independent Turkic States

The demographic and economic characteristics of the Independent Turkic States will be examined by considering several key indicators. Table 1 has been prepared to examine the demographic characteristics. The populations of Turkic states, their population growth rates, age dependency ratios, and life expectancy have been analysed comparatively with the world and European Union (EU) averages.

Table: 1
Demographic Indicators in Independent Turkic States, The World, and The EU (2022)^a

Countries	Population	Population Growth (%)	Age Dependency Ratio (%)	Life Expectancy (Year)
Azerbaijan	10 141 756	0,04	44,06	72,7
Kazakhstan	19 634 983	2,28	60,53	73,1
Kyrgyzstan	6 974 900	2,93	63,90	71,4
Turkish Republic of Northern Cyprus	390 745	0,93	12,80	81,0
Turkmenistan	6 430 770	1,39	56,90	68,7
Türkiye	84 979 913	0,98	46,77	77,5
Uzbekistan	35 648 100	2,07	54,67	71,1
World	8 024 997 028	0,79	55,18	72,7
EU	446 800 000	0,04	33,10	80,6

Notes: ^a The data for the Turkish Republic of Northern Cyprus belongs to 2021.

Reference: The data of the Turkish Republic of Northern Cyprus; <<https://istatistik.gov.ct.tr/TEMEL-ISTATISTIKLER/NÜFUS-VE-DEMOGRAFI-ISTATISTIKLERI>>, 05.03.2025.

The data for other countries and the world; <<https://databank.worldbank.org/reports.aspx?source=health-nutrition-and-population-statistics:-population-estimates-and-projections>>, 05.03.2025.

The data for the EU: <https://ec.europa.eu/eurostat/databrowser/view/tps00198/default/table?lang=en&category=t_demo_t_demo_ind>, 05.03.2025.

In 2022, the total population of the Independent Turkic States was 164,201,167. This figure corresponds to 2% of the world population in the same year and 36,7% of the population of the 27-member EU. Among the Independent Turkic States, the country with the largest population is Türkiye (84.979.913), followed by Uzbekistan (35.648.100). In third place is Kazakhstan (19.634.983), followed by Azerbaijan (10.141.756). The country with the smallest population is the Turkish Republic of Northern Cyprus. Kyrgyzstan (6.974.900) and Turkmenistan (6.430.770) have similar populations.

The population growth rates of Turkic states outside Azerbaijan are above the world and EU averages (See Table 1). In Türkiye and the Turkish Republic of Northern Cyprus, the population growth rate is below 1%, although it remains above the world and EU averages. Kyrgyzstan (2,98%), Kazakhstan (2,28%), and Uzbekistan (2,07%) are countries with high population growth rates.

The third indicator in Table 1 is the age dependency ratio. This ratio is obtained by dividing the dependent population (the sum of the populations aged 0-14 and 65 and over) by the working-age population (15-64). A high dependency ratio is one of the most fundamental indicators of developing countries. In Kazakhstan (60,53), Kyrgyzstan (63,90), and Turkmenistan (56,90), the age dependency ratios are above the world average (55,18) and the EU average (33,10). The most fortunate country in this regard is the Turkish Republic of Northern Cyprus, with a rate of 12,80%. Azerbaijan (44,06) and Türkiye (46,77) perform better than the world average of 55,18% in terms of the age dependency ratio.

The country with the highest average life expectancy is the Turkish Republic of Northern Cyprus, with 81 years. In the Turkic states, except for Turkmenistan, where the life expectancy is 68,7 years, it is close to the world average of 72,7 years.

Table: 2
Macroeconomic Indicators in Independent Turkic States, The World, The EU (2023)

Countries	Economic Growth %	Per Capita Income (Constant 2015 US Dollar)	Inflation Rate (Change in Consumer Price Index, %)	Unemployment Rate %
Azerbaijan	1,1	5.595	8,78	5,6
Kazakhstan	5,1	11.283	14,72	4,8
Kyrgyzstan	6,1	1.212	10,75	4,0
Turkish Republic of Northern Cyprus	7,4	11.129	83,63	6,3
Turkmenistan	6,3	8.490	-0,36	4,1
Türkiye	4,5	14.055	53,85	9,4
Uzbekistan	5,9	3.473	12,86	4,5
World	2,7	11.364	5,13	4,9
EU	3,4	34.169	6,29	6,0

Source: Data for the countries except the Turkish Republic of Northern Cyprus: <<https://databank.worldbank.org/reports.aspx?source=health-nutrition-and-population-statistics:population-estimates-and-projections>>, 05.03.2025.

Data for the Turkish Republic of Northern Cyprus: Kıbrıs Türk Ticaret Odası (2023), *Rakamlarla Kuzey Kıbrıs Türk Cumhuriyeti ve Yatırım Ortamı*.

Table 2 presents macroeconomic indicators, including economic growth, per capita income, the inflation rate, and the unemployment rate. In 2023, the highest economic growth was recorded in the Turkish Republic of Northern Cyprus at 7,4%. This was followed by Turkmenistan (6,3%) and Kyrgyzstan (6,1%). Except for Azerbaijan, which grew by only 1,1% in 2023, the other Turkic states had growth rates above the world average of 2,7% and the EU average of 3,4%.

The Turkic Republic with the highest per capita income is Türkiye, with 14,055 dollars. Following Türkiye are Kazakhstan with 11,283 dollars and the Turkish Republic of Northern Cyprus with 11,129 dollars. Türkiye's data is above the world average of 11,364 dollars. However, the income levels in Kyrgyzstan (\$1,212), Uzbekistan (\$3,473), and Azerbaijan (\$5,595) are well below the world average.

In 2023, the inflation rate in the Turkish Republic of Northern Cyprus was 83,63%, while in Türkiye it was 53,85%. The most successful country in terms of inflation is Turkmenistan, with a rate of -0,36%. Azerbaijan follows this with 8,78%. In other Turkic states, inflation is double-digit, exceeding the world average (5,13%) and the EU average (6,29%).

Just as with inflation rates, the countries with the worst unemployment rates are Türkiye with 9,4% and the Turkish Republic of Northern Cyprus with 6,3%. In other Turkic states, unemployment rates range from 4% (Kyrgyzstan) to 5,6% (Azerbaijan) and are at the world average.

4. Literature

The literature addressing the socioeconomic development of the Independent Turkic States can be divided into three groups. In the first group, the existing potential of the Turkic

states, including their populations and underground and aboveground resources, has been addressed. In the second group of studies, developments recorded by the Turkic states in the period following independence were examined. In the last group, the degree of integration among Turkic states has been evaluated based on foreign trade, factor flows, and tourism activities.

4.1. Studies Analysing the Current Potentials of Turkic States

One of these studies was conducted by Gürbüz and Karabulut (2009: 32) for 15 countries that gained independence after the dissolution of the USSR. These countries were clustered based on their similarities using 36 socioeconomic variables. The authors emphasised that geographical, historical and economic factors are influential in the similarities between countries.

Mercan and Acer (2013: 178) examined the relationship between economic growth and income distribution in Türkiye, the Caucasus, and Central Asian Turkic. The study shows that growth improves income distribution in Türkiye and Azerbaijan, whereas it worsens it in other Turkic republics. The reasons for the income distribution disorder in these countries have been identified as economic and social adaptation problems.

Akengin (2017: 9) has argued that cultural proximity, a highly educated large population, and rich underground resources are significant potentials for the Turkic republics.

The rich energy resources and minerals of the Turkic republics, geopolitical advantages, and new trade routes are redefining the place and position of the Turkic world in the global economy. The Turkic republics, which are increasingly significant within the Silk Road economies, could become an important force in the global economy due to their energy resources and their location along the Asia-Europe-Africa trade routes (Tezer, 2018: 26).

In a study covering seven Independent Turkic States and 15 autonomous Turkic republics, it was found that the Turkic world's population is gradually increasing. The Turkic world possesses significant economic and human resources (Gökburun, 2021: 26).

In a study examining the economic and political potential of the Turkic States Organization, it was observed that the total GDP of all member countries ranks 13th in the world, and that trade volumes increased by 1,8 times during the 2010-2020 period (Aydilek, 2022: 10). Additionally, it has been noted in another study that the total foreign trade volume of the Turkic States Organization in 2022 was 560 billion dollars (Baghirov, 2022: 53). Data for the year 2024 shows that the total GDP of the member and observer countries of the organization is 900 billion dollars, their total trade volume is 508.8 billion dollars, and their population is 174.5 million people (Turkic State Organisation, 2024: 5). In many studies, it is recommended that the Organization of Turkic States should institutionalize to enhance its political potential (Çınar & Uzun, 2023: 156).

The economic potential of Turkic states is also determined by the quantities of underground resources they possess (Turan, 2022: 393). Almost the entire population over the age of 15 in these countries is literate, and the existence of universities established through mutual agreements in Turkic states is also considered a significant potential (Turan, 2022: 394). However, a World Bank report shows that despite high educational participation rates in Turkic states, there are significant deficiencies in the quality of education (World Bank, 2024: 40).

4.2. Studies Analysing the Developments of Turkic States After Independence

The developments recorded by the Turkic republics after independence have been examined through studies conducted in the 20th, 25th, and 30th years of their independence. In the first study, which examines the integration process of the Turkic republics from an economic perspective, it emphasises that economic integration is necessary for economic development, political stability, and security (Erol & Şahin, 2013: 9).

Kara and Solak (2017: 356) stated in their study that Turkic republics have introduced significant reforms to integrate into the global economy, liberalise foreign trade, and attract foreign capital. The demographic and economic changes that emerged in the Turkic Republics during the 25 years following independence have also been addressed. During this process, the young population in the Turkic Republics has decreased (Bayrak et al., 2018: 11).

In his study, Yılmaz (2021: 11) analysed the economic, political, and social changes experienced by the Turkic republics on the 30th anniversary of their independence. The analysis was conducted on a country-by-country basis, and the relations of each with Türkiye were also evaluated. By mentioning regional integration efforts, it has been emphasised that the mentioned countries can complement each other economically and can increase their production capacities.

4.3. Studies Addressing the Integration Level of Turkic States

The studies in this group examine the integration of the Turkic Republics into the world economy through international economic activities, including foreign trade, foreign capital flows, and tourism. A study examining the relationship between economic growth, foreign trade, and poverty in the Turkic Republics of Central Asia found that foreign trade reduces poverty (Ceylan & Şahbaz, 2024: 14). However, studies indicate that the Turkic Republics are unable to attract the desired level of foreign investment. In 2021, foreign direct investment increased by 64%, reaching 1.58 trillion dollars. While direct investments in developed economies increased by 134% (UNCTAD, 2022: 14).

The Turkic Republics accounted for 1,6% of the world's GDP, 2,4% of the world's trade volume, and 2,2% of the world's population in 2022 (Gasimli, 2023: 13). In more detailed analyses of these countries, export and import intensity indices have been calculated. From 2010 to 2019, Türkiye's trade intensity index with these countries was

greater than 1. The export and import intensity indices have also exceeded 1. Considering these values, it is understood that Türkiye has benefited from these trade relations, except for Uzbekistan (Demir, 2020: 291).

In some studies, it has been emphasized that the integration between Türkiye and these republics is insufficient (Doru & Aslan, 2019: 14). In the period 1994-2008, the exports of the Turkic Republics had significantly increased, but Türkiye's foreign trade with the Turkic Republics had not increased to the desired level (Gülse et al., 2009: 20). The same result was emphasized in the analyses conducted by Ersungur et al. (2007: 290). Another study conducted in 2012 indicated that the foreign trade between Türkiye and the Turkic Republics did not exceed the 2% level (Eren, 2012: 70). In some studies, factors that facilitate and hinder integration have been emphasized (Geybullayev, 2002: 14). To enhance economic cooperation, it is suggested to create a joint regional policy on a sectoral basis and implement a new incentive and insurance system (Alagöz et al., 2004: 71). Ece (2023: 50) states in her work that after the Turkic Republics gained their independence, there was a desire to revive the historical Silk Road. For this purpose, China has made significant investments in this area with its Belt and Road Initiative. The route will start from China and extend to the Netherlands. It is emphasised that this project will provide economic, commercial, and cultural benefits to China, Türkiye and the Turkic republics. Seyidoğlu and Gönültaş (2014: 201) emphasise that, with the modern Silk Road project, economic, social, and cultural relations between Türkiye and the Central Asian Turkic States will accelerate, economic prosperity will increase, and fast, easy transportation will be provided.

5. Variables and Countries Included in Empirical Analysis

Empirical analyses were conducted using 47 variables and including 156 countries. These variables have been grouped into six categories: general economic indicators, demographic indicators, foreign trade indicators, labour force indicators, communication indicators, and political indicators (See Table 3). All the data were obtained from the World Bank and refer to the year 2022. The countries included in the analysis are not listed here again because they are provided in the section discussing the results of the cluster analysis.

Table: 3
Variables Used in Empirical Analysis

VARIABLES	CODE
GENERAL ECONOMIC INDICATORS	
1. Manufacturing value added (annual % growth)	MANF
2. Gross capital formation (annual % growth)	TOTL
3. GDP growth (annual %)	MKTP
4. GDP per capita growth (annual %)	PCAP
5. Final consumption expenditure (annual % growth)	CONTOTL
6. Services, value added (annual % growth)	SRVTOTL
7. GDP per capita (constant 2015 US\$)	GDPPCAP
8. Gross fixed capital formation (annual % growth)	GDIFTOT
9. Gross savings (% of GDP)	GNSICTR
10. General government final consumption expenditure (% of GDP)	GOVTZS
11. General government final consumption expenditure (annual % growth)	GOVTKD
12. Agriculture, forestry, and fishing, value added (% of GDP)	AGRTOTL
13. Agriculture, forestry, and fishing, value added per worker (constant 2015 US\$)	AGREMPL

14. Final consumption expenditure (% of GDP)	CONTOTL
15. Industry (including construction), value added (annual % growth)	INDTOTL
16. Manufacturing, value added (% of GDP)	INDMNFZS
17. Medium and high-tech manufacturing value added (% manufacturing value added)	MNFTCHZS
DEMOGRAPHIC INDICATORS	
18. Life expectancy at birth, female (years)	LEFE
19. Life expectancy at birth, male (years)	LEMA
20. Life expectancy at birth, total (years)	LEIN
21. Mortality rate, adult, female (per 1,000 female adults)	AMRTFE
22. Mortality rate, infant (per 1,000 live births)	IMRT
23. Mortality rate, adult, male (per 1,000 male adults)	AMRTMA
24. Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (per 100,000 population)	WASH
FOREIGN TRADE INDICATORS	
25. Current account balance (% of GDP)	CAB
26. Trade in services (% of GDP)	NFSV
27. Imports of goods and services (annual % growth)	IMP
28. Exports of goods and services (% of GDP)	EXPGBP
29. Exports of goods and services (annual % growth)	EXPGRW
30. ICT goods exports (% of total goods exports)	ICTG
31. ICT goods imports (% total goods imports)	ICTGI
32. High-technology exports (% of manufactured exports)	TECHMF
33. Travel services (% of service exports, BoP)	TRVLX
34. Travel services (% of service imports, BoP)	TRVLM
LABOUR FORCE INDICATORS	
35. Labour force participation rate for ages 15-24, female (%) (modelled ILO estimate)	TLFFEM1524
36. Labour force participation rate for ages 15-24, male (%) (modelled ILO estimate)	TLFMAL1524
37. Labour force participation rate for ages 15-24, total (%) (modelled ILO estimate)	TLF1524
38. Labour force participation rate, total (% of total population ages 15-64) (modelled ILO estimate)	TLF1564
39. Ratio of female to male labour force participation rate (%) (modelled ILO estimate)	TLFCACTFM
40. Labour force, female (% of total labour force)	TLFTOTAFE
41. Labour force participation rate, total (% of total population ages 15+) (modelled ILO estimate)	TLFCACTZS
COMMUNICATION INDICATORS	
42. Mobile cellular subscriptions (per 100 people)	TCELSETSP2
43. Secure Internet servers (per 1 million people)	ITNETSECRP6
44. Individuals using the Internet (% of population)	ITNETUSERZS
45. Fixed broadband subscriptions (per 100 people)	ITNETBBNDP2
46. Fixed telephone subscriptions (per 100 people)	ITMLTMAINP2
POLITICAL INDICATOR	
47. Proportion of seats held by women in national parliaments (%)	SGGENPARLZS

6. Methodology

In this article, two multivariate statistical analysis methods, principal components analysis and cluster analysis, have been used. Principal components analysis was first used by Pearson in 1901 and later developed by Hotelling in 1933. In statistical research, a large number of variables can be included in the analysis. Some of the variables may be highly correlated with each other. However, in statistical analyses, the variables should be independent. The presence of a high level of correlation between variables and a large number of variables leads to the following problems (Karaer & Tatlıdil, 2019: 4):

- The presence of a relationship between variables leads to the multicollinearity problem,
- The high number of variables leads to problems such as computational difficulty, cost, and time loss.

Principal component analysis is used to address these problems. In principal components analysis, a set of variables, such as $X_1, X_2, X_3, \dots, X_r$, is reduced to a smaller number of principal components without significant information loss, and the analysis is conducted using these new variables. The fact that the variables we use in the analyses have

different units of measurement, such as percentages, per mille, and others, has necessitated standardising the data before the principal components analysis. The reason for standardising the data before statistical analysis is that variables expressed in different units of measurement, such as percentages, per mille, and others, can yield erroneous results when analysed together. All the data used in the analysis are standardised using the formula $z = (x_i - \mu) / \sigma$; thus, all the data are transformed to a distribution with a mean of zero and a standard deviation of one (Nakip, 2003: 408).

The r principal components of the vectors $Z_1, Z_2, Z_3, \dots, Z_r$ obtained from the standardization of the vectors $X_1, X_2, X_3, \dots, X_r$ can be expressed as follows:

$$Y_1 = (a_1)^t Z = a_{11}Z_1 + a_{12}Z_2 + \dots + a_{1r}Z_r \quad (1)$$

$$Y_1 = (a_2)^t Z = a_{21}Z_1 + a_{22}Z_2 + \dots + a_{2r}Z_r \quad (2)$$

.....

$$Y_r = (a_r)^t Z = a_{r1}Z_1 + a_{r2}Z_2 + \dots + a_{rr}Z_r$$

In these equations, Z_1, Z_2, Z_r are the rows of the standardised data matrix, Y_1, Y_2, Y_r are the principal components, and a_r are constant values that show which variable each principal component is associated with. Principal components are independent of each other, and the variance of each principal component is equal to the eigenvalue of the corresponding correlation matrix.

The second method used is cluster analysis. Cluster analysis is generally used to group objects with similar characteristics. Here, the purpose of this analysis is to identify countries worldwide at the same level of development as the Independent Turkic States.

7. Empirical Results

Before starting the principal components analysis and cluster analysis, the first task was to standardise the data we would use. After standardising the data, an attempt was made to determine whether it was suitable for principal components analysis. For this purpose, the Kaiser-Meyer-Olkin (KMO) and Bartlett's Test of Sphericity were applied. The KMO test is 73,6%. This value is greater than 0,50, so the variables we selected to measure countries' relative development levels are suitable for principal components analysis. The result of the Bartlett's Test was also found to be significant ($\text{sig.} 0.000 < 0.05$) (See Table 4).

Table 4
KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy	,736
Bartlett's Test of Sphericity	
Approx. Chi-Square	9171,781
Df	1081
Sig.	,000

Since standardised data were used, the correlation matrix was utilised in the subsequent stages of the analysis. Eigenvalues will be used to determine the number of principal components to be used in the clustering analysis. The principal components with eigenvalues of one or greater will be used in the clustering analysis. Table 5 shows that 12 principal components have eigenvalues greater than 1. The percentage of total variance explained by each principal component is shown in Table 5. The first principal component explains 25,236% of the total variance; the second principal component explains 10,572% of the total variance; the third principal component explains 7,914% of the total variance. Twelve principal components explain 76,978% of the total variance. This result indicates that our dataset can be explained by 12 variables, which account for 76,978% of the total variance. Thus, the number of variables used in the cluster analysis has been reduced to 12 through principal component analysis.

Table 5
Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	11,861	25,236	25,236	11,861	25,236	25,236
2	4,969	10,572	35,808	4,969	10,572	35,808
3	3,720	7,914	43,722	3,720	7,914	43,722
4	3,069	6,530	50,252	3,069	6,530	50,252
5	2,468	5,250	55,503	2,468	5,250	55,503
6	1,935	4,118	59,620	1,935	4,118	59,620
7	1,889	4,018	63,639	1,889	4,018	63,639
8	1,514	3,221	66,860	1,514	3,221	66,860
9	1,342	2,855	69,716	1,342	2,855	69,716
10	1,196	2,544	72,260	1,196	2,544	72,260
11	1,133	2,410	74,670	1,133	2,410	74,670
12	1,085	2,309	76,978	1,085	2,309	76,978
13	.968	2,059	79,038			

It is possible to determine which variables predominantly represent each principal component from the principal component matrix (See Table 6). The first principal component is primarily represented by the following variables: life expectancy at birth for females (LEFE), life expectancy at birth for the total population (LEIN), life expectancy at birth for males (LEMA), mortality rate per live birth (IMRT), mortality rate per thousand adult females (AMRTFE), mortality rate due to unsafe water and poor sanitation conditions (WASH), mortality rate per thousand adult males (AMRTA), percentage of the population using the internet (ITNTUSERZS), internet broadband subscription (ITNETBBNDP2), share of value added from agriculture, forestry, and fishing sectors in gross domestic product (AGRTOTL), fixed telephone line subscription (ITMLTMAINP2), GDP per capita (GDPPCAP), and value added per worker in agriculture, forestry, and fishing sectors (AGREEMPL).

Table 6
Rotated Component Matrix

Rotated Component Matrix ^a												
	Component											
	1	2	3	4	5	6	7	8	9	10	11	12
(LEFE)	,963			,124								
(LEIN)	,960			,127								
(LEMA)	,943	,121		,129								
(IMRT)	-,922											,185
(AMRTEE)	-,892			-,113	,113						,172	
(WASH)	-,849			,127				,104				,214
(AMRTMA)	-,848			-,136	,176					,113	,139	
ITNETUSERZS	,839						,188	,112		,164		
ITNETBBNDP2	,835			,116	,303			,123				
(AGRTOTL)	-,746						-,215	-,118		-,118		,233
ITMLTMAINP2	,695	-,110		,120	,237							,178
(GDPPCAP)	,660	,283			,141		,367	,245		-,216		,178
(AGREMP)	,603	,238			,128			,304	,295	-,147		,195
(MNFTECZS)	,486			,355			,167	,330			,133	,137
(ITELSETSP2)	,463	-,146	,285	,389		-,117	,155	-,253	-,159		,159	
ITNETSECRP6	,373	,215		,189	,169		,241	,251	,138	-,219		
(TLFI524)		,951			,141					-,107		
(TLFMAL1524)		,906			-,177		-,131					
(TLFFEMI524)		,844			,428					-,134		
(TLFCACTZS)		,827			,255		,138	-,172	-,166	,180	,123	-,130
(TLFI564)	,362	,718			,426		,155		-,116	,132	,126	-,121
(CONTOTL)			,825						,117			,124
(INDTOTL)			,793		-,143				,204			
(SRVTOTL)	,194		,764		,173	,217			-,126			-,106
(EXPGRW)			,739			,125		,141			-,173	-,122
(IMP)			,684		,135		-,120	,110	-,285		,147	
(ICTG)	,144			,930								
(ICTGI)	,223			,902					-,102			
(TECHMF)	,250			,838	,146					-,141		
(TLFTOTAFE)		,188			,918	-,103						
(TLFCACTFM)		,349			,865		,131					
SGGENPARLZS	,196	,123			,431	,117	-,356	,265	,100	-,197		
(MKTP)						,918					,114	
(PCAP)	,144		,135			,885				,143		
(MANF)				,109	-,252	,702				-,196		
(NFSV)	,266						,797		,106	-,165		
EXPGRDP)	,311		,104	,322			,755	,223				
(CAB)			,170	,251		-,150		,667	-,162			
(TOTL)		,214	,239	,115		-,174	-,242	-,520			,262	
(INDMNFZS)	,185			,102				,316	-,711		,111	
(GOVTZS)	,205		-,114			-,109		,160	,661	,343	,369	-,100
(CONTOTLZS)	-,379	-,177	-,190	-,127	,106		-,309		,453	,359	-,225	
(TRVLM)							-,126			,792		,124
(TRVLX)	-,126			-,203		,253	-,126	-,398	,112	,437	-,151	,154
(GDIFTOT)	-,111					,394					,706	,212
(GOVTKD)	-,102		,367					,117			,614	-,219
(GNSICTR)										-,158		-,832

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalisation.

^a Rotation converged in 14 iterations.

Labour force participation rate variables generally represent the second principal component. The third principal component, in which Kyrgyzstan performed best and ranked 14th among world countries, is formed by the variables of annual growth in final consumption expenditures (CONTOTL), annual value growth added in the industrial sector (INDTOTL), annual value growth added in the services sector (SRVTOTL), growth in exports (EXPGRW), and annual growth in the import of goods and services (IMP). The fourth principal component is represented by variables that reveal the share of information

and communication technologies in total exports and imports, as well as the share of high-tech exports in manufacturing industry exports. The fifth main component is represented by the variables of the proportion of women in the total workforce (TLFTOTAFE) and the ratio of the female workforce to the male workforce (TLFCACTFM). The dominant variables in the sixth principal component are the annual percentage increases in GDP, per capita income, and the value added by the manufacturing industry. Considering the seventh principal component, represented by the variables' share of service trade in GDP (NFSV) and share of goods and services exports in GDP, the most successful country in the ranking is Azerbaijan (24th place). In the eighth principal component, the dominant variables are the current account balance's share of GDP and the annual percentage increase in gross capital formation. Based on this eighth principal component, Uzbekistan ranked 48th among the most successful countries.

The ninth principal component, in which the Turkic states did not show a clear ranking, is influenced by the variables' share of value added in the manufacturing industry in GDP (INDMNFZS) and share of government final consumption expenditure in GDP (GOVTZS). The variables with significant weight within the tenth principal component are the share of travel services in service exports (TRVLX) and the share of travel services in service imports (TRVLM). The variables that influence the eleventh principal component, in which Turkic states do not perform well, are the annual increases in government final consumption expenditure (GOVTKD) and the share of gross savings in GDP. The 12th principal component shows a strong correlation with the savings-to-GDP ratio.

The first purpose of using principal components analysis was to reduce the number of variables. The second aim, as mentioned in the "introduction" section, was to determine the performance of the Turkic Republics in terms of each principal component, in other words, to establish the rankings of the Turkic Republics among the world countries based on principal components. These rankings will be examined in Table 9, along with the results of the cluster analysis, to help determine the strengths and weaknesses of the Turkic Republics.

Cluster analysis was conducted using 12 principal components from a principal components analysis, which together represent 47 main variables. Cluster analysis was performed using the Ward method. To determine the number of clusters, the agglomeration schedule was used. When looking at the coefficients from the 147th row of the agglomeration schedule, nine significant jumps are observed. The coefficient of 1055,863 in row 146 increased to 1114,796 in row 147, then to 1190,270, and finally to 1269,415. To determine whether we made the correct decision regarding the number of clusters, we conducted a cluster analysis with 8 and 10 clusters, which are 1 less and 1 more than the solution we found, respectively. It has been revealed that only the nine-cluster selection yielded results consistent with the dendrogram¹. In the eight- and ten-cluster solutions, some countries could not be included in the dendrogram clusters. Additionally, due to the large number of

¹ As the dendrogram for 156 countries is a very large figure, it is not presented here.

countries, the agglomeration table, which is very long and shows the stages of each of the 156 countries' mergers, was truncated from the 7th row to the 145th row to create Table 7.

Table 7
Agglomeration Schedule

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	43	44	,389	0	0	27
2	63	104	,849	0	0	19
3	41	102	1,445	0	0	23
4	28	51	2,096	0	0	46
5	118	135	2,759	0	0	36
6	107	127	3,429	0	0	52
7	52	151	4,122	0	0	29
Rows 8-144 have not been provided because the table is too long.						
145	1	23	1007,691	136	135	147
146	83	149	1055,863	141	0	148
147	1	4	1114,796	145	142	148
148	1	83	1190,270	147	146	155
149	7	71	1269,415	117	130	154
150	2	5	1348,805	140	143	151
151	2	42	1437,759	150	144	152
152	2	31	1528,574	151	139	153
153	2	84	1633,766	152	0	154
154	2	7	1744,010	153	149	155
155	1	2	1860,000	148	154	0

7.1. Relative Development of Turkic States

The relative development of Turkic states across 156 countries will be examined through country clusters derived from cluster analysis (See Table 8). The cluster numbers in Table 8 do not indicate the clusters' development levels. It has only been used to distinguish between country groups with different levels of development. Each cluster shows the countries with a similar level of development based on 47 variables included in the empirical analysis. The Independent Turkic States are located in Clusters 1, 2, and 9. While Kyrgyzstan, Türkiye, and Uzbekistan are in Cluster (Group) 1, Kazakhstan is alone in Cluster (Group) 2, and Azerbaijan and Turkmenistan are in Cluster (Group) 9. Kyrgyzstan, Türkiye, and Uzbekistan rank similarly among 156 countries in terms of development. While Kazakhstan does not show development comparable to that of any Turkic state, Azerbaijan and Turkmenistan share similar levels of development because they are in the same cluster.

The countries in Custer 1 belong to the regions of Latin America (Dominican Republic, Ecuador, Peru, Brazil, etc.), Central and South Asia (Kyrgyzstan, Uzbekistan, India, Pakistan), the Middle East and North Africa (Saudi Arabia, Egypt, Morocco, Tunisia, etc.), the Balkans and Eastern Europe (Albania, Kosovo), and Southeast Asia (Indonesia, Bangladesh) (See Table 8). According to the World Bank's 2024-2025 income classification, Panama, Oman, Saudi Arabia, Kuwait, and Qatar, which are part of this group, are high-income countries, while the other countries fall into the upper-middle-income and lower-middle-income groups (Metreau et al., 2024). In this group, Türkiye is in the upper-middle-income category, while Kyrgyzstan and Uzbekistan are in the lower-middle-income category. Most of the countries in Cluster 1 are developing countries and face several economic deficiencies, including low per capita income, high unemployment and inflation

rates, and insufficient infrastructure investment. However, among the Turkic states in this group, Türkiye has a larger economy compared to Kyrgyzstan and Uzbekistan, due to its international position. According to 2023 data, it is the 17th largest economy in the world (World Bank, 2024).

Table 8
Country Clusters Obtained as a Result of Cluster Analysis

Cluster 1 Dominican Republic, Ecuador, Kyrgyz Republic , El Salvador, Peru, Brazil, Honduras, Nicaragua, Guatemala, Belize, Kosovo, Saudi Arabia, United Arab Emirates, Türkiye , Uzbekistan , Panama, Albania, Bangladesh, Indonesia, India, Pakistan, Morocco, Tunisia, Egypt Arab Republic, Iran Islamic Republic, Algeria, Iraq, Bahrain, Qatar, Kuwait, Oman
Cluster 2 Kazakhstan , Uruguay, Japan, Mongolia, Estonia, Lithuania, Slovenia, Belarus, Russian Federation, Brunei Darussalam, Moldova, Sri Lanka, Belgium, Italy, Portugal, Spain, Greece, Bosnia and Herzegovina, Croatia, North Macedonia, Serbia, Argentina, Chile, Puerto Rico, Bhutan, Mauritius, Colombia, Hungary, Latvia, Poland, Romania, Slovak Republic, Bulgaria, Thailand, Armenia, Georgia, Capo Verde, Fiji, Bahamas, Montenegro, Cyprus, Seychelles, Botswana
Cluster 3 Djibouti, Lebanon
Cluster 4 Czech, Korea Republic, China, Mexico, Malaysia, Vietnam, Philippines, Hong Kong
Cluster 5 , Libya
Cluster 6 Australia, Iceland, New Zealand, Denmark, Netherlands, Norway, France, United Kingdom, Israel, Austria, Sweden, Germany, Canada, Finland, Switzerland
Cluster 7 Ireland, Malta, Singapore, Luxembourg
Cluster 8 Lesotho, Marshal Islands, Palau, Ukraine
Cluster 9 Burundi, Mozambique, Ethiopia, Tanzania, Niger, Madagascar, Paraguay, Solomon Islands, Bolivia, Cameroon, Haiti, Ghana, Kenya, Azerbaijan , Angola, Uganda, Cambodia, Zimbabwe, Burkina Faso, Mali, Cote d'Ivoire, Chad, Guinea, Guinea Bissau, Nigeria, Comoros, Congo Democratic Republic, Sierra Leone, Gabon, Mauritania, Samoa, Sudan, Gambia, Afghanistan, Senegal, Tajikistan, Nepal, Togo, Turkmenistan , Papua New Guinea, Rwanda, Namibia, South Africa, Equatorial Guinea, Cuba, Tonga

Cluster 2 includes 45 countries, including Kazakhstan. Some of the countries in this cluster are Central Asian and Eastern European; some are European; some are Latin American; and the rest are tropical island countries. Some of the European countries joined the EU in 2004 and 2007, while others are conducting full membership negotiations with the EU. Therefore, the EU members in this group are relatively less developed. Among this group, Russia and Japan are high-income countries, while the other countries are classified as lower- or upper-middle-income. Kazakhstan, one of the Turkic republics, is classified as an upper-middle-income country (Metreau et al., 2024). Kazakhstan is the second largest country in the Eurasian Economic Union in terms of land area and has comparative advantages in the production and export of underground resources (Falkowski, 2017: 31).

Cluster three consists of two countries, Djibouti and Lebanon. The first of these countries is located on the African continent, while the second is in the Middle East of Asia. Djibouti is classified as a lower-middle-income country, while Lebanon is classified as an upper-middle-income country (Metreau et al. 2024).

The countries in Cluster 4, excluding Mexico and the Czech Republic, are from Asia. Among these countries, Hong Kong and South Korea are high-income, while the other countries are middle-income (Metreau et al. 2024). As an upper-middle-income country, Libya has been placed in the fifth cluster alone. The most notable feature of the countries in

Group 6, which are located on different continents, is that they all have high-income country status. Similarly, the countries in Cluster 7 are classified as high-income countries by the World Bank. Four countries with different geographical and economic characteristics have formed Cluster 8. Among these countries, Lesotho and the Marshall Islands are low-income, Palau is high-income, and Ukraine is upper-middle-income.

In Cluster 9, which includes 47 countries, Azerbaijan and Turkmenistan are located. Most of the countries in this group are located in Sub-Saharan Africa. Most countries are classified as low-income, while some are in the lower-middle-income group. Unlike the other countries in the group, Turkmenistan and Azerbaijan are classified as upper-middle-income countries by the World Bank in its 2024 classification.

As a result of these explanations, we can say that Turkic states generally follow a trajectory similar to that of middle-income developing countries.

7.2. Strengths and Weaknesses of Turkic States

In Table 9, the rankings of the Turkic states in each principal component among 156 countries, along with their standings within their respective groups relative to the countries with the best and worst rankings, are presented. For example, in the first section of Table 9, it is observed that Kyrgyzstan, Türkiye, and Uzbekistan, which are in the first cluster, have rankings of 100, 48, and 82, respectively, among countries worldwide according to the first principal component. It is also observed that the country with the best ranking in the first principal component within the same cluster is the United Arab Emirates, with an international ranking of 14. It can be seen that the country with the worst ranking in the first principal component within the same cluster is Pakistan, with a ranking number of 126. These rankings, based on principal components, show the strengths and weaknesses of the Turkic states with respect to the variables each principal component represents.

When we examine the rankings in which Kyrgyzstan has succeeded among 156 countries, in other words, its strengths, we can say that it ranks tenth in the sixth principal component, fourteenth in the third principal component, and twenty-sixth in the tenth principal component. The sixth core component is represented by the annual percentage increases in GDP, per capita income, and the value added by the manufacturing industry. The third key component is determined by the annual growth in final consumption expenditures (CONTOTL), annual value growth added in the industrial sector (INDTOTL), annual value growth added in the services sector (SRVTOTL), growth in exports (EXPGRW), and annual growth in the import of goods and services (IMP) variables. The tenth key component is represented by the share of travel services in service exports (TRVLX) and the share of travel services in service imports (TRVLM) variables.

Conversely, Kyrgyzstan's weaknesses are determined by the eleventh, fifth, twelfth, and seventh principal components. The eleventh principal component is heavily represented by the variables annual growth of general government final consumption expenditure

(GOVTKD) and annual growth of gross fixed capital formation (GDIFTOT). In the fifth principal component, the weighted variables are the share of female labour force in total labour force (TLFTOTAFE) and the ratio of female to male labour force participation rate (TLFCACTFM). In the twelfth principal component, the variable that has a significant impact is gross savings as a percentage of GDP. The variables affecting the seventh principal component are trade in services as a percentage of GDP (NFSV) and export of goods and services as a percentage of GDP (EXPGBP).

Table: 9
The Intra-Group Performances of Turkic Republics

Cluster 1

Principal Component	The Best Performance in the cluster	The worst Performance in the cluster	Kyrgyz Republic	Türkiye	Uzbekistan
1	United Arab Emirates (14)	Pakistan (126)	100	48	82
2	United Arab Emirates (14)	Pakistan (126)	100	48	82
3	Belize (3)	Egypt (148)	14	26	39
4	United Arab Emirates(27)	Bahrain (153)	44	146	145
5	Albania (64)	Oman (156)	120	139	119
6	Iraq (4)	Morocco (138)	10	48	62
7	Qatar (8)	Nicaragua (153)	109	83	138
8	India (27)	Panama (138)	93	90	48
9	Iraq (15)	Indonesia (151)	77	139	130
10	Albania (3)	Algeria (151)	26	93	39
11	Saudi Arabia (4)	Kosovo (153)	122	125	95
12	Albania (4)	Oman (148)	110	13	24

Cluster 2

Principal Component	The Best Performance	The worst Performance	Kazakhstan	
1	Spain(3)	Boswana (124)	88	
2	Spain(3)	Boswana (124)	88	
3	Motenegro (9)	Fiji (150)	123	
4	Thailand (9)	Brunei Darusselam (155)	40	
5	Moldova (1)	Srilanka (141)	53	
6	Fiji (1)	Srilanka (155)	117	
7	Cyprus (6)	Argentina (154)	62	
8	Porto Rico (3)	Bahamas (155)	140	
9	Cabo Verde (18)	Porto Rico (156)	132	
10	Cabo Verde (9)	Chile (128)	103	
11	Bhutan (5)	Srilanka (151)	82	
12	Porto Rico (14)	Bulgaria (155)	104	

Cluster 9

Principal Component	The Best Performance	The worst Performance	Azerbaijan	Turkmenistan
1	Cuba (66)	Nigeria (154)	97	110
2	Cuba (66)	Nigeria (154)	97	110
3	Guinea (5)	Afghanistan (156)	73	104
4	Papua New Guinea (10)	Zimbabwe (148)	134	43
5	Turkmenistan (2)	Afghanistan (152)	47	2
6	Niger (11)	Afghanistan (153)	77	53
7	Nigeria (12)	Nepal (156)	24	118
8	Guinea (4)	Gambia (154)	136	106
9	Tonga (4)	Congo (155)	108	82
10	Nigeria (21)	Afghanistan (156)	95	139
11	Zimbabwe (1)	Madagascar (154)	89	133
12	Sierra Leone (1)	Zimbabwe (156)	149	96

Regarding the eleventh principal component, Kyrgyzstan should make savings attractive to reduce consumption expenditures and increase the formation of gross fixed capital that creates value-added not directed towards consumption. Regarding the fifth fundamental component, Kyrgyzstan needs measures to increase women's employment. In Kyrgyzstan, which gained independence in 1991, the regime change that followed led to a decrease in women's employment. In 1991, 81,6% of women were employed, while in 2007

this rate declined to 42,3% (Najimudinova, 2015: 12). The low employment rate of women is not solely due to the regime change. Culturally, the responsibility placed on women for raising children and managing household chores also contributes to this (Najimudinova, 2015: 11). In this case, the most important factor in increasing women's employment in Kyrgyzstan would be the state's commitment to gender equality. The twelfth principal component shows that the share of savings in Kyrgyzstan's GDP is low. In 2022, per capita income in Kyrgyzstan was realised at 1314 dollars at current prices (Kocaeli Chamber of Commerce, 2022: 7). The low income level also leads to insufficient savings. Therefore, to increase savings in Kyrgyzstan, per capita income needs to be raised. The variables affecting the seventh principal component indicate that Kyrgyzstan's share of foreign trade in GDP is low. This situation is due to Kyrgyzstan exporting products with low demand and, consequently, low prices in world markets. Some agricultural products, textile products, and plastics are significant items in Kyrgyzstan's exports (Kocaeli Chamber of Commerce, 2022: 12). To improve this situation, Kyrgyzstan's export structure needs to shift towards high-value-added industrial products.

Türkiye's strengths are represented by the variables of the twelfth, third, first, and second principal components. Accordingly, Türkiye performs well among countries worldwide in terms of savings-to-GDP ratios, life expectancy, growth-related indicators, and labour force participation rates. The fourth component, in which Türkiye ranks 146th, the fifth key component, in which it ranks 139th, and the ninth key component are the areas where Türkiye is weak. The fourth principal component is determined by the share of information and communication technologies in foreign trade and the share of high-tech exports in manufacturing industry exports. The fifth principal component comprises variables indicating the position of the female workforce in the labour market. The ninth component consists of the manufacturing industry's share of value added in GDP and the share of public final consumption expenditures in GDP.

To improve its weaknesses, Türkiye should do the following:

- The production of high-tech goods should be increased. To this end, R&D expenditures, currently at 1% of GDP, should be increased to the 3% target set by knowledge societies.
- To increase women's employment, the number of nurseries and day care centres where working women can leave their children should be increased.
- Manufacturing industry production should be made attractive with incentives and tax exemptions.

Uzbekistan, which is in Cluster 1, performs well in the rankings of world countries for the variables represented by the second, tenth, and third principal components, while it has performed poorly in the rankings formed by the fourth, seventh, and ninth principal components. Uzbekistan should invest in high-tech industries and develop its manufacturing sector. As a result, the export structure will change from primary goods to industrial products.

The Turkic states in Cluster 1 have never been the worst-performing country within the cluster, and their names have not appeared in the "worst performance" column of Table 9.

Kazakhstan has never ranked as the best or the worst among the countries in its cluster; it has always been in the middle. Kazakhstan has been in a better position than the Turkic states in Cluster 1 in the ranking based on the fourth principal component, which is represented by variables measuring the share of information and communication technologies in total exports and imports, and the share of high-tech exports in manufacturing industry exports. Similar success applies to the fifth and seventh principal components as well. However, Kazakhstan has not achieved a strong ranking on the variables represented by the third, sixth, eighth, and ninth principal components. The third component is represented by annual percentage growth in GDP; the sixth component, by annual percentage growth in services value added; the eighth component, by annual percentage change in gross fixed capital formation; and the ninth component, by gross savings as a percentage of GDP. The low share of savings and gross fixed capital formation in GDP reflects Kazakhstan's low economic growth rate. According to the World Bank data we used for our analyses, Kazakhstan achieved a growth rate of 3.2% in 2022. This rate is the lowest growth rate among the Turkic states included in the empirical analysis. Increasing the growth rate can be achieved by further promoting the services sector, which holds a 59,2% share of Kazakhstan's national income, and the industrial sector, which holds a 35,2% share (DEİK, 2021: 3). The production in the agriculture sector, which has a 5,7% share in GDP, remains limited in its impact on growth because it varies depending on climatic conditions.

The ninth cluster includes Azerbaijan and Turkmenistan. When looking at their intra-cluster performance by component, these two countries have never been in the worst-performing position. In fact, Turkmenistan has been the most successful country in the fifth cluster, ranking second in the fifth core component, which includes variables related to the female labour force. Azerbaijan showed a good ranking in the fifth and seventh principal components, while it showed a weak ranking in the fourth, eighth, and twelfth principal components.

The variables with weight in the fourth principal component are the share of ICT goods exports in total goods exports, the share of ICT goods imports in total goods imports, and high technology exports as a percentage of manufacturing exports. The variables weighted in the eighth principal component are: current account balance as a percentage of GDP and gross fixed capital formation. The variable with weight in the twelfth principal component is gross savings as a percentage of GDP. These findings indicate that Azerbaijan needs to develop policies to shift its export structure from primary products to high-tech products. Additionally, policies that encourage savings will increase gross fixed capital formation.

8. Conclusion

In this article, the relative development levels of six independent Turkic states - Türkiye, Azerbaijan, Turkmenistan, Kazakhstan, Uzbekistan, and Kyrgyzstan - among 156 countries have been determined.

In 2022, the population of the Turkic states constituted 2% of the world population and 36.7% of the EU population. Kyrgyzstan, Kazakhstan, and Uzbekistan are countries with high population growth rates. Kyrgyzstan, Uzbekistan, Azerbaijan, and Turkmenistan are countries with per capita incomes below the world average. The two countries in the worst situation regarding inflation and unemployment rates are Türkiye and the Turkish Republic of Northern Cyprus.

Principal component and cluster analyses were applied using 47 variables. In the first stage, 47 variables were reduced to 12 principal components through principal component analysis, and the countries were ranked according to each principal component. The first principal components contain four groups of variables, which can be classified under life expectancy indicators, mortality rate indicators, communication indicators, and some general economic indicators such as GDP per capita. Labour force participation rate variables represent the second principal component. The third principal component is generally composed of variables related to annual growth. The fourth principal component is represented by variables that reveal the share of high technology in total exports and imports. The proportion of women in the total workforce represents the fifth component. The sixth principal component is related to national income. The seventh principal component is related to foreign trade variables. In the eighth principal component, the dominant variables are the current account balance's share of GDP and the annual percentage increase in gross capital formation. While the ninth component relates to value added in the manufacturing industry, the tenth component is represented by services trade. The last two principal components are related to government final consumption expenditure and the share of savings in GDP, respectively.

The rankings based on the principal components show the areas in which countries are successful or unsuccessful across the variable groups they represent. Therefore, the variable groups with the worst rankings illuminate the areas that countries should prioritise in their development policies. Turkic states have not ranked worst among 156 countries in any principal component within their group. However, Kyrgyzstan needs to develop improvement policies for the indicators in the 11th key component, which ranks 122. Similarly, Türkiye and Uzbekistan need to develop policies to improve the indicators in the fourth principal component; Kazakhstan, in the eighth principal component; Azerbaijan, in the 12th principal component; and Turkmenistan, in the 10th principal component.

The strengths and weaknesses of each Turkic state have been detailed in the relevant section, and policy recommendations have been made. Instead of re-discussing these issues for each Turkic state here, the common weaknesses will be pointed out. The common issues

in all of them are the low share of savings in GDP, women's insufficient representation in the workforce, the inadequacy of gross fixed capital formation and the insufficient share of high-tech goods exports in GDP.

In the second stage, cluster analysis was conducted. The analysis results show that 156 countries can be grouped into 9 clusters representing 9 levels of development, with the Turkic states placed in Clusters 1, 2, and 9. Kyrgyzstan, Türkiye, and Uzbekistan are in Cluster 1, demonstrating a similar level of development, while Kazakhstan is in Cluster 2, and Azerbaijan and Turkmenistan are in Cluster 9. Turkic Republics have generally been grouped into clusters that show a similar level of development to that of developing countries. Türkiye, Azerbaijan, Kazakhstan, and Turkmenistan are classified as upper-middle-income countries by the World Bank, while Kyrgyzstan and Uzbekistan are classified as lower-middle-income countries.

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Why Do Some Civilisations Collapse? An Evolutionary Game Theory Model of Societal Decline

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Bazı Uygarlıklar Neden Yok Olur? Toplumsal Çöküşün Evrimsel Oyun Teorik Modeli

Abstract

The collapse of civilisations is a recurring theme in human history. This paper formalises the concept of societal decline through the lens of evolutionary game theory (EGT) and replicator dynamics, illustrating how interactions among competing social groups, such as elites, commoners, and external forces, can produce feedback loops that lead to collapse. Historical case studies are quantitatively analysed to corroborate the theoretical framework. Graphics demonstrate how resource depletion, inequality, and institutional fragility create conditions conducive to collapse. Findings indicate that societies with adaptive institutions and sustainable cooperation tend to ensure their survival, while those that ignore harmful dynamics risk collapse.

Keywords : Evolutionary Game Theory, Replicator Dynamics, Societal Collapse, Institutional Economics, Resource Depletion.

JEL Classification Codes : C73, D74, N10, Q54, P16.

Öz

Uygarlıkların çöküşü, insanlık tarihinin tekrar eden bir temasıdır. Bu makale, toplumsal çöküş kavramını evrimsel oyun teorisi (EOT) ve çoğaltıcı dinamikler çerçevesinde biçimlendirerek, elitler, sıradan halk ve dış güçler gibi rekabet hâlindeki sosyal gruplar arasındaki etkileşimlerin çöküşe yol açan geri besleme döngüleri oluşturabileceğini göstermektedir. Çalışmada tarihî vaka çalışmaları teorik çerçevenin geçerliliğini desteklemek amacıyla nicel olarak analiz edilmiştir. Grafikler, kaynakların tükenmesi, eşitsizlik ve kurumsal kırılganlık gibi unsurların çöküşe elverişli koşullar yarattığını ortaya koymaktadır. Bulgular, uyum sağlayabilen kurumlara ve sürdürülebilir iş birliğine sahip toplumların varlıklarını sürdürme eğiliminde olduğunu, zararlı dinamikleri görmezden gelenlerin ise çöküş riski taşıdığını göstermektedir.

Anahtar Sözcükler : Evrimsel Oyun Teorisi, Çoğaltıcı Dinamikler, Toplumsal Çöküş, Kurumsal İktisat, Kaynak Tükenmesi.

1. Introduction

Throughout history, civilisations have risen to great heights, only to experience decline and eventual collapse. The fall of once-mighty societies such as the Roman Empire, the Mayan civilisation, and the Soviet Union presents a critical question: Why do some civilisations collapse while others endure? The complexity of societal decline has long been examined through historical, sociological, and economic lenses. Yet, recent advancements in evolutionary game theory (EGT) offer a new perspective on the mechanisms underlying collapse. By applying EGT, we can model interactions among elites, commoners, and external threats to understand how strategic behaviours evolve and how societies can be led toward stability, fragility, or collapse.

Game theory has traditionally focused on the analysis of rational decision-making within competitive contexts (von Neumann & Morgenstern, 1944: 46-47). However, evolutionary extensions of this framework introduce a dynamic perspective in which strategies adapt and evolve based on their relative success within a given population (Maynard-Smith & Price, 1973: 16-17). This evolutionary approach is particularly valuable for examining long-term societal dynamics, as it provides insights into how both individual and institutional behaviours shift in response to changing incentives. Utilising the replicator dynamics framework, we can effectively model the interactions of critical societal factors such as elite exploitation dynamics, commoner cooperation or defection, and external threats, thereby elucidating the pathways that shape a civilisation's trajectory.

Historical case studies illustrate converging decline mechanisms across various civilisations. The Roman Empire exemplifies this, marked by intensifying elite extraction, diminishing civic engagement, and mounting external pressures from barbarian incursions (Tainter, 1988: 49-69). These factors, when evaluated through an EGT lens, resonate with theoretical predications of societal instability. Similarly, the Mayan civilisation demonstrated a trajectory of resource overexploitation that culminated in environmental degradation, sociopolitical fragmentation, and heightened susceptibility to external shocks (Diamond, 2011: 157-178). In both instances, the inability to sustain a stable interaction model among elite dominance, public collaboration, and effective external deterrence precipitated systemic collapse.

This study develops a formal evolutionary game-theoretical model to analyse the dynamics of societal decline. By defining strategies for different societal groups, elites, commoners, and external threats and employing replicator dynamics, we explore how civilisations transition between equilibrium states. The results provide insight into whether decline is an inevitable feature of complex societies or whether institutional mechanisms can sustain long-term stability. Furthermore, we discuss policy implications, drawing from historical lessons to suggest strategies for modern societies to avoid systemic breakdown.

The subsequent sections of this paper are organised as follows. Section 2 delineates the Replicator Dynamics Framework, providing a comprehensive overview of the

mathematical model that delineates societal evolution. Section 3 incorporates case studies, with an in-depth analysis of the fall of the Roman Empire, Maya civilisation, and the Soviet Union. Section 4 explores policy implications and contemporary lessons, the broader implications of our findings, emphasising the conditions that contribute to societal resilience or eventual collapse. Lastly, Section 5 concludes with recommendations for future research trajectories at the nexus of evolutionary dynamics, institutional stability, and historical economic systems.

2. Evolutionary Game Theory and the Dynamics of Collapse

EGT provides a framework for analysing strategic interactions and their evolution in societal contexts. Unlike classical game theory, which assumes fully rational actors, EGT emphasises adaptive strategies in which individuals adjust their behaviour based on relative success within the population (Maynard-Smith & Price, 1973: 16-17). This perspective is valuable for studying societal collapse, as it reveals the long-term impacts of elite extraction strategies, commoner cooperation versus defection, and external threats to societal resilience.

Societies can achieve stable equilibria where cooperation fosters institutional strength, or they may descend into instability if exploitation and defection go unchecked. When instability reaches a critical threshold at which elite overextraction, commoner defection, and external pressures reinforce each other, collapse becomes inevitable (Tainter, 1988: 49-69).

In this section, we develop an EGT model to analyse societal collapse, focusing on strategies of elites, commoners, and external adversaries. We assess the model's equilibrium states and explore factors influencing civilisations' paths towards flourishing, decline, or collapse. This framework helps us understand historical instances of societal failure and their relevance to current governance and institutional resilience.

2.1. Background: Main-Theoretic Model

The collapse of civilisations has been a topic of extensive inquiry in history, sociology, and economics. Numerous theories have attempted to explain why once-thriving societies deteriorate and ultimately fail. Traditional explanations include environmental degradation (Diamond, 2011: 15-18), economic mismanagement (Tainter, 1988: 69), institutional decay, and external invasions (Acemoglu & Robinson, 2012: 21-32). However, these perspectives often lack a formal mathematical framework to model the dynamic interactions between key societal agents, namely elites, commoners, and external threats. EGT provides a rigorous approach to understanding these interactions by offering a framework that models adaptive decision-making, strategic evolution, and the long-term stability or collapse of societies.

Replicator dynamics, a foundational mechanism in EGT, offers a rigorous mathematical framework for analysing the temporal evolution of strategies within a

population (Weibull, 1997: 69-71). This model articulates how successful strategies proliferate, while unsuccessful ones wane, with the dynamics governed by relative payoffs rather than any external optimisation processes. When applied to the study of societal collapse, replicator dynamics facilitates the modelling of interactions among elites, commoners, and external threats, elucidating how the strategic behaviours of these groups evolve over time and potentially culminate in systemic failure.

In our framework, three primary agents interact:

- Elites (E): Dominant elites possess significant control over resources and institutional frameworks. Their strategic decision-making revolves around two primary approaches: either to extract value through exploitative practices or to invest in sustainable initiatives for long-term viability.
- Commoners (C): In socio-economic structures, commoners serve as the labour force, actively contributing to the economy's productivity. Their engagement can manifest in two distinct behaviours: cooperation, characterised by adherence to regulatory frameworks and tax obligations, or defection (rebellion), which may involve tax evasion or insurrection. This dichotomy reflects underlying tensions within the system that can impact overall economic stability and governance.
- External Threats (X): These encompass geopolitical risks, economic disruptions, or environmental challenges that influence the dynamics between elite groups and the general populace. Their interactions can lead to significant shifts in policy, stability, and socio-economic conditions.

Each group evolves its strategic approach in response to the feedback derived from interactions, as described by the replicator equation. This mathematical model quantifies the dynamics of adaptive behaviour, enabling predictions about a system's stability, its capacity for successful adaptation, and its potential for collapse under external pressures. This replicator will also be used in the first case study (the Roman case).

2.1.1. Replicator Dynamics

To formally define the dynamics, let:

- x be the proportion of elites engaging in extraction (rather than sustainability)
- y be the proportion of commoners engaging in defection (rather than cooperation)
- z be the proportion of external threats escalating instability.

The prevalence of extraction, defection, and external pressures influences each group's payoff function. The payoff functions π for each group are:

$$\pi_E = a(1 - x) - bx - cy \quad (1)$$

$$\pi_C = d(1 - y) - ex - fz \quad (2)$$

$$\pi_X = g(1 - z) - hx \quad (3)$$

where

- a, b, c, d, e, f, g, h represent societal parameters (e.g., institutional resilience, wealth inequality, military spending)
- π_E, π_C, π_X denote the payoff functions for elites, commoners, and external threats, respectively.
- The terms capture the effects of strategic choices (extraction, defection, conflict) on societal outcomes.

The influence of societal parameters is crucial for comprehending the underlying equations.

- a : Institutional Resilience - Represents how much elites benefit from maintaining a low-extraction equilibrium. Higher values of a incentivise sustainable governance.
- b : Elite Exploitation Rate - Determines the cost imposed on elites when they extract too much. A higher b means more institutional decay and instability.
- c : Commoner Resistance to Elite Extraction - Captures how much commoners resist when elites extract excessively. Higher values of c indicate stronger civil unrest or revolts.
- d : Social Cooperation Strength - Reflects the benefits of social cohesion for commoners. A larger d means a more cooperative society with lower defection.
- e : Wealth Inequality & Tax Burden - Represents the economic pressure that commoners face. When e is high, taxation or wealth disparities drive defection.
- f : Vulnerability to External Threats - Measures how external pressures weaken commoners. A larger f means that commoners suffer greater losses from external instability.
- g : Military Deterrence - Indicates how well external threats are contained. When g is large, external threats are less effective, stabilising society.
- h : Elite Investment in Military/Conflict - Determines how much elites contribute to either suppressing internal unrest or managing external threats. If h is high, elites prioritise military control over social stability.

The interplay of these parameters significantly impacts the dynamics of societal stability, deterioration, or eventual collapse by influencing the interactions among elites, the general populace, and external pressures. The replicator equations governing the evolution of each strategy over time are:

$$\frac{dx}{dt} = x(\pi_E - \bar{\pi}_E) \quad (4)$$

$$\frac{dy}{dt} = y(\pi_C - \bar{\pi}_C) \quad (5)$$

$$\frac{dz}{dt} = z(\pi_X - \bar{\pi}_X) \quad (6)$$

where

$$\overline{\pi_E} = x\pi_E + (1-x)\pi_E^{sus} \quad (7)$$

$$\overline{\pi_C} = y\pi_C + (1-y)\pi_C^{sus} \quad (8)$$

$$\overline{\pi_X} = z\pi_X + (1-z)\pi_X^{sus} \quad (9)$$

$\overline{\pi_E}$, $\overline{\pi_C}$ and $\overline{\pi_X}$ are the average payoffs in the population and

$$\pi_E^{sus} = a(1-x) \quad (10)$$

$$\pi_C^{sus} = d(1-y) \quad (11)$$

$$\pi_X^{sus} = g(1-z) \quad (12)$$

When elites engage in low-exploitation behaviour, sustainability is achieved, eliminating costs b and c . Likewise, if the commoners remain cooperative and do not rebel (eliminates e and f) and if there is a passive external threat (eliminates h), situations can be expressed through equations 10, 11, and 12, respectively. The equations outline the dynamic relationships governing the evolution of elite exploitation, commoner defection, and the impact of external threats on social stability over time.

2.1.2. Stability Analysis and Equilibria

The core idea behind replicator dynamics is quite simple: when a strategy yields a payoff above the population average (meaning it performs better than others), the proportion of individuals using that strategy will increase over time. Conversely, if a strategy's payoff is below the average, its proportion will decline. Mathematically, this dynamic is represented through time derivatives, which quantify the direction and rate of change in the population share of each strategy.

To analyse long-term societal trajectories, we examine the system's equilibrium points. Setting $\frac{dx}{dt} = 0$, $\frac{dy}{dt} = 0$, $\frac{dz}{dt} = 0$ allows us to find fixed points where societal strategies stabilize. When a replicator equation equals zero, the population share of that strategy remains unchanged. This indicates that the system has reached an equilibrium point. Such points are useful for assessing the relative stability of various strategies. From an evolutionary perspective, this implies that no single strategy can outcompete the others. Unless disrupted by an external shock, the system is likely to maintain this configuration over time. These equilibria can represent stable societies, fragile systems on the brink of collapse, or even scenarios leading to total systemic breakdowns.

Three potential key equilibria can be achieved.

(1) Stable Society (Low Extraction, High Cooperation, Minimal External Threats)

- If institutional strength is high (a large, b small), elites choose sustainability.

- If commoners trust institutions (d large, e small), cooperation persists.
- If external threats are deterred (g large, h small), society stabilises.
- Result: Civilisations flourish (e.g., Chinese Tang Dynasty, Dutch Republic).
- (2) Declining Society (Medium Extraction, Moderate Defection, Increasing External Threats)**
 - If inequality grows, commoners start defecting (e increases, d drops).
 - External threats escalate instability (z rises).
 - Result: Society enters a fragile equilibrium, at risk of collapse (e.g., late Roman Empire).
- (3) Collapse (High Extraction, High Defection, High External Threats)**
 - If elites exploit excessively, commoners refuse cooperation.
 - External threats take advantage of the internal crisis.
 - Result: Society collapses (e.g., Mayan Civilisation, Soviet Union).

Stable society is the point $(x, y, z) = (0, 0, 0)$, where no elites engage in extraction, no commoners defect (high cooperation), and no external threats escalate instability (minimal external threats). Assume all elites initially do not extract (resident strategy at $x = 0$). A small mutant fraction $x > 0$ of extractors would then have a payoff

$$\pi_{E^1} = a - ax - bx \approx a - (a + b)x \quad (13)$$

while a non-extracting elite gets

$$\pi_{E^2} = a - ax \quad (14)$$

The difference is $-bx$. For small $x > 0$, $\pi_{E^2} > \pi_{E^1}$. Thus, if $b > 0$ then any rare extractor gets a lower payoff than the resident (non-extractor), and extractors will die out. In this case, the “no-extraction” strategy resists invasion.

Now, we can analyse $y = 0$. At this point, all commoners cooperate. A rare defector has payoff

$$\pi_C = d(1 - y) \quad (15)$$

which equals the cooperator’s payoff. So, for small y , there is no disadvantage for the mutant (a neutral condition). Thus, defectors neither gain nor lose payoff when rare. Overall, $y = 0$ state is neutrally stable. Similarly, when $z = 0$, both payoffs are equal. So, the state $(0, 0, 0)$ is a replicator fixed point, but it is only conditionally stable. A fully cooperative society is weakly evolutionarily stable.

Collapse is the point $(x, y, z) = (1, 1, 1)$. If all elites currently extract, a tiny mutant non-extractor is $x = 1 - \varepsilon$. Then the extractors get

$$\pi_{E^1} = a\varepsilon - b(1 - \varepsilon) - c \quad (16)$$

and non-extractors get

$$\pi_{E^2} = a\varepsilon \quad (17)$$

Non-extracting mutant does better. Only if $b + c < 0$ (i.e. bizarre negative extraction cost) would extractors outperform; extracting is over-punishing.

With all defecting commoners, $y = 1$. A small cooperator mutant can be written as $y = 1 - \varepsilon$. The payoff of defectors is

$$\pi_{C^1} = d\varepsilon - e - f \quad (18)$$

whereas non-defectors get

$$\pi_{C^2} = d\varepsilon \quad (19)$$

Cooperators do better if $e + f > 0$. Thus, an all-defect society is invaded by cooperators unless $e + f < 0$.

Lastly, with all threats escalating ($z = 1$), a peaceful mutant is $z = 1 - \varepsilon$. Thus, again, there are two different payoffs. For escalators

$$\pi_{X^1} = g\varepsilon - h \quad (20)$$

and for a peaceful mutant

$$\pi_{X^2} = g\varepsilon \quad (21)$$

If $h > 0$, peace yields a higher payoff. Overall, the full-collapse state is likewise not evolutionarily stable under normal (positive) parameters.

On the other hand, declining society ($x_0 + y_0 + z_0 = 1$) is interior point. In a mixed state, the extractor payoff is

$$\pi_{E^1} = a(1 - x_0) - bx_0 - cy_0 \quad (22)$$

while for non-extractors

$$\pi_{E^2} = a(1 - x_0) \quad (23)$$

In other words, elite extraction is not stable. Cooperators among elites would do better. Likewise, defectors and commoners get lower payoffs. Any rare non-extractor, cooperator, or peaceful mutant would obtain a higher payoff than the corresponding resident. Thus, no single strategy in each category can resist invasion: elites would cease extracting, defectors would revert to cooperation, and escalators would revert to peace. This state is unstable.

A stable society is characterised by low elite extraction, high cooperation among commoners, and minimal external threats. The sustainability of this equilibrium depends on strong institutional frameworks that regulate elite behaviour, foster public trust, and deter external aggressors. In this state:

- If institutional strength is high, elites are incentivised to avoid excessive resource extraction, opting for policies that sustain economic and social stability. Strong institutions ensure a fair distribution of resources, reducing the incentives for the elite to exploit the system for short-term gain.
- If commoners trust institutions, cooperation persists, and societal productivity remains high. Trust in institutions ensures that individuals are willing to pay taxes, follow the law, and invest in the future rather than defect to self-serving strategies.
- If external threats are deterred, the civilisation remains insulated from geopolitical instability. Strong military, diplomatic strategies, or geographic advantages prevent external shocks from destabilising internal structures.

As inequality rises, societal cohesion weakens, leading to a fragile equilibrium characterised by elite resource extraction, moderate defection by commoners, and increasing external threats. Key processes contributing to societal decline include:

- Growing inequality diminishes trust in institutions, as commoners view them as exploitative, leading to reduced productivity and cohesion.
- External threats exploit domestic vulnerabilities, making the society more susceptible to invasions, economic competition, and conflicts.
- Effective deterrence of external threats protects the civilisation from geopolitical instability, preventing disruptions to its internal structures.

At the end of the societal trajectory, collapse occurs when:

- Elites engage in extreme exploitation ($x \rightarrow 1$), prioritising short-term gains over long-term stability. This leads to unsustainable economic and social structures, with wealth concentrated in the hands of a few while the majority suffer.
- Commoners refuse cooperation ($y \rightarrow 1$), rejecting institutional authority and engaging in widespread defection. This could manifest as tax revolts, civil wars, or economic breakdowns, where individuals prioritise personal survival over collective stability.
- External threats escalate ($z \rightarrow 1$), taking advantage of internal disorder. A collapsing society often becomes vulnerable to foreign invasions, economic embargoes, or systemic shocks that hasten its disintegration.

Once this equilibrium is reached, recovery is almost impossible without a complete restructuring of political, economic, and social institutions. Collapse often leads to prolonged fragmentation, depopulation, and the loss of technological or cultural achievements.

The equilibria are shown in Figures 1, 2, and 3.

Figure: 1
Stable Society

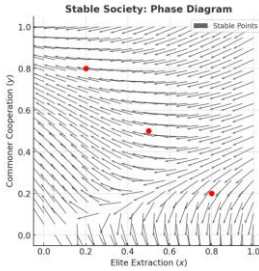


Figure: 2
Declining Society

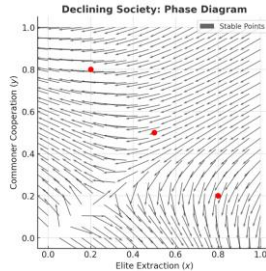
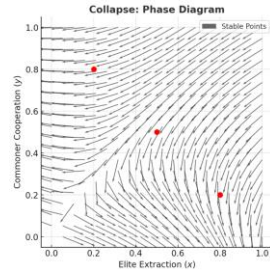


Figure: 3
Collapse



The phase diagrams depict how societies evolve under various conditions of cooperation, elite extraction, and external threats. Each equilibrium reflects the strategic interactions among elites, commoners, and external pressures. The replicator dynamics framework explains these societal transitions, influenced by changing incentives, institutional strength, and external factors.

In the stable society phase, cooperation levels remain high due to strong institutions and minimal elite extraction. The phase diagram shows vector flows converging on a stable equilibrium, where elite extraction is sufficiently low to prevent mass defection and commoners maintain trust in institutions. A reinforcing feedback loop sustains this equilibrium: as institutions strengthen, cooperation increases, and external threats diminish as societal cohesion grows.

Stable societal structures can be seen in the Tang Dynasty (7th-10th century CE) and the Dutch Republic (16th-18th century CE). The Tang Dynasty demonstrated effective governance through a strong bureaucracy, land redistribution to curb elite power, and a meritocratic system that fostered economic stability (Elvin, 1973: 54-69). Similarly, the Dutch Republic achieved balance with trade-focused policies, a decentralised yet effective governance model, and a strategy for elite extraction that facilitated cooperation between merchants and labourers (de Vries & van der Woude, 1997: 9-46). This stability is depicted as an attractor point in Figure 1, illustrating resilience to external shocks. Conversely, the Declining Society phase is characterised by rising inequality, weakening institutions, and escalating external threats.

A relevant case study is the late Roman Empire (3rd-5th century CE). Initially, the Roman system thrived on a stable relationship between elites and commoners, supported by military conquests and tax revenues. However, increased elite extraction through heavy taxation and land concentration led to decreased commoner engagement, as evidenced by lower military enlistment, reduced agricultural output, and rising uprisings (Tainter, 1988: 209-216). External threats, particularly barbarian invasions, worsened the instability,

making recovery harder. The accompanying phase diagram illustrates this fragile equilibrium, indicating a trend toward collapse without reforms or stabilisation efforts.

The phase diagrams depict how civilisations evolve through different equilibrium states shaped by institutional strength, inequality, and external pressures. A stable equilibrium occurs when elite extraction practices are moderate and strong institutions promote cooperation. In contrast, rising inequality and weakened institutions lead to instability. Without intervention, these factors can cause civilisations to disintegrate, making recovery unlikely after a collapse.

3. Case Studies: Modelling Collapse

Understanding societal collapse through the lens of replicator dynamics offers a powerful framework for analysing the factors that contribute to the decline of civilisations. By modelling the interactions among elites, commoners, and external threats, we can trace the trajectories of societies over time and identify critical tipping points where collapse becomes inevitable. This section presents case studies of historical collapses, demonstrating how variations in extraction, defection, and external pressures have shaped the fates of different civilisations. We mainly use the main model (especially for the first two case studies). Then we'll model a new replicator dynamic.

The first case study explores the decline of the Roman Empire, in which increasing taxation, institutional decay, and relentless external invasions accelerated its collapse. By modelling elite extraction, commoner defection, and external threats, we illustrate how Rome transitioned from a stable state to an irreversible downward spiral. The second case study examines the fall of the Mayan civilisation, where environmental stress and elite overexploitation led to societal fragmentation. Our model captures how the erosion of trust in leadership and the over-extraction of resources pushed the Mayans into a state of collapse. Finally, we analyse the Soviet Union's dissolution, demonstrating how economic inefficiencies, rising elite extraction, and internal defection contributed to its sudden breakdown.

3.1. The Roman Empire: Institutional Decay and Hawk-Dove Dynamics

The fall of the Roman Empire is one of the most extensively studied examples of societal collapse. It is often attributed to a combination of institutional decay, economic instability, military overextension, and external invasions. From an evolutionary game-theoretic perspective, Rome's decline can be understood through a Hawk-Dove framework. In this context, the interaction between elites (Hawks) and commoners (Doves) determines the empire's stability. Changes in strategy, driven by shifting incentives, ultimately led to a breakdown in cooperation and the rise of extractive equilibria, contributing to the empire's collapse. The main model is suitable for the modelling of the fall of the Roman Empire.

To formalise the decline, three strategic groups in Roman society are defined:

- **Elites (x):** The ruling class, including emperors, senators, and military officials, who extract wealth from commoners.
- **Commoners (y):** The majority population, comprising farmers, artisans, and merchants, who either comply with elite rule or defect by evading taxes or rebelling.
- **External Threats (z):** Barbarian groups, including Visigoths, Vandals, and Huns, who capitalise on Roman instability.

The payoff functions are based on the levels of extraction, defection, and external threats, as discussed in Section 2. Here a, b, c govern elite behaviour (institutional resilience, corruption, military spending), d, e, f determine commoner reactions (trust in institutions, tax resistance, economic burden) and g, h influence external threats (barbarian cohesion, Roman military deterrence).

We can use the replicator dynamics described in section 2. Again setting $\frac{dx}{dt} = 0$, $\frac{dy}{dt} = 0, \frac{dz}{dt} = 0$ the equilibrium point can be solved.

- **Stable Empire:** Low extraction ($x \approx 0$), high cooperation ($y \approx 0$), and minimal external threats ($z \approx 0$).
- **Declining Empire:** Moderate extraction (x rises), increasing defection (y rises), and rising threats (z rises).
- **Collapse:** High extraction ($x \rightarrow 1$) high defection ($y \rightarrow 1$), and full-scale invasions ($z \rightarrow 1$). The Sack of Rome (410 CE) and the deposition of Romulus Augustulus (476 CE) represent the final equilibrium shift toward systemic failure.

3.1.1. Simulation and Graphical Representation

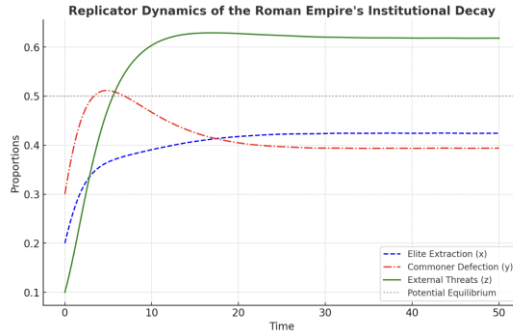
Initially, elite extraction starts at a moderate level but decreases over time. This suggests that as the Roman elite over-extracted resources and imposed heavy taxes, they faced resistance from commoners and external threats, forcing them to reduce their exploitation.

The defection rate among commoners starts relatively high, peaks slightly, and then stabilises. This reflects historical events where discontent among the population increased due to high taxation, military conscription, and economic decline, leading to mass desertions and reduced loyalty to the empire.

The proportion of external threats steadily rises before stabilising. Historically, this aligns with the increasing invasions and pressures from barbarian groups, who took advantage of the empire's internal instability.

The simulation graphic is shown in Figure 4.

Figure: 4
Replicator Dynamics of Roman Collapse



To ensure that our replicator-dynamics simulations faithfully reflect historical trajectories, each model parameter was chosen based on secondary literature estimates or reconstructed empirical data. We set $a = 0.8$ to reflect relatively strong but deteriorating bureaucratic structures during the principate. This value is grounded in Heather’s (2005: 3-46) research, which scores the early empire around 0.85 on a normalised 0 – 1 scale and drops to 0.6 by the third century. $b = 0.5$ captures the increasing decay and instability (Goldsworthy, 2009: 138-154) and $d = 0.85$ assumes a high baseline of civic engagement in early Imperial Italy (Putnam et al., 1994: 163-181), while $e = 0.6$ captures growing tax-resistance in the Crisis of the Third Century (Tainter, 1988: 129-145).

The system appears to reach a stable equilibrium in which all three groups persist at moderate levels. This suggests that, even though Rome faced institutional decay, its collapse was not instantaneous but rather a prolonged decline in which elites, commoners, and external pressures balanced at a critical point. If external pressures had escalated further or if elite extraction had persisted at elevated levels, the system could have been driven toward a complete collapse.

This graphic illustrates a dynamic simulation of institutional decline within the Roman Empire, focusing on the interplay among elite extraction, commoner defection, and external threats, over time. Utilising replicator dynamics, the model effectively captures the evolutionary pathways of these variables, culminating in the empire's collapse. The depicted trajectories reveal the intricate feedback loops between economic exploitation, social instability, and external military pressures that contributed to the overall disintegration of Roman institutions.

Initially, elite extraction remains relatively low, reflecting a period of institutional stability where governance structures maintain a sustainable level of taxation and resource allocation. However, as the empire experiences economic and administrative strain, elites begin to extract more wealth through excessive taxation, forced labour, and the

monopolisation of land. This process intensifies over time, reaching a critical threshold that accelerates social discontent.

3.1.2. Historical Data

Historically, Figure 4 aligns with the later stages of the Roman Empire, particularly during the Dominate period (3rd-5th centuries AD), when emperors imposed heavy taxation and monetary debasement to finance military campaigns and bureaucratic expansion (Heather, 2005: 431-458). The rise in elite extraction diminishes commoners' economic security, leading to the next phase of mass defection.

As elite extraction increases, commoners begin to defect from institutional cooperation. This defection is represented by a sharp increase in y , signifying growing social unrest, tax evasion, and participation in rebellion. Historically, the declining loyalty of the lower classes and regional governors led to widespread non-compliance with imperial policies, weakening the centralised Roman administration (Tainter, 1988: 49).

A critical turning point is observed when commoner defection surpasses 50%, illustrating how the collapse of social cooperation creates systemic instability. This stage corresponds to events such as the Bagaudae revolts (peasant uprisings in Gaul and Hispania) and the widespread desertion of Roman legionaries due to inadequate pay and deteriorating living conditions.

Initially, external threats remain low, indicating a period where Rome's military deterrence is effective. However, as commoner defection rises and elite extraction remains high, Rome's ability to defend itself weakens. External forces, particularly Germanic tribes, Persian armies, and internal usurpers, capitalise on this vulnerability, leading to an exponential increase in external pressures.

The model suggests an equilibrium point where extraction, defection, and external threats interact dynamically. Unlike stable societies that return to equilibrium after minor disturbances, this trajectory suggests an irreversible collapse once societal strain surpasses a critical threshold. The equilibrium at approximately 50% (grey dotted line) indicates a state of prolonged fragility rather than recovery, with institutional resilience having eroded beyond repair.

This finding aligns with Tainter's Collapse Theory (1988), which posits that civilisations fail when the cost of maintaining complexity exceeds societal benefits. Rome's inability to restore balance through reforms, despite attempts such as Diocletian's economic policies and Constantine's military restructuring, confirms the presence of a self-reinforcing cycle of decay that ultimately led to systemic disintegration (Tainter, 1988: 49).

This simulation provides a formalised, mathematical representation of the Roman Empire's collapse through the lens of evolutionary game theory. The interaction between

extraction, defection, and external threats demonstrates that societal stability is highly dependent on institutional flexibility and the adaptive capacity of governance structures.

This approach reinforces the argument that the decline of civilisations is not a sudden event but a gradual, compounding process driven by institutional rigidity, economic exploitation, and geopolitical vulnerability (Diamond, 2011: 1-25). In conclusion, the Roman case serves as a crucial historical example of how strategic miscalculations and systemic inefficiencies can erode once-powerful empires.

3.2. The Mayan Civilisation: Tragedy of the Commons and Resource Depletion

The disintegration of the Mayan civilisation serves as a significant case study for examining societal decline through the framework of replicator dynamics. In contrast to the Roman Empire, which experienced systemic decay alongside external threats, the Mayan collapse was predominantly driven by environmental overexploitation, intensified internal competition, and maladaptive resource management (Diamond, 2011: 157-178). The Tragedy of the Commons model (Hardin, 1968) effectively elucidates the mechanisms through which self-interested behaviours among both elites and commoners precipitated ecological degradation and ultimately destabilised the socio-ecological system. By incorporating these dynamics into an evolutionary game-theoretic framework, we can rigorously analyse how defection strategies, elite extraction practices, and environmental feedback loops synergistically contributed to the civilisation's downfall.

In this model, again, there are three interacting populations:

- Elites (x) : The ruling class, who extracted resources and maintained control.
- Commoners (y): The workforce, primarily agriculturalists who produced surplus.
- Environmental Resources (z): The finite ecological capital, including forests, soil, and water.

The payoff functions for each group, incorporating resource dependency and strategic interactions, are given as:

$$\pi_E = a(1 - x) - bx - cy - dz \quad (24)$$

$$\pi_C = d(1 - y) - ex - fz \quad (25)$$

$$\pi_R = g(1 - z) - hx \quad (26)$$

The parameters delineate critical societal and ecological variables that influence the dynamics among elites, commoners, and environmental resources. As illustrated in Table 1, each parameter distinctly contributes to shaping the longitudinal trajectory of civilisation, impacting its stability, potential decline, or eventual collapse.

Table: 1
Main Parameters

Parameter	Description
a (Institutional Capacity)	Represents the effectiveness of governance and institutions in regulating resource use and maintaining social order. A high <i>a</i> leads to stability, while a low <i>a</i> indicates corruption and institutional decay.
b (Elite Extraction from Commoners)	Measures how much economic surplus elites extract from the agricultural workforce. Higher values indicate increased taxation, forced labour, or monopolisation of resources, potentially leading to social unrest.
c (Commoner Influence on Elites)	Captures the extent to which elite benefits depend on commoner cooperation. Higher values mean that commoner defection significantly reduces elite gains, impacting societal stability.
d (Commoner Productivity & Economic Resilience)	Represents the ability of commoners to sustain themselves economically. A high <i>d</i> suggests a productive workforce, while a low <i>d</i> means declining agricultural output and economic hardship.
e (Impact of Elite Extraction on Commoners)	Quantifies how elite taxation and labour demands influence commoner defection. Higher values indicate greater exploitation, driving commoners toward resistance, migration, or rebellion.
f (Environmental Depletion Effects on Commoners)	Captures how resource degradation affects commoners' livelihoods. High <i>f</i> values indicate that environmental stress (e.g., soil depletion, deforestation) leads to economic decline and reduced cooperation.
g (Environmental Regeneration Capacity)	Measures the ability of natural resources to recover from exploitation. A high <i>g</i> suggests a resilient ecosystem, while a low <i>g</i> indicates irreversible environmental damage.
h (Elite-Driven Environmental Degradation)	Represents how elite resource extraction accelerates environmental destruction. Higher values indicate unsustainable elite activities, such as deforestation for large-scale construction, and worsening ecological collapse.

To find the equilibrium points for the Mayan civilisation model, the replicator dynamics based on the given payoff functions should be analysed. These replicator dynamics are similar to the main model.

$$\dot{x} = x(\pi_E - \bar{\pi}) \quad (27)$$

$$\dot{y} = y(\pi_C - \bar{\pi}) \quad (28)$$

$$\dot{z} = z(\pi_R - \bar{\pi}) \quad (29)$$

where $\bar{\pi}$ is the average payoff and is equal to

$$\bar{\pi} = x\pi_E + y\pi_C + z\pi_R \quad (30)$$

This section examines the average payoff equations for the entire population. The equation calculates the total average payoff by accounting for each group's contributions within the system. In replicator dynamics, the share of a particular strategy (or group) increases if its payoff is higher than the average, and decreases if it is lower.

After solving, we get the equilibrium points as

$$x^* = \frac{a-cy-dz}{a+b} \quad (31)$$

$$y^* = \frac{d-ex-fz}{d} \quad (32)$$

$$z^* = \frac{g-hx}{g} \quad (33)$$

These equilibrium values show the balance between elite extraction, commoner defection, and resource depletion. If extraction ($b - h$) and depletion (f) are too high, the system may reach a critical point where x , y or z collapses to zero or one, leading to societal breakdown. However, if the institutional capacity, resource regeneration capabilities, and

economic resilience are sufficiently robust, the system has the potential to achieve stabilisation. These relationships are illustrated in Figure 5.

Figure: 5
Equilibrium Elite Fraction

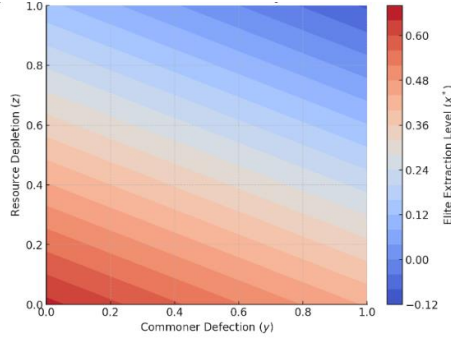


Figure 5 depicts the equilibrium state of elite extraction within the Mayan civilisation model, emphasising the interplay between commoner defection and resource depletion. The colour gradient highlights the varying degrees of elite extraction, with red hues denoting higher levels and blue hues lower levels.

For the Classic Maya instance, $a = 0.6$ was chosen based on paleopolitical reconstructions (Turner & Sabloff, 2012: 13908-13909), indicating moderate central control over city-state networks. We set $b = 0.7$ to represent tribute intensities in Late Classic polities, such as increased taxation, forced labour, or monopolisation of resources. (Dunning et al., 2012: 3654-3655). $d = 0.75$ reflects communal labour obligations (corvée) documented in Classic inscriptions (which also means a productive workforce), $e = 0.8$ models increased exploitation drives commoners toward resistance, migration, or rebellion (Hodell et al., 2001: 1367-1370). Lastly, $g = 0.4$ is drawn from pollen-based forest-recovery rates in Petén lakes (Dunning et al., 2012: 3654-3655).

The data illustrated indicates an inverse relationship between resource depletion (z) and elite extraction (x^*). As resource depletion intensifies, the ruling elite's capacity to extract surplus diminishes. This phenomenon arises from the dependence of elite extraction mechanisms on the availability of environmental resources. As these resources become increasingly scarce, the feasibility of sustained elite extraction declines correspondingly.

The level of commoner defection (y) also negatively influences elite extraction. Higher defection rates indicate social instability and reduce economic productivity, making it more difficult for elites to sustain high extraction levels. Potential collapse zones are identified, with areas marked in deep blue indicating scenarios where elite extraction

approaches zero or enters negative territory. This situation highlights the system's unsustainability, suggesting a trajectory towards potential institutional collapse.

The sustainability and stability of societal regions are crucial. The lower-left quadrant of the plot, shown in red, represents a scenario in which elite extraction is sustainable, supported by low defection rates among commoners and minimal resource depletion. This suggests that Mayan society's stability relied on effective social cooperation and resource management. Overall, the phase diagram highlights the complex relationship between social dynamics and environmental factors in the Mayan civilisation. It suggests that unsustainable resource extraction and rising defection rates may have contributed to societal collapse, emphasising the importance of these interdependencies in understanding the civilisation's resilience and vulnerabilities.

3.2.1. Historical Data and Interpretation

Archaeological and paleoenvironmental data robustly corroborate the theoretical framework established in this study. Historical reconstructions indicate that Mayan elites persistently extracted wealth and labour from commoners, even amid mounting environmental and economic pressures. A particularly notable piece of evidence is the escalation in monument construction during the civilisation's waning phases, coinciding with a decline in agricultural productivity (Turner & Sabloff, 2012: 13908-13909). This pattern suggests that elites prioritised maintaining their political legitimacy and social hierarchy through opulent constructions rather than addressing resource constraints that posed significant risks to long-term societal resilience.

Environmental studies indicate that deforestation and soil erosion were particularly severe in critical agricultural areas, such as the Petén region (Dunning et al., 2012: 3654). Pollen analysis of lake sediments reveals a sharp decline in forest cover, accompanied by an increase in maize pollen, suggesting large-scale deforestation driven by agricultural expansion. However, as soil degradation intensified, the capacity to sustain high agricultural yields diminished. This aligns with the model's prediction that resource depletion (z) negatively affects both commoners (y) and elites (x), creating a feedback loop that pushes society toward collapse.

As agricultural productivity fell, commoners faced increasing food shortages and economic hardship. Ethnohistorical records and archaeological evidence suggest that many commoners responded by defecting either by migrating to other regions or by revolting against elite control. In some cases, evidence of violent uprisings and abandoned settlements supports the notion that social instability was escalating. The collapse of major urban centres, such as Tikal and Copán, aligns with this interpretation, as these cities experienced a combination of warfare, political fragmentation, and depopulation during their final years.

Additionally, climate data derived from cave stalagmites and sediment cores indicate prolonged drought during the later stages of the Classic Maya period (Hodell et al., 2001:

1367-1370). Severe droughts would have exacerbated the effects of deforestation and soil erosion, further reduced food production, and intensified social conflict. In line with the model, environmental degradation (h) combined with elite extraction (x) likely reached a critical threshold beyond which the system became unsustainable.

The decline of the Mayan civilisation can be attributed to a multifaceted interplay of factors, rather than a singular cause. Key contributors included resource depletion, elite mismanagement, and escalating social instability. The replicator dynamics framework employed in this analysis elucidates these interactions by illustrating how the interplay of intensified resource extraction, commoner defection, and environmental degradation evolves, ultimately precipitating an irreversible tipping point. Historical evidence corroborates this interpretation, underscoring that the resilience of societies depends on effective governance, sustainable resource management, and collaborative efforts among diverse societal groups.

3.3. The Soviet Union: Free-Rider Problem and Economic Stagnation

The dissolution of the Soviet Union is a significant case study of systemic economic stagnation attributable to the free-rider problem. This phenomenon occurs when individuals exploit collective resources without making commensurate contributions to their maintenance or production. By employing an evolutionary game-theoretical framework, we can rigorously model the strategic interactions among various societal factions. This analysis elucidates the dynamics that culminated in economic inefficiencies, political volatility, and the eventual disintegration of the Soviet system.

In this model, as in the previous one, three important agents and strategic interactions are defined.

- Party Elites (x) : The ruling class, including Communist Party officials and high-ranking bureaucrats, who controlled economic and political resources.
- Workers and Producers (y) : The general labour force, responsible for industrial and agricultural production under state planning.
- Shadow Economy Participants (z) : Individuals engaged in black-market activities and informal trade to circumvent inefficiencies in the planned economy.

Elites benefited from centralised control, resource extraction, and privilege, but they depended on maintaining worker compliance. Over time, they became increasingly parasitic, extracting wealth without providing incentives for efficiency. Workers and producers faced declining productivity due to a lack of incentives and inefficiencies in central planning. Many began defecting from the formal economy, reducing effort and engaging in “shirking” (minimising work while still receiving state wages). Lastly, participants in the shadow economy engage in black-market trade, diverting resources from the planned economy into more efficient informal networks, which further weakens the formal system.

Instead of the previous payoff functions, we now introduce nonlinear strategic dependencies:

$$\pi_E = A - Bx - Cy^2 - Dz^2 \quad (34)$$

$$\pi_W = E - Fx - Gy - Hz \quad (35)$$

$$\pi_S = I - Jx - Ky - Lz^2 \quad (36)$$

Table: 2
Parameters for New Replicators

Parameter	Description
<i>A</i>	The elite's economic and political power is independent of other groups.
<i>B</i>	Negative effect of elite expansion on their own per capita benefits (diminishing returns to elite growth).
<i>C</i>	Nonlinear burden of worker participation on elite economic rents (e.g., higher costs of maintaining the workforce).
<i>D</i>	Nonlinear effect of shadow economy growth on elite power and resources (e.g., tax evasion, corruption).
<i>E</i>	Baseline productivity of the workers under state-controlled production.
<i>F</i>	Negative effect of elite control on worker productivity (e.g., excessive bureaucracy, corruption).
<i>G</i>	Decreasing returns to scale for workers as the workforce expands, leading to inefficiencies.
<i>H</i>	Negative effect of shadow economy growth on state-sector productivity (e.g., labour migration, black-market leakage).
<i>I</i>	Initial profitability and attractiveness of engaging in the shadow economy.
<i>J</i>	Negative impact of elite intervention on shadow economy growth (e.g., repression, crackdowns).
<i>K</i>	Influence of the workforce on the shadow economy (e.g., defecting from state production).
<i>L</i>	Nonlinear diminishing returns in the shadow economy due to overcrowding, corruption, or inefficiencies.

Lastly, the quadratic terms (y^2, z^2) reflect increasing inefficiencies due to systemic decay. Rather than using the standard form, we introduce cross-group dependency and feedback effects, leading to a more interdependent evolutionary dynamic:

$$\frac{dx}{dt} = x[\pi_E - \bar{\pi}] + \alpha x(1 - x)(y - z) \quad (37)$$

$$\frac{dy}{dt} = y[\pi_W - \bar{\pi}] - \beta y(1 - y)(x + z) \quad (38)$$

$$\frac{dz}{dt} = z[\pi_S - \bar{\pi}] + \gamma z(1 - z)(x - y) \quad (39)$$

where α, β, γ introduce asymmetry and nonlinear feedback, capturing how each group dynamically adjusts based on others. Additional terms introduce strategic adjustments, in which each group shifts behaviour based on relative benefits.

In the Soviet model, nonlinear terms were used to capture the diminishing returns seen in the centrally planned economy. Initially, resource expansion led to significant gains, but beyond a certain point, further increases yielded smaller outputs. Nonlinearity also reflects the threshold behaviour of the shadow economy, where minor instances of black-market trading had little impact on the formal sector. Additionally, nonlinear interactions illustrate the complex feedback between party elites, workers, and the underground economy. Increased elite predation reduced worker productivity while fueling the shadow sector, which in turn diminished the state's capacity to extract resources and led to further elite repression. Finally, incorporating nonlinearities is crucial for demonstrating bifurcation phenomena.

Replicator dynamics can be interpreted as follows:

- (1) Elite Instability (x fluctuating due to y and z)
 - (a) The ruling class's control weakens when both worker productivity declines (y), and the shadow economy expands (z).
 - (b) If elites extract too much, y falls, and z rises, pushing the system toward stagnation.
- (2) Workers' Dilemma (y declines as z increases)
 - (a) If workers see more benefits in informal trade (z), they defect from the system.
 - (b) Central planning failure forces them into low-effort equilibria, accelerating state collapse.
- (3) Shadow Economy as a Catalyst (z expansion destabilises the system)
 - (a) If the underground economy surpasses a critical threshold ($z^* > 0.5$), it outcompetes state production.
 - (b) This leads to capital flight, resource leakage, and eventual state collapse.

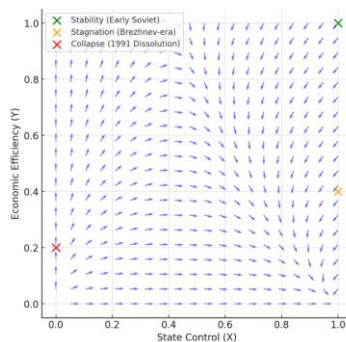
Setting for $\frac{dx}{dt} = 0, \frac{dy}{dt} = 0, \frac{dz}{dt} = 0$, equilibrium analysis can be done.

Table: 3
Equilibrium Conditions

Situation	Condition	Example
Stability	$x^* \approx 1, y^* \approx 1, z^* \approx 0$	The early Soviet period was marked by full state control.
Stagnation	$x^* \approx 1, y^* \approx 0.5, z^* \approx 0.5$	Brezhnev-era inefficiencies emerge.
Collapse	$x^* \approx 0, y^* \approx 0.2, z^* \approx 0.8$	1991 dissolution

This analysis can be seen through Figure 6.

Figure: 6
Soviet Economic Evolution



We use $A = 0.9$ for the 1920s-1930s period, reflecting rapid bureaucratic expansion under Stalin (Allen, 2009: 91), then decrease it linearly to 0.4 by the 1980s to model ossification under Brezhnev (Hanson, 2003: 162-164). $B = 0.8$ reflects the negative effect

of elite expansion (Davies, 1989: 55-70). $D = 0.9$ for the 1930s effect of shadow economy growth on elite power and resources (high mobilisation), declining to 0.5 by the 1970s (Ellman, 2014: 295-320). Lastly, $C = 0.5$ for higher costs of maintaining the workforce, $F = 0.7$ for the negative effect of elite control on worker productivity (Kindleberger & Aliber, 2005: 239-256), and $H = 0.8$, capturing the negative effect of shadow economy growth on state-sector productivity (Gregory, 2001: 112-132).

The stability equilibrium (green point) corresponds to the early Soviet period, when the state's centralised control over economic resources created a system of relative order and predictability. During this phase, state-planned industrialisation, strict resource allocation, and high levels of control over labour and production ensured stability. However, this equilibrium was not sustainable in the long term, as inefficiencies gradually emerged within the system.

The stagnation equilibrium, indicated by the yellow point, reflects the economic conditions prevalent during the Brezhnev era, marked by enduring inefficiencies, suboptimal resource allocation, and entrenched bureaucratic inertia that collectively contributed to economic stagnation. This period is typified by declining productivity, escalating corruption, and a systemic inability to implement effective reforms within the centralised economic framework. The accompanying diagram illustrates that once the system became ensconced in this equilibrium, returning to full stability proved exceptionally challenging, as the dynamics that fostered inefficiency became self-reinforcing.

The collapse equilibrium, represented by the red point, signifies the dissolution of the Soviet Union in 1991. During this time, economic and political instability intensified, leading to systemic failure. This state was marked by a near-total breakdown of centralised planning, significant economic contractions, and the emergence of alternative institutional structures that ultimately replaced the Soviet system. The diagram illustrates that once the system crossed a critical threshold of inefficiency and instability, collapse became inevitable.

In conclusion, the graphic illustrates how economic and institutional dynamics interact over time, creating self-reinforcing feedback loops that drive systemic transformations. The transition between different equilibria is non-linear, indicating that small changes in the strategic behaviour of economic agents, such as policymakers, bureaucrats, and workers, can lead to long-term, potentially irreversible consequences. This interpretation is consistent with historical observations, where efforts at reform were often either too weak or implemented too late to prevent eventual collapse.

3.3.1. Historical Data and Experience

The economic history of the Soviet Union offers strong empirical evidence supporting the evolutionary dynamics presented in this study. From its founding in 1922 until its dissolution in 1991, the USSR experienced significant phases that correspond with

our theoretical equilibrium points. These phases included initial stability under centralised planning, stagnation as inefficiencies built up, and ultimately collapse due to systemic dysfunction (Allen, 2009: 1-19).

During the early years of Soviet rule, the centralised command economy successfully mobilised resources for industrialisation, military expansion, and infrastructural development (Davies, 1989: 55-70). The planned economy eliminated unemployment, controlled prices, and maintained strict state control over economic activity. This phase corresponds to the stability equilibrium ($x^* \approx 1, y^* \approx 1, z^* \approx 0$) where the ruling elite (party elites) had complete control over economic resources, and the workforce (workers) was fully engaged in state production. Black-market activities (Shadow Economy Participants) were negligible (Gregory, 2001: 179-191).

The rapid industrialisation of the Soviet Union under Joseph Stalin, particularly through the implementation of the Five-Year Plans, serves as a prime example of this stability. Heavy industries such as steel, coal, and machinery experienced significant growth, allowing the USSR to catch up with its Western industrialised counterparts (Gregory, 2001: 89-104). Despite the severe human costs, including forced collectivisation, political purges, and widespread repression, the state maintained strict control. Economic output rose sharply, creating an appearance of stability that reinforced the dominance of party elites and solidified the workforce's dependence on state-run industries (Fitzpatrick, 1999: 14-20).

However, the rigidity of central planning meant that as inefficiencies accumulated, cracks began to emerge in the system. The suppression of market mechanisms led to misallocation of resources, overproduction in some sectors, and severe shortages in others (Ellman, 2014: 1-21). While early Soviet stability ensured economic growth and industrial expansion, the absence of adaptive mechanisms eventually led to stagnation.

By the 1960s, under the leadership of Leonid Brezhnev, systemic inefficiencies became more pronounced, marking the beginning of the stagnation phase ($x^* \approx 1, y^* \approx 0.4, z^* \approx 0.5$) (Hanson, 2003: 100-124). In this equilibrium, party elites maintained control, but worker productivity declined as economic incentives weakened. Simultaneously, the shadow economy, unofficial markets, bribery, and black-market activities expanded to compensate for the inefficiencies of the planned economy (Hanson, 2003: 124-125).

The Brezhnev era saw a growing reliance on heavy industry and a focus on extensive economic growth, coupled with bureaucratic inefficiencies (Hanson, 2003: 100-125). State-owned enterprises lacked competition, leading to minimal incentive for innovation or productivity. The "free-rider problem" emerged as workers, guaranteed wages and job security regardless of performance, had little motivation to work efficiently, contributing to the period's stagnation. At the same time, black-market activities thrived as state-run stores failed to meet consumer demands. Informal networks emerged, with farmers selling produce illegally, bribery becoming necessary for goods and services, and private enterprises operating under the radar (Berliner, 1978: 30-42). This shadow economy indicated an

unstable equilibrium with persistent inefficiencies, though full collapse had not yet happened.

Despite multiple reform initiatives, including the economic restructuring efforts spearheaded by Alexei Kosygin in the late 1960s, the central planning apparatus remained rigid (Hewett, 1988: 257-270). The Soviet leadership's hesitance to adopt a more market-oriented approach worsened inefficiencies, ultimately exacerbating economic stagnation.

Lastly, by the late 1980s, the Soviet economic model was unsustainable. The collapse equilibrium ($x^* \approx 0, y^* \approx 0.2, z^* \approx 0.8$) became a reality: party elites lost control, workers disengaged from the state-run economy, and shadow economy participants dominated (Gaidar, 2007: 132-140).

Mikhail Gorbachev's efforts at reform through *perestroika* (economic restructuring) and *glasnost* (political openness) inadvertently accelerated the collapse of the system. *Perestroika* aimed to introduce limited market mechanisms, reduce state control over businesses, and improve efficiency. However, it disrupted existing networks of control without providing viable alternatives, resulting in economic chaos (Hewett, 1988: 303-348). As state-run industries struggled, production decreased, and shortages intensified, pushing more people toward the shadow economy.

By 1991, the Soviet economy was in freefall, struggling to meet basic needs as inflation surged and political unrest grew (Ellman & Kantorovich, 1998: 169-187). The central government's inability to coordinate the economy led to widespread defections, with republics seeking independence and workers leaving state-run industries (Suny, 1993: 127-147). The formal dissolution of the Soviet Union in December 1991 marked the collapse of the state-controlled economy, ushering in a period of economic and political uncertainty, dominated by oligarchs and privatisation efforts (Ellman & Kantorovich, 1998: 169-187).

In conclusion, the Soviet Union's historical trajectory from a stable, controlled system to stagnation and eventual collapse aligns with our evolutionary game-theoretical framework. The replicator dynamics illustrate key transitions in Soviet economic history, showing how strategic interactions among economic agents influenced stability and contributed to its breakdown.

4. Policy Implications and Contemporary Lessons

Analysing the decline of historical civilisations through the EGT framework yields critical insights with significant implications for contemporary policymaking. Factors contributing to societal collapse, such as elite overextraction, commoner defection, resource depletion, and the impact of external shocks, extend beyond ancient examples like the Roman Empire, the Maya civilisation, and the Soviet Union, remaining pertinent to modern economic and political ecosystems. This section elucidates how lessons from EGT models of societal collapse can inform modern governance strategies and economic policies, thereby enhancing institutional resilience and mitigating the risks of stagnation and systemic failure.

4.1. Institutional Stability and Governance

One of the most critical lessons from historical collapses is the importance of institutional adaptability. The rigid hierarchical structures of the Soviet Union, the excessive bureaucratic expansion of the Roman Empire, and the exploitative elite dynamics in the Maya civilisation all demonstrate that institutions unable to reform themselves in response to economic and social pressures tend to collapse (Acemoglu & Robinson, 2012: 152-158). In modern economies, ensuring institutional flexibility through transparent governance, accountability mechanisms, and adaptive policymaking is crucial in preventing systemic failures.

For example, in contemporary authoritarian regimes, economic stagnation often results from the same free-rider problem observed in the Soviet Union. Rent-seeking elites extract wealth at the expense of productive citizens, creating inefficiencies in resource allocation. Reducing elite predation through strong legal institutions and enforcement of property rights can mitigate these risks (North, 1990: 54-61). Policymakers must prioritise the rule of law, meritocratic bureaucracy, and the separation of economic and political power to prevent elite overextraction and societal instability.

4.2. Economic Inequality and Social Cooperation

Evolutionary game theory elucidates the ongoing tension between cooperation and defection in social dynamics. The case studies examined previously indicate that when constituents perceive the economic framework as inequitable or exploitative, they are more inclined to engage in defecting behaviours manifesting as migration, rebellion, or withdrawal from economic participation. This trend is particularly salient in contemporary economies characterised by escalating income inequality and diminishing social mobility, as Piketty (2014: 237-271) highlights.

To counteract this, redistributive policies, investments in human capital, and social safety nets must be implemented to maintain social cohesion. The Scandinavian economic model, for instance, demonstrates that balancing economic efficiency with equity fosters long-term stability and reduces the likelihood of defection dynamics (Esping-Andersen, 1990: 55-77). Societies that fail to address economic grievances risk facing increasing political polarisation, populism, and eventual institutional breakdown.

4.3. Resource Management and Environmental Sustainability

The Tragedy of the Commons, exemplified by the decline of the Maya civilisation, highlights the critical need for sustainable resource management practices. When individual agents prioritise immediate economic benefits at the expense of communal resources, the resulting environmental degradation intensifies and can precipitate systemic collapse (Hardin, 1968: 1244-1246). Presently, we face analogous existential threats from the climate crisis, deforestation, and the over-extraction of natural resources, all of which underscore the urgency for effective governance and collective action to mitigate these challenges.

Policy solutions must incorporate environmental externalities through market mechanisms such as carbon pricing, resource extraction regulations, and investments in renewable energy (Ostrom, 1990: 20-32). Successful models, exemplified by Costa Rica's Payments for Environmental Services (PES) program, illustrate that incentivising sustainable practices fosters long-term resilience. However, neglecting to address environmental challenges, especially in rapidly industrialising economies, risks perpetuating the resource depletion cycle that has historically led to economic collapses.

4.4. Globalisation and External Shocks

The dynamics of external shocks observed in historical societal collapses are strikingly pertinent in our globalised era. Much as the Roman Empire faced barbarian invasions and trade disruptions, or the Soviet Union faced external military pressures and economic isolation, contemporary economies remain susceptible to global financial crises, geopolitical conflicts, and pandemics (Kindleberger & Aliber, 2005: 1-30).

To bolster resilience, nations must diversify trade partners, develop robust supply chain frameworks, and implement adaptive economic policies that can absorb external shocks. The 2008 financial crisis served as a stark illustration of the systemic vulnerabilities present within global financial institutions, resulting in significant instability across markets. The subsequent regulatory reforms and various macroprudential policies exemplify how institutional adaptability can effectively reduce the risks of collapse in interconnected economies (Reinhart & Rogoff, 2011: 3-20).

4.5. Learning from Past Collapses: Policy Recommendations

Given the historical patterns of societal decline, policymakers can draw several key lessons to enhance institutional and economic resilience:

- **Promote Institutional Adaptability:** Governments should foster democratic accountability, enforce property rights, and prevent elite overconcentration of power to ensure long-term stability (Acemoglu & Robinson, 2012: 70-96).
- **Address Economic Inequality:** Strengthening progressive taxation, social safety nets, and education investment can mitigate economic grievances and prevent defection dynamics (Piketty, 2014: 493-530).
- **Enhance Environmental Sustainability:** Implementing market-based environmental policies, strict regulations, and international climate cooperation can prevent resource depletion cycles (Ostrom, 1990: 59-89).
- **Increase Economic Resilience to External Shocks:** Developing robust financial regulations, trade diversification, and adaptive monetary policies can protect economies from global crises (Reinhart & Rogoff, 2011: 53-54).
- **Encourage Cooperation Over Defection:** Strengthening civic engagement, public trust, and social capital can sustain cooperative equilibria and prevent societal fragmentation (Putnam et al., 1994: 163-181).

In conclusion, the decline of civilisations tends to adhere to recognisable patterns characterised by elite overextraction, economic stagnation, environmental mismanagement, and external perturbations. Utilising EGT frameworks enables a nuanced analysis of these dynamics, providing policymakers with critical insights. By examining historical case studies and implementing strategic interventions informed by this theoretical lens, contemporary societies can mitigate the risk of repeating historical failures.

The sustainability of modern civilisations hinges on their capacity to foster cooperative dynamics, optimise resource distribution, and effectively respond to evolving environmental and socio-economic conditions. Societies that neglect inherent structural vulnerabilities are susceptible to stagnation and potential disintegration, while those that emphasise strategic long-term stability and resilience are better positioned to flourish amid growing complexity and uncertainty.

5. Conclusion

This study presents a formal framework for analysing societal collapse using EGT and replicator dynamics. It highlights the strategic interactions among elite factions, the general populace, and external threats, showing how these factors influence long-term societal stability or decline. By integrating mathematical modelling with historical case analyses, the research demonstrates that societal collapse is not an arbitrary event. Rather, it results from structured incentives, resource limitations, and feedback mechanisms that intensify instability over time.

A key insight from this research is that EGT offers a dynamic perspective on societal collapse. Unlike traditional economic models, which assume that individuals make decisions in isolation, evolutionary models consider the adaptive behaviours of both individuals and institutions over time. This approach is particularly useful for understanding how elites modify their governance strategies, how commoners react to changing economic conditions, and how external threats exploit internal vulnerabilities. The findings suggest that collapse is often driven by self-reinforcing cycles of elite overextraction, commoner disengagement, resource depletion, and external shocks. Societies that do not address these dynamics inevitably experience stagnation and decline.

The historical case studies validate the EGT model of collapse. For the Roman Empire, declining institutional effectiveness led to predatory elite strategies, increased taxation, and commoner defection, resulting in vulnerability to invasions and economic decline. The Mayan case highlighted the tragedy of the commons, in which resource depletion from soil degradation and deforestation led to high elite extraction, driving commoners to migrate or rebel. The decline of the Soviet Union illustrated the free-rider problem, as ineffective state redistribution disincentivised productivity, causing widespread defection, stagnation, and dissolution. These case studies show that while historical circumstances vary, the strategic structures remain consistent. Societies collapse not just due to external shocks or leadership failures but through the gradual erosion of cooperation. The

mathematical models indicate that once a society reaches critical levels of elite predation, commoner defection, and institutional decay, collapse becomes inevitable. These findings have important implications for modern societies, many of which share similar vulnerabilities.

A key policy implication of this study is the need for institutional resilience. To prevent societal collapse, elite incentives must promote long-term stability over short-term wealth extraction. Historical evidence shows that transparent governance, strong legal institutions, and measures against elite corruption enhance stability. Additionally, economic policies should address rising inequality and labour-market disengagement to avoid mass defection. The collapses of the Soviet Union and Rome illustrate that when people view the system as exploitative, they either disengage or resist, speeding up the decline.

Environmental sustainability is a pivotal element for ensuring long-term socio-economic stability. The decline of the Maya civilisation serves as a cautionary tale regarding the repercussions of resource mismanagement and ecological degradation. Present-day societies encounter analogous threats, primarily through climate change, biodiversity loss, and unsustainable industrial practices. We must implement robust, evidence-based policies that not only regulate resource consumption but also incentivise sustainable practices across industries. Failure to act decisively may lead contemporary civilisations to replicate the vulnerabilities that precipitated the collapse of historical societies.

External threats are often the final catalyst for collapse, but rarely act alone. The Roman Empire's internal weaknesses left it unable to resist external pressures, while the Soviet Union's economic stagnation made it vulnerable to geopolitical shocks. This highlights the importance of prioritising geopolitical stability, economic diversification, and institutional adaptability to withstand crises.

Future research should enhance this framework by integrating empirical datasets, agent-based simulations, and network models to improve predictive accuracy. By analysing trends in economic inequality, institutional corruption, and ecological degradation through the lens of EGT, researchers can identify societies at risk of collapse. Additionally, agent-based simulations can help understand how individual decisions lead to macro-level collapse patterns. Expanding these models to current societies can provide policymakers with tools for early warning systems and effective intervention strategies.

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Innovations in Monte Carlo-Based Markov Switching Tests: An Application to Türkiye's GDP Data

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Monte Carlo Tabanlı Markov Rejim Değişimi Testlerinde Yenilikler: Türkiye GSYİH Serileri Üzerine Bir Uygulama

Abstract

This study explores the application of Monte Carlo-based methodologies, specifically the “Local Monte Carlo Likelihood Ratio Test (LMC-LRT)” and the “Maximised Monte Carlo Likelihood Ratio Test (MMC-LRT)”, within the context of Markov switching models to analyse Türkiye’s quarterly GDP data from 1998Q1 to 2024Q2. These tests, developed by Rodríguez-Rondon and Dufour (2024), address challenges associated with non-standard asymptotic distributions and nuisance parameters, offering robust solutions for identifying regime shifts. The empirical analysis demonstrates that the “Markov Switching Autoregressive (MSAR)” model significantly outperforms the baseline Autoregressive (AR) model, capturing two distinct economic regimes characterised by differing means and variances. The Monte Carlo-based tests strongly reject the null hypothesis of no regime-switching ($p < 0.05$), validating the presence of structural breaks in Türkiye’s GDP dynamics. The findings emphasise the utility of advanced methodologies for analysing economic time series, providing policymakers with valuable insights and reinforcing the theoretical contributions of Monte Carlo-based approaches. This study highlights the practical and theoretical significance of regime-switching models in understanding economic dynamics and structural changes over time.

Keywords : LMC-LRT, Markov Regime-Switching Models, MMC-LRT, Monte Carlo Methods, Türkiye GDP.

JEL Classification Codes : C15, C22, E32, E37.

Öz

Bu çalışma, Türkiye’nin 1998Q1-2024Q2 dönemine ait çeyreklik GSYİH verilerini analiz etmek için Monte Carlo tabanlı yöntemlerin, özellikle “Yerel Monte Carlo Olabilirlik Oranı Testi (LMC-LRT)” ve “Maksimize Edilmiş Monte Carlo Olabilirlik Oranı Testi (MMC-LRT)”, Markov rejim değişimi modelleri kapsamında uygulanmasını incelemektedir. Rodríguez-Rondon ve Dufour (2024) tarafından geliştirilen bu testler, standart olmayan asimptotik dağılımlar ve ilgisiz parametrelerle ilgili sorunları ele alarak rejim geçişlerinin tespit edilmesi için güvenilir çözümler sunmaktadır. Yapılan ampirik analiz sonucunda, “Markov Rejim Değişimli Otoregresif (MSAR)” modelinin temel Otoregresif (AR) modele kıyasla belirgin şekilde daha başarılı olduğu ve ortalama ile varyansları farklılık gösteren iki ayrı ekonomik rejimi yakalayabildiği görülmüştür. Monte Carlo tabanlı testler, rejim değişiminin olmadığı yönündeki sıfır hipotezini güçlü biçimde reddederek ($p < 0.05$), Türkiye’nin GSYİH dinamiklerinde yapısal kırılmalar olduğunu doğrulamıştır. Bulgular, ekonomik zaman serilerini analiz etmede gelişmiş yöntemlerin önemini vurgulamakta, politika yapıcılar için değerli içgörüler sağlamakta ve Monte Carlo tabanlı yaklaşımların teorik katkısını pekiştirmektedir. Bu çalışma, ekonomik dinamikleri ve zaman içindeki yapısal değişimleri anlamada rejim değişimi modellerinin pratik ve teorik önemine dikkat çekmektedir.

Anahtar Sözcükler : LMC-LRT, Markov Rejim Değişikliği Modelleri, MMC-LRT, Monte Carlo Yöntemleri, Türkiye GSYİH.

1. Introduction

To date, numerous applied time-series analyses have been conducted on real GDP data using various models. While linear time series models were initially predominant for such data, recent studies have demonstrated that fluctuations in GDP exhibit an asymmetric structure (Marchese, 2010). Classical regression models assume linear relationships. However, economic theory plays a relatively passive role in upholding the assumption of linearity. In many cases, such as stock returns, exchange rates, and the trend behaviour of numerous macroeconomic variables, the data-generating process is inherently nonlinear. Consequently, linear characteristics may fail to provide a realistic representation for econometric models analysing these behaviours (Das, 2023). The central problem addressed in this study is the identification and modelling of structural breaks and regime shifts in Türkiye's GDP dynamics, which are often overlooked when conventional linear approaches are applied. Periods of financial crises, policy reforms, and external shocks make it particularly important to capture regime-switching behaviour in macroeconomic data.

The Markov switching model developed by Goldfeld and Quandt (1973) is considered a foundational method for modelling regime changes in nonlinear time series. This model provides a probabilistic approach to capturing regime transitions, introducing a new paradigm in econometric analysis (Goldfeld & Quandt, 1973). The study by Goldfeld and Quandt (1973) developed a significant method for identifying and addressing heteroskedasticity issues in econometric modelling. However, such methods were insufficient for modelling structural changes and regime shifts in time series analysis. In this context, Hamilton (1989) introduced Markov regime-switching models, which represented a major innovation in the field. Hamilton's work enabled the dynamic modelling of structural breaks in the time series, offering a more flexible approach to econometric analysis. This model is particularly useful for identifying distinct macroeconomic regimes (e.g., recession and growth) and estimating the transition probabilities between them. The Markov regime-switching model proposed by Hamilton complements the approach of Goldfeld and Quandt, which focuses on detecting heteroskedasticity, by providing a new perspective on instability and regime shifts. This model has been widely applied not only in the analysis of macroeconomic indicators but also in financial market modelling (James D. Hamilton, 1989). Despite this extensive body of literature, a critical gap remains: most empirical studies either rely on traditional likelihood ratio tests that face serious limitations (e.g., non-standard asymptotic distributions and nuisance parameters) or focus on developed economies, while applications to emerging markets like Türkiye are scarce. This study aims to fill this gap by combining methodological innovations (Monte Carlo-based testing) with a case study on Türkiye's GDP series.

Determining the number of regimes is a critical aspect of the Markov switching model. Since the number of regimes is not always known, hypotheses are formulated for a specific number of regimes (e.g., M_0) and for alternative numbers of regimes (e.g. $M_0 + m$) (Rodriguez-Rondon & Dufour, 2024). However, standard hypothesis-testing techniques are not readily applicable in this context because certain model parameters are not defined under the null hypothesis, and the usual regularity conditions required to derive the asymptotic distribution of the test statistics are not satisfied. The examination of the asymptotic distribution of the likelihood ratio test for Markov switching models has garnered significant attention, and Hansen (1992) examines this issue within the scope of the explanation (Hansen, 1992). Nevertheless, most of the existing procedures, including those focusing on the likelihood ratio test approach, can only address cases where the null hypothesis assumes a linear model (i.e., $H_0: M_0 = 1$) and the alternative hypothesis assumes a two-regime Markov switching model (i.e., $H_0: M_0 + m = 2$, where $M_0 = m = 1$) (Rodriguez-Rondon & Dufour, 2024). The sole exception is the work of Kasahara and Shimotsu (2018), who demonstrated the asymptotic validity of a parametric bootstrap procedure for the likelihood ratio test statistic when the null hypothesis involves a model with M_0 regimes and the alternative hypothesis involves a model with $M_0 + 1$ regimes, where $M_0 \geq 1$ and $m = 1$ (Kasahara & Shimotsu, 2017). In contrast, Dufour and Luger (2017) propose a moment-based approach that utilises "Monte Carlo" techniques as described in Dufour (2006), allowing for relaxation of many of the conventional assumptions. Specifically, the authors introduce test statistics based on the moments of least-squares residuals, designed to capture distinct characteristics of a two-component mixture distribution. Consequently, their procedure is still applicable only to the basic case where $M_0 = m = 1$, as with other methods, but they propose a testing procedure that leverages "Monte Carlo" techniques to achieve exact inference (Dufour, 2006; Dufour & Luger, 2017).

Rodriguez and Rondon (2024) have built on the "Monte Carlo" procedures outlined by Dufour (2006) and applied them to a likelihood-ratio testing framework for Markov switching models. This approach addresses issues in traditional hypothesis testing procedures, such as nonstandard asymptotic distributions and nuisance parameters, within the likelihood-ratio framework. Specifically, they proposed the "Local Monte Carlo Likelihood Ratio Test (LMC- LRT)" and the "Maximisation Monte Carlo Likelihood Ratio Test (MMC-LRT)," which can be used to determine the number of regimes in both Markov switching models and Hidden Markov Models. These tests consider very general settings, involving models with M_0 regimes under the null hypothesis and $M_0 + m$ regimes under the alternative hypothesis, where $M_0 \geq m$ and $m \geq 1$. Notably, the MMC-LRT is an exact test that is valid both in finite samples and asymptotically. Additionally, it is robust to the identification issues commonly encountered in Markov switching models (Rodriguez-Rondon & Dufour, 2024). Based on this background, the research question guiding this study is: Can Monte Carlo-based Markov switching tests provide statistically robust evidence of regime shifts in Türkiye's GDP dynamics, overcoming the limitations of classical likelihood-ratio approaches? We hypothesise that Monte Carlo-based methods

(LMC-LRT, MMC-LRT) will outperform traditional AR models in detecting structural breaks and will validate the presence of multiple regimes in Türkiye's GDP series.

In this study, we evaluated the "Local Monte Carlo Likelihood Ratio Test" and the "Maximisation Monte Carlo Likelihood Ratio Test (MMC-LRT)," developed for testing the detectability of regime changes under the null hypothesis in the context of Markov switching models, using Türkiye's GDP data. The second section of the study presents the relevant literature, and the third section explains the methodology for Markov switching. In the fourth section, the relevant tests will be performed on GDP values using the MSTest package, developed by Rodriguez and Rondon (2024) in R. The results will be shared in the conclusion section, and the newly developed tests for the Markov switching model will be evaluated in the discussion section.

2. Literature Review

Goldfeld and Quandt (1973) proposed a Markov switching model to estimate the parameters of regression models when observations are generated by one of two distinct regimes. The model assumes that transitions between regimes are governed by a Markov chain defined by a transition probability matrix and does not require prior knowledge of which regime generated each observation. In this framework, maximum-likelihood estimates were derived under the assumption of independent regime transitions. The study provided both a theoretical structure and an applied approach for modelling regime shifts, making a significant contribution to econometric analysis (Goldfeld & Quandt, 1973). Following this study, Hamilton (1989) further advanced Markov switching models, enabling the dynamic modelling of regime changes and applying them particularly to the analysis of structural breaks in time series and economic cycles. Hamilton's approach introduced significant innovations, such as the direct estimation of transition probabilities and the modelling of uncertainties in assigning observations to regimes, thereby making substantial contributions to the field (James D. Hamilton, 1989).

Traditional approaches for detecting structural breaks include the Chow (1960) test for a single known break point, the Zivot-Andrews (1992) test for a unit root with one structural break, and the Bai-Perron (1998, 2003) methodology for multiple structural changes. While these methods provide valuable benchmarks, they often rely on restrictive assumptions, such as known break dates or asymptotic approximations, and may suffer from reduced power in small samples. In contrast, the Monte Carlo-based Markov Switching tests employed in this study provide exact inference and a more flexible framework for identifying regime shifts, thereby overcoming several of the limitations of traditional methods.

The Markov switching model has been extensively applied across various fields, including business cycles (Chauvet, 1998; Chauvet & Hamilton, 2005; Hamilton, 2005), interest rate dynamics (Garcia & Perron, 1996), financial markets (Marcucci, 2005) and

VAR models (Herwartz & Lütkepohl, 2014; Lanne et al., 2010; Lütkepohl et al., 2021), among others.

As previously mentioned, standard hypothesis testing techniques are not readily applicable in this context because certain model parameters are not defined under the null hypothesis, and the usual regularity conditions required to derive the asymptotic distribution of the test statistics are not satisfied (Rodriguez-Rondon & Dufour, 2024). Additionally, Carter and Steigerwald (2012) discuss the challenges of achieving consistency of quasi-maximum likelihood estimators and tests within Markov switching models, highlighting issues related to regularity conditions and the dependence of conditional state probabilities on regressors, which further complicate hypothesis-testing procedures (Carter & Steigerwald, 2012). Building upon the challenges highlighted by Carter and Steigerwald (2012), Cho and White (2007) delve deeper into testing regime-switching hypotheses by introducing a quasi-likelihood ratio framework. They address the difficulties posed by non-standard asymptotic distributions and nuisance parameters, proposing methods that expand the utility of mixture models in Markov switching contexts (Cho & White, 2007). Garcia (1998) rigorously analyses the asymptotic null distribution of the likelihood ratio test in the context of Markov switching models. Garcia addresses the complexities posed by unidentified nuisance parameters under the null hypothesis and proposes a framework that provides robust approximations for the empirical distribution of test statistics, offering critical insights on econometric applications (Garcia, 1998). Hansen (1992) introduced a powerful framework for testing parameter stability in econometric models. Hansen addressed the challenges posed by nonstandard asymptotic distributions and nuisance parameters, offering robust tests based on cumulative first-order conditions. His methodology provides critical tools for understanding model instability and regime shifts, complementing earlier approaches to hypothesis testing in Markov switching contexts (Hansen, 1992). Hansen (1992)'s robust framework for testing parameter stability, Kasahara and Shimotsu (2017) extend this methodology to dynamic programming models. They introduce computationally efficient estimation techniques that address challenges associated with the dimensionality of the state space, further advancing tools for analysing regime stability and structural changes in econometric applications (Kasahara & Shimotsu, 2018). Qu and Zhuo (2020) extend the discussion by addressing the challenges of nonstandard asymptotic distributions and nuisance parameters in regime-switching models. They develop refined likelihood-ratio-based tests for detecting regime shifts, providing critical advances in the asymptotic characterisation of such tests within nonlinear econometric frameworks (Qu et al., 2020).

Markov switching models provide powerful tools for detecting regime changes in time series analysis. Hansen (1992) introduced a framework for testing parameter stability in these models, addressing challenges such as nonstandard asymptotic distributions and nuisance parameters. Subsequently, Kasahara and Shimotsu (2017) extended this framework by offering solutions tailored to dynamic programming models. Building on these advancements, Ou and Zhuo (2020) refined likelihood-ratio-based tests for detecting regime shifts, offering improved asymptotic distributions and greater effectiveness in econometric

applications. These studies, particularly those that build on Hamilton's (1989) foundational work on regime-switching models, aim to fill critical methodological gaps in the literature.

Most standard procedures, including those focusing on the likelihood ratio test (LRT), are limited to scenarios where the null hypothesis assumes a linear model $H_0: M_0 = 1$ and the alternative hypothesis is a two-regime Markov switching model $H_0: M_0 + m = 2$, where $M_0 = m = 1$. An exception to this is the work of Kasahara and Shimotsu (2018), who established the asymptotic validity of the parametric bootstrap procedure for the LRT when the null hypothesis involves a model with M_0 regimes, and the alternative hypothesis involves $M_0 + 1$ regimes ($M_0 \geq 1$ and $m = 1$). However, their results apply to a limited class of models and rely on restrictive assumptions. Qu and Zhuo (2021) proposed the SupLR($\Delta \in$) test. They demonstrated the asymptotic validity of the parametric bootstrap for broader models, but still within the framework of $M_0 = m = 1$, and their approach also depends on restrictive assumptions. Other researchers, such as Carrasco, Hu, and Ploberger (2014), Antoine et al. (2023), and Dufour and Luger (2017), have proposed alternative approaches that rely on different methodologies (Antoine et al., 2023; Carrasco et al., 2014). For instance, Carrasco, Hu, and Ploberger (2014) introduced an optimal test for assessing parameter stability in random-coefficient and Markov switching models, but it is best suited for cases where the null hypothesis assumes a linear model and the alternative is a two-regime model. This limitation arises because their parameter stability test is only asymptotically valid and cannot compare general Markov switching models with $M_0, M > 1$. On the other hand, Dufour and Luger (2017) introduced a moment-based approach using "Monte Carlo" techniques that relaxes many restrictive assumptions, such as stationarity and Gaussian errors. They developed test statistics based on the moments of least-squares residuals to capture characteristics of a two-component mixture distribution. While their method is valid for finite samples and avoids many of the issues faced by asymptotic approaches, it remains applicable only to cases where $M_0 = m = 1$. Overall, existing LRT approaches and related methods tend to rely on restrictive assumptions and are often limited in scope, highlighting the need for more flexible and robust testing procedures.

This paper builds on the "Monte Carlo" procedures described by Dufour (2006). It applies them to a likelihood-ratio test framework for Markov switching models, addressing key challenges such as nonstandard asymptotic distributions and nuisance parameters. The proposed tests, namely the "Local Monte Carlo Likelihood Ratio Test (LMC-LRT)" and the "Maximised Monte Carlo Likelihood Ratio Test (MMC-LRT)," enable the determination of the number of regimes in both Markov switching and Hidden Markov Models. These tests are applicable in general settings where models with M_0 regimes under the null hypothesis are compared to models with $M_0 + m$ and regimes under the alternative, for $M_0 \geq 1$ and $m \geq 1$. The MMC-LRT is an exact test valid in finite samples and asymptotically, and it is robust to identification issues common in Markov switching models. Notably, these tests eliminate the need for standard assumptions such as stationarity, Gaussian errors, or constrained parameter spaces, making them applicable to more complex scenarios, including multivariate settings, such as Markov switching VAR models and multivariate Hidden

Markov models, which are rarely addressed in the prior literature. Furthermore, the tests do not rely on asymptotic distribution, allowing their application in cases where previous test procedures, including the parametric bootstrap, are not asymptotically valid or lack established asymptotic results. This study provides novel insights into non-standard cases such as non-stationary processes, non-Gaussian errors, multivariate setups, and scenarios with $m > 1$, which have received limited attention in the literature on regime determination. Simulation results demonstrate that the LMC-LRT and MMC-LRT effectively control the test size and achieve better power than alternative methods, particularly when $M_0 = m = 1$. Additionally, the paper applies the test proposed by Dufour and Luger (2017) to non-stationary processes (y_t), offering new insights in this context. All test implementations are carried out using the R package MStest, detailed in the companion paper by Rodriguez-Rondon and Dufour (2024). While the primary focus of this study is on Markov switching models due to their generality, the proposed tests are equally applicable to Hidden Markov Models, further broadening their utility.

In addition to methodological contributions, several country-specific applications highlight the practical use of regime-switching models. For example, Chauvet (1998) applied Markov-switching models to U.S. business cycles and successfully identified recessionary and expansionary periods. Krolzig (1997) investigated regime dynamics in European economies, focusing on Germany and the United Kingdom, and demonstrated that MS-VAR models effectively capture shifts in monetary and business cycles. Kim and Halbert (1999) analysed U.S. GDP and unemployment and showed that regime-switching models improve forecasting accuracy during recessions. Similarly, Clements and Krolzig (2003) examined business-cycle asymmetries across OECD countries and found strong evidence of nonlinear dynamics. For emerging markets, Abiad (2003) used regime-switching techniques to study financial liberalisation episodes in developing economies, while Cerra and Saxena (2005) applied the approach to Asian economies, linking regime shifts to financial crises.

These international examples demonstrate that Markov switching models are not only relevant for developed economies but also highly applicable to emerging markets, where structural breaks and external shocks are more frequent. However, empirical applications in Türkiye remain relatively scarce, thereby enhancing the originality and contribution of this study.

In the next section, the methodological approach for the Markov switching model will be explained, followed by the application of the "Local Monte Carlo Likelihood Ratio Test (LMC-LRT)" and the "Maximised Monte Carlo Likelihood Ratio Test (MMC-LRT)", proposed by Rodriguez-Rondon and Dufour (2024), to Türkiye's GDP data.

3. Methodology for Markov Switching Model

A Markov switching model is a process in which the dependent variable y_t depends on its own lags and is influenced by both regime-independent variables (x_t) and regime-

dependent variables z_t , as determined by a latent Markov process S_t . The general model can be expressed as:

$$y_t = x_t \beta + z_t \delta_{s_t} + \sigma_{s_t} \varepsilon_t \quad (1)$$

where y_t is either a scalar or a vector, x_t includes regressors with constant coefficients, z_t includes regressors whose coefficients depend on s_t , and ε_t is the error process. The number of regressors is defined by $q = (q_y \times p) + q_w$, where $q_y = 1$ for univariate settings or $q_y > 1$ for multivariate settings, p is the number of lags, and q_w is the number of exogenous regressors. In multivariate settings, the covariance matrix Σ_s replaces the scalar variance σ_{s_t} , and vectorisation operators [$\text{vec}()$, $\text{vech}()$] are applied to matrix-valued parameters.

The latent Markov process S_t is governed by a transition matrix P , where each element $p_{ij} = \Pr(S_t = j \mid S_{t-1} = i)$ represents the probability of transitioning from regime i to regime j . The columns of P must sum to one:

$$\sum_{j=1}^M p_{ij} = 1, \quad \forall i \quad (2)$$

Ergodic probabilities, which represent the long-run or steady-state distribution of time spent in each regime, are calculated using the following equation:

$$\pi = (A'A)^{-1}A'e_{M+1}, \quad A = [I_M - P] \quad (3)$$

where ε_{M+1} is the $(M + 1)$ th column of I_{M+1} . The conditional density of y_t given past information Y_{t-1} is expressed as:

$$f(y_t \mid Y_{t-1}; \theta) = \sum_{s_t=1}^M \sum_{s_{t-1}=1}^M \dots \sum_{s_{t-p}=1}^M f(y_t, s_t = s_t, \dots, s_{t-p} = s_{t-p} \mid Y_{t-1}; \theta) \quad (4)$$

where the joint density of y_t and the latent states is:

$$f(y_t, s_t = s_t, \dots, s_{t-p} = s_{t-p} \mid Y_{t-1}; \theta) = \Pr(S_t^* = s_t^* \mid Y_{t-1}; \theta) \frac{1}{\sqrt{2\pi\sigma_{s_t}^2}} \exp\left(-\frac{[y_t - x_t\beta - z_t\delta_{s_t}]^2}{2\sigma_{s_t}^2}\right) \quad (5)$$

and $\Pr(S_t^* = s_t^* \mid Y_{t-1}; \theta) \Pr(S_t^* = s_t^* \mid Y_{t-1}; \theta)$ is the probability of the latent state sequence S_t^* . The sample log-likelihood conditional on the first p observations is:

$$L_T(\theta) = \sum_{t=1}^T \log f(y_t \mid Y_{t-1}; \theta) \quad (6)$$

where θ encompasses all parameters:

$$\theta = (\beta, \delta_1, \dots, \delta_M, \sigma_1, \dots, \sigma_M, \text{vec}(P)) \quad (7)$$

For multivariate models, $\text{vec}(\cdot)$ and $\text{vech}(\cdot)$ are applied to β , δ_{s_t} , and Σ_{s_t} .

Markov switching models differ from Hidden Markov Models, where the latter excludes lags of and simplifies interactions between y_t and S_t . Estimation typically uses the Expectation- Maximization (EM) algorithm, Bayesian methods, or the Kalman filter. While Maximum Likelihood Estimation (MLE) can be used in simple cases ($M = 2$), challenges like multimodal likelihoods limit its application. A two-step estimation procedure, combining EM results as initial values for Newton-type optimisation, improves empirical estimates. This study focuses on Markov switching models but extends hypothesis testing to Hidden Markov Models, accommodating diverse applications (Rodriguez-Rondon & Dufour, 2024). In the following process, Rodriguez-Rondon and Dufour (2024) introduce the “Maximised Monte Carlo Likelihood Ratio Test (MMC-LRT)” and the “Local Monte Carlo Likelihood Ratio Test (LMC-LRT)” for Markov switching models, building on methods by Garcia (1998), Qu and Zhuo (2021), and Kasahara and Shimotsu (2018). These tests address cases in which the null distribution depends only on nuisance parameters and eliminate restrictive assumptions, such as stationarity or constrained parameter spaces. The log-likelihood for models with $M > 1$ regimes is expressed as:

$$L_T(\theta_i) = \sum_{t=1}^T \log f(y_t | Y_{t-1}; \theta_i) \quad (8)$$

where $\theta_i = (\beta, \delta_1, \dots, \delta_M, \sigma_1, \dots, \sigma_M, \text{vec}(P)) \in \bar{\Omega}_i$. Under the null hypothesis $M = 1$, the log- likelihood simplifies to:

$$L_T(\theta_0) = \sum_{t=1}^T \log f(y_t | Y_{t-1}; \theta_0) \quad (9)$$

with:

$$f(y_t | Y_{t-1}; \theta_0) = \frac{1}{\sqrt{2\pi\sigma_{s_t}^2}} \exp\left(-\frac{[y_t - x_t\beta - z_t\delta_{s_t}]^2}{2\sigma_{s_t}^2}\right) \quad (10)$$

and $\theta_0 = (\beta, \sigma) \in \bar{\Omega}_0$. These formulations allow comparison between a null hypothesis (H_0) with $M_0 = 1$ regime and an alternative hypothesis (H_1) $M_0 + m = 2$ regimes, as: $H_0: \delta_1 = \delta_2 = \delta$, $H_1: (\delta_1, \delta_2) = (S_1^*, S_2^*)$, $S_1^* \neq S_2^*$.

The likelihood ratio statistic is:

$$LRT = 2 \left[\sup_{\theta_1 \in \bar{\Omega}_1} L_T(\theta_1) - \sup_{\theta_0 \in \bar{\Omega}_0} L_T(\theta_0) \right] \quad (11)$$

“Monte Carlo” simulations generate N independent replications of LRT to compute the p-value:

$$p_N[x|\theta_0] = \frac{NG_N[x|\theta_0] + 1}{N + 1} \quad (12)$$

The MMC-LRT maximises this p-value over the nuisance parameter space, while the LMC- LRT focuses on a local consistent estimate (θ_0):

$$C_T = \{\theta_0 \in \overline{\Omega_0}: \left| \widehat{\theta}_0 - \theta_0 \right| < c\} \quad (13)$$

In both cases, the procedures are valid even without asymptotic distributions, extending to multivariate, nonstationary, and non-Gaussian environments. These features make MMC-LRT and LMC-LRT more general than parametric bootstrap methods, as they efficiently handle scenarios where $m > 1$, transition probabilities are on the boundary, or regressors are weakly exogenous. Overall, these tests ensure finite-sample validity with fewer simulations, offering robust, computationally efficient solutions for hypothesis testing in Markov switching models.

4. Application to MMC-LRT and LMC-LRT for Markov Switching Model with Türkiye's GDP Data

In this section of the study, quarterly data from the first quarter of 1998 to the second quarter of 2024 were obtained from the Turkish Statistical Institute (TÜİK) to apply the "Monte Carlo Moment-Based Test" and the "Local Monte Carlo Likelihood Ratio Test (LMCLRT)" within the context of the Markov Switching model. The dataset consists of quarterly nominal GDP series for Türkiye obtained from TÜİK. The series was first seasonally adjusted and then transformed into first differences to achieve stationarity, as confirmed by ADF and KPSS tests. The starting point of 1998 is determined by data availability, as consistent and comparable quarterly GDP series are accessible from this period onward. Although Türkiye experienced major macroeconomic challenges in the early 1990s, including the 1994 crisis, the post-1998 period provides a reliable framework for analysis. It ensures methodological consistency for the application of Monte Carlo-based Markov Switching tests. Subsequently, stationarity tests were conducted using the KPSS and ADF tests.

In macroeconomic time series such as GDP, the distinction between deterministic and stochastic components is crucial for interpreting structural dynamics. A series that becomes stationary after differencing (difference-stationary) typically implies the existence of deterministic components alongside stochastic shocks. This distinction is important because structural breaks in such series may reflect either transitory shocks or more permanent regime shifts. Consequently, the interpretation of results may vary depending on whether shocks are temporary or persistent. Recent studies in the Turkish context, such as Tanrıöver and Yamak (2022), emphasise the importance of identifying the persistence of economic shocks using cumulative impulse-response functions. In line with this literature, the present study acknowledges that decomposing GDP into its deterministic and stochastic components is critical and that structural breaks can capture both transitory adjustments and permanent shifts in the economy. This provides a strong justification for applying Monte Carlo-based Markov Switching tests, which are designed to detect such regime changes flexibly.

The concept of structural breaks has been a central issue in time series econometrics since the seminal contribution of Perron (1989), who demonstrated that ignoring break

points in macroeconomic data can lead to spurious unit root results and misleading inferences. Subsequent studies, particularly those of Bai and Perron (1998, 2003), advanced the field by proposing econometric tests for detecting multiple structural breaks at unknown time points. These frameworks emphasise that structural changes often arise from crises, major policy reforms, or external shocks that alter the underlying data-generating process. While such methods provide valuable tools for understanding shifts in economic dynamics, they are generally based on asymptotic approximations and restrictive assumptions. In contrast, this study highlights a more recent line of research that employs Monte Carlo-based Markov Switching tests, offering exact inference and greater robustness in the presence of nonlinearities and regime shifts.

Although additional tests, such as Jarque-Bera or distributional moments (skewness, kurtosis), could be reported, the primary focus of this study is not on validating distributional assumptions but on modelling regime shifts. Markov Switching models are specifically designed to handle deviations from normality and nonlinear dynamics. For this reason, we limited the preliminary analysis to stationarity tests (ADF and KPSS), which are directly relevant for time series modelling and sufficient for applying regime-switching methods.

Table: 1
ADF Test Results

Variable	ADF	Critical Value(%1)	Critical Value(%5)	Critical Value (10%)	p-value	Lag Lenght	Result
log_gsyih_diff_series	-4.6198	-3.43	-2.86	-2.57	0.01	4	Stationary

The Augmented Dickey-Fuller (ADF) test was applied to the log-differenced time series (log_gsyih_diff_series) to assess its stationarity. The test statistic was found to be -4.6198, which is lower than the critical values at the 1% (-3.43), 5% (-2.86), and 10% (-2.57) significance levels. This indicates strong evidence against the null hypothesis of non-stationarity. Additionally, the p-value for the test was 0.01, further supporting the rejection of the null hypothesis at conventional significance levels. The test employed a lag order of 4 to account for potential autocorrelation in the data. Given that the test statistic is significantly below the critical thresholds and the p-value is well below 0.05, the log-differenced series can be confidently classified as stationary. This result suggests that the transformation and differencing applied to the original data were effective in stabilising the mean and removing non-stationary trends, making the series suitable for subsequent time series modelling and analysis.

Table: 2
KPSS Test Results

Variable	Test-Statistic	Critical Value	Lag	Result
log_gsyih_diff_series	0.4372	10%: 0.347, 5%: 0.463, 2.5%: 0.574, 1%: 0.739	1	Non-stationary (at 5%) Stationary(at%10)

The KPSS and ADF tests provide complementary insights into the stationarity of the log- differenced series (log_gsyih_diff_series). From the KPSS test, the test statistic (0.43720) exceeds the 5% critical value (0.4630), leading to rejection of the null hypothesis

of stationarity at this level. However, at the 10% significance level (0.3470), the test statistic does not exceed the critical value, implying that the null hypothesis cannot be rejected. This suggests that the series can be considered stationary at a less strict 10% significance level but shows marginal evidence of non-stationarity at stricter levels (e.g., 5%).

On the other hand, the Augmented Dickey-Fuller (ADF) test strongly supports the hypothesis of stationarity. The test statistic (-4.6198) is significantly lower than the critical values at all levels (1%: -3.43 , 5%: -2.86 , and 10%: -2.57), with a p -value of 0.01. This result indicates convincing evidence against the null hypothesis of non-stationarity and supports the alternative hypothesis of stationarity.

By integrating the results of both tests, the log-differenced series can be concluded to be stationary, particularly given the stronger statistical evidence from the ADF test. While the KPSS test hints at marginal non-stationarity at the 5% level, its stationarity at the 10% level aligns with the ADF test’s findings. Therefore, the series is deemed suitable for further analysis and modelling under the assumption of stationarity.

Table: 3
Summary of Results

<i>Model/Test</i>	<i>Log-Likelihood</i>	<i>AIC</i>	<i>BIC</i>	<i>Key Coefficients</i>	<i>p-value</i>
<i>AR Model</i>	217.0239	- 428.0478	- 420.1146	$\mu=0.0112, \phi1=-0.1707, \sigma=0.0009$	N/A
<i>MSAR Model</i>	242.9951	- 467.9902	- 444.1907	$\mu1=-0.0049, \mu2=0.0160, \sigma1=0.0029, \sigma2=0.0002$	N/A
<i>Monte Carlo Test</i>	N/A	N/A	N/A	LMC min: $p=0.01$, MMC min: $p=0.01$	$p<0.05$
<i>LMC-LRT</i>	N/A	N/A	N/A	$p<0.05$ indicates rejection of the null hypothesis	$p<0.05$

The results of the AR model, the Markov Switching AR (MSAR) model, the “Monte Carlo Moment-Based Test,” and the “Local Monte Carlo Likelihood Ratio Test (LMC-LRT)” reveal significant insights into the dynamics of the data. While the AR model provides a baseline fit with moderate autoregressive behaviour ($\phi1=-0.1707$), the MSAR model significantly improves model performance with distinct regimes ($\mu1=-0.0049$, $\mu2=0.0160$) and variances ($\sigma1=0.0029, \sigma2=0.0002$), as evidenced by higher log-likelihood and lower AIC/BIC values. Both the “Monte Carlo Moment-Based Test” and “LMC-LRT” strongly reject the null hypothesis of no regime-switching ($p<0.05$), confirming the presence of structural changes and the superiority of the MSAR model over the single-regime AR model. These findings align with Rodriguez-Rondon and Dufour (2024), emphasising the robustness of Monte Carlo-based approaches to handling non-standard asymptotic distributions and nuisance parameters, thereby validating the regime-switching framework as a powerful tool for analysing economic time-series data.

5. Conclusion

“The Monte Carlo Moment-Based Test” and the “Local Monte Carlo Likelihood Ratio Test (LMC-LRT)” strongly rejected the null hypothesis of no regime-switching ($p<0.05$), confirming the presence of structural breaks in Türkiye’s GDP dynamics. These results align with theoretical expectations, as Monte Carlo-based tests are particularly robust

against issues of non-standard asymptotic distributions and nuisance parameters. These challenges are prevalent in regime-switching analyses.

From a practical perspective, the findings emphasise the importance of using advanced methodologies, such as Monte Carlo-based testing, to analyse economic indicators such as GDP. The MSAR model's significant structural changes identified in Türkiye's GDP dynamics provide policymakers with valuable insights, indicating distinct economic periods that may require tailored policy responses.

In conclusion, the results substantiate the theoretical contributions of Rodriguez-Rondon and Dufour (2024) and demonstrate the effectiveness of Monte Carlo-based approaches for identifying and validating regime-switching behaviour. The application to Türkiye's GDP data further highlights the practical utility of these methods in real-world economic contexts, providing a robust framework for analysing time series with structural changes and enhancing the understanding of economic dynamics over time.

6. Discussion

The application of Markov Switching models and Monte Carlo-based testing to Türkiye's GDP data from 1998Q1 to 2024Q2 yields important insights into the economy's structural dynamics. The significant improvements in model performance when moving from a baseline Autoregressive (AR) to a Markov Switching Autoregressive (MSAR) model underscore the need to capture regime-switching behaviour in economic time series. The MSAR model's ability to identify two distinct regimes, characterised by differing means ($\mu_1=-0.0049$, $\mu_2=0.0160$) and variances ($\sigma_1=0.0029$, $\sigma_2=0.0002$), indicates periods of contrasting economic stability and growth, which may correspond to broader macroeconomic shifts, such as financial crises or periods of rapid expansion.

"The Monte Carlo Moment-Based Test" and the "Local Monte Carlo Likelihood Ratio Test (LMC-LRT)" played pivotal roles in validating these structural changes, rejecting the null hypothesis of no regime-switching at $p<0.05$. This demonstrates the robustness of these methods, particularly in scenarios where traditional asymptotic assumptions are violated. By addressing nuisance parameters and non-standard distributions, Monte Carlo-based tests provide a reliable framework for identifying regime changes in complex economic environments.

The findings highlight the practical implications for policymakers and researchers. The distinct regimes identified in Türkiye's GDP dynamics could reflect responses to external shocks, policy interventions, or structural reforms. For policymakers, understanding these shifts is crucial for designing targeted interventions that address the unique challenges of each regime. For researchers, the study underscores the importance of incorporating regime-switching models and robust testing methodologies when analysing economic time series. The empirical analysis reveals that Türkiye's GDP series exhibits distinct regime shifts corresponding to major crises and recovery periods. By applying Monte Carlo-based

Markov Switching tests, these shifts can be identified more reliably than with traditional methods, as the approach provides exact inference and is robust to small sample and identification problems. This methodological innovation has important policy implications. First, it enhances policymakers' ability to detect turning points in real time, thereby strengthening early-warning mechanisms against economic downturns. Second, it allows fiscal and monetary authorities to design countercyclical measures that are better aligned with actual regime changes rather than relying on linear projections that may overlook nonlinear dynamics. Finally, this approach improves the accuracy of macroeconomic forecasting models, which is essential for evidence-based policymaking in emerging markets such as Türkiye.

From a theoretical perspective, the results align with the contributions of Rodriguez-Rondon and Dufour (2024), reinforcing the relevance of Monte Carlo-based approaches in regime-switching analyses. The application demonstrates how these methods extend beyond theoretical models to practical, real-world economic data, enabling a deeper understanding of underlying structural dynamics.

In summary, this discussion emphasises the value of combining Markov Switching models with Monte Carlo-based tests to uncover and validate structural changes in economic time series. The results not only provide insights into Türkiye's economic dynamics but also offer a replicable methodology for analysing similar data in other contexts, enhancing the analytical toolkit available to economists and policymakers.

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The Neoliberal Restructuring of Turkish Agriculture: An Analysis of State Forms and Class Power through the Lens of Historical-Political Economy, 1960-Present

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Türkiye Tarımının Neoliberal Yeniden Yapılandırılması: Devlet Bıçimleri, Sınıf İktidarı ve Tarihsel-Siyasal İktisat Merceğinden Bir Çözümleme, 1960'tan Günümüze

Abstract

This article offers a historically grounded and theoretically rigorous political economy analysis of Türkiye's agrarian transformation from 1960 to the present, framing agriculture not as a residual economic subsector but as a strategically contested terrain where class power, state forms, and internationally articulated capital intersect. It argues that the persistent crises of Turkish agriculture can only be understood by unpacking the successive regimes of accumulation and the evolving configurations of state power that have serially rearticulated the sector to the global circuits of capital. Agricultural policy, far from being a neutral technocratic instrument, has functioned as a site of class struggle, wherein the state, as the collective organiser of the ruling bloc (first the industrial bourgeoisie, later finance capital), mediated the extraction and redistribution of agrarian surplus in accordance with the imperatives of accumulation. The study highlights how the internationalisation of domestic capital since the 1980s, together with the prescriptions of international financial institutions tasked with reproducing global capital on a world scale, catalysed a paradigmatic shift: dismantling protectionist frameworks, eroding smallholder viability, and re-engineering agrarian production along neoliberal lines. The cumulative outcome has been the far-reaching deconstruction of Türkiye's agrarian economy, transforming its socio-economic role, hollowing out food sovereignty, and binding rural production ever more tightly to volatile, crisis-prone global markets.

Keywords : Agriculture, Financial Bourgeoisie, Import Substitution, Industrial Bourgeoisie, Neoliberalism, Structural Adjustment.

JEL Classification Codes : Q1, Q10, Q17, Q18.

Öz

Bu makale, Türkiye'nin 1960'tan günümüze uzanan tarımsal dönüşümünü tarihsel olarak temellendirilmiş ve kuramsal yoğunluğu yüksek bir siyasal iktisat okumasıyla ele almakta; tarımı yalnızca iktisadi bir alt sektör olarak değil, sınıf iktidarı, devlet bıçimleri ve uluslararası sermaye ilişkilerinin kesiştiği stratejik bir mücadele alanı olarak kavramsallaştırmaktadır. Makale, Türkiye tarımındaki süregelen krizlerin, birbiri ardına değişen birikim rejimleri ve bu rejimlere paralel olarak yeniden yapılandırılan devlet bıçimleri incelenmeden anlaşılamayacağını ileri sürmektedir. Tarım politikası -teknokratik ve nötr bir araç olmaktan ziyade- bir sınıf mücadelesi alanı olarak işlev görmüş; devlet, egemen blokun (önce sanayi burjuvazisi, ardından finans kapital) kolektif örgütleyicisi olarak, tarımsal artığın sermaye birikimi lehine tahsisini ve yönlendirilmesini sağlamıştır. Çalışma, 1980'lerden itibaren ülke sermayesinin uluslararasılaşmış sermaye ile kurduğu ilişkilerin ve küresel sermayenin yeniden üretim koşullarını sağlamayı görev edinen uluslararası finans kuruluşlarının

telkinlerinin, korumacı kurumsal yapıları tasfiye eden, küçük üreticinin direncini zayıflatan ve tarımsal üretimi neoliberal hatlar boyunca yeniden tasarlayan bir dönüşümü tetiklediğini göstermektedir. Sonuçta, Türkiye tarım ekonomisi derin bir yapısököme uğramış; toplumsal-ekonomik işlevi dönüşmüş, gıda egemenliği aşınmış ve kırsal üretim giderek daha kırılgan hâle gelmiş, krizlere açık küresel birikim döngülerine sıkıca eklenmiştir.

Anahtar Sözcükler : Finans Burjuvazisi, İthal İkamesi, Neoliberalizm, Sanayi Burjuvazisi, Tarım, Yapısal Uyum.

1. Introduction

Agriculture has long served as a strategic battleground in the political economy of development. In this arena, food security, capital accumulation, and the reproduction of social relations intersect under historically specific configurations of state power and class rule. Far from being a static or purely "technical" sector, its role has been historically contingent, continually redefined by state-led development projects, international institutional conditionalities, and shifting hierarchies within the global division of labour. This article advances a critical historical-political economy reading of Türkiye's agrarian transformation from 1960 to the present, conceptualising agriculture as a contested terrain in which successive state forms, ruling-class coalitions, and transnational capital have interacted to produce shifting regimes of accumulation and profoundly uneven outcomes. It contends that the persistent crises of Turkish agriculture cannot be understood apart from the historical reconfiguration of the state apparatus that has progressively subordinated agrarian production to global market imperatives.

The first analytic move traces the transition from an accumulation regime rooted in agrarian capitalism in the 1950s to the consolidation of industrial capitalism in the 1960s, a moment when the industrial bourgeoisie emerged as the hegemonic fraction within the ruling bloc. Import-substitution industrialisation (ISI), the dominant strategy between 1960 and 1980, was designed to privilege industrial accumulation, relegating agriculture to the role of residual supplier of cheap food and labour and transforming it into a mechanism for the extraction of surplus to be channelled into industrial investment.

The second analytical step explores the neoliberal rupture inaugurated by the January 24th Decisions of 1980, which institutionalised the project of market liberalisation under conditions of authoritarian stabilisation. These reforms dismantled price supports, curtailed input subsidies, privatised state-owned enterprises, and integrated the agrarian sector into global circuits of competition and volatility. Under the Motherland Party (ANAP) government led by Turgut Özal, the state was reconstituted as the administrative apparatus of the bourgeoisie, aligning agrarian policy with the strategic imperatives of big capital, epitomised by TÜSİAD, and with the conditionalities of IMF stand-by agreements and World Bank structural adjustment programs.

The 1989 Decree No. 32 marked a decisive moment, accelerating financial liberalisation, embedding financialised capitalism, and recalibrating state priorities toward the interests of rentier and finance capital, a trajectory culminating in the 1994 crisis. The April 5th Decisions and the 1995 Customs Union Agreement further entrenched this orientation, eroding the protective mechanisms of the ISI era and rendering agriculture increasingly vulnerable to international price shocks and speculative flows.

The post-2000 period constitutes the most decisive stage in the neoliberal restructuring of Turkish agriculture. The IMF stand-by agreement of 1999, the World Bank-backed Agricultural Reform Implementation Project of 2001, and the Transition to a Strong Economy Program under Kemal Derviş marked the consolidation of a new regulatory state form designed to create and maintain the institutional architecture required for capital accumulation under neoliberal globalisation. In this phase, agrarian policy became sharply aligned with the imperatives of transnational capital, leading to a structural erosion of agricultural self-sufficiency and rendering Türkiye increasingly dependent on imports for key staples despite maintaining an overall net exporter position in aggregate trade balances (see Ministry of Trade, 2023: 8). This paradox underscores a deeper process of de-agrarianization, in which domestic production has become insufficient for certain strategic crops, thereby highlighting structural vulnerabilities. Recent global events, including the COVID-19 pandemic and the Russia-Ukraine war, have heightened Türkiye's agricultural sector's exposure to global market fluctuations, further underscoring the fragility of food sovereignty and the risks of subordinating agrarian production to volatile international conditions.

This article's contribution is twofold. First, it offers a historically grounded and theoretically rigorous account of Türkiye's agrarian transformation, tracing its trajectory across successive regimes of accumulation, agrarian, industrial, and financial, while foregrounding the state as the central apparatus through which class power is exercised. Second, it addresses a major lacuna in the literature by re-centring agrarian questions within political economy analysis, demonstrating how neoliberal restructuring systematically dismantled agrarian self-sufficiency, deepened class polarisation, and transformed rural production into a vehicle for global capital accumulation. In doing so, it illuminates the constellation of state strategies, class dynamics, and international pressures that have produced Türkiye's contemporary agrarian crisis and contributes to wider debates on development, dependency, and the future of food sovereignty.

The article proceeds as follows: Section 1 examines the institutionalisation of ISI between 1960 and 1980 and its implications for agrarian surplus extraction and class realignments. Section 2 analyses the neoliberal turn inaugurated by the January 24th Decisions and consolidated under ANAP, situating it within the global rise of the New Right and the IMF-World Bank stabilisation agenda. Section 3 traces the post-1989 financial liberalisation process, the 1994 crisis, and the April 5th Decisions, focusing on their effects on the agrarian sector. Section 4 explores the post-2000 transformation under the Transition to a Strong Economy Program and the legislative reforms that entrenched de-agrarianization.

Section 5 assesses the compounded effects of the COVID-19 pandemic and the Russia-Ukraine war on an already fragile agrarian structure. The conclusion synthesises these findings, reconceptualises the state-agriculture nexus, and calls for a paradigm shift toward ecologically grounded, socially just agricultural policies.

2. Breaking the Agrarian Mould: Class Realignments, State Forms, and the Industrial Turn in Turkish Development

The 1960s marked a critical conjuncture in the Turkish economy, representing the transition from an agrarian to an industrial capitalist accumulation regime, the ascendancy of import-substitution industrialisation (ISI), and the concomitant rise of the industrial bourgeoisie as a hegemonic class fraction. These structural shifts inevitably reconfigured agriculture and the institutional architecture of agrarian policy. Any attempt to analyse the agricultural policies of this decade must therefore be situated within the broader global order forged in the aftermath of the Second World War and the agrarian strategies promoted under that order.

The transition to multi-party politics after 1945 fundamentally altered the balance of power between the state and society, granting agricultural producers, who constituted a large share of the electorate, substantial political leverage. The electoral victory of the Democrat Party in 1950 ushered in a new era of rural-oriented governance, marked by policy frameworks more responsive to peasant demands and institutional transformations aligned with this orientation (Pamuk, 2008: 390). The shift from statism to a market-oriented economy was accompanied by foreign aid flows, most notably Marshall Aid, which financed agricultural expansion. This was not merely a policy preference but a structural imposition: the conditionalities of foreign assistance, as articulated in the Thornburg and Barker Reports, explicitly subordinated industrialisation to agricultural development, leaving the latter as the primary engine of accumulation. Consequently, Türkiye's development model of the 1950s became predominantly agrarian in character (Oktar & Varlı, 2010: 17). The onset of the Korean War in 1950 further amplified this trajectory, boosting global prices for agricultural commodities and raw materials, while the rapid mechanisation of Turkish agriculture, evidenced by the surge in tractors and other inputs, precipitated dramatic increases in output¹.

Agriculture constituted the central axis of the Democratic Party's (DP) economic and political discourse between 1950 and 1960, embedding Türkiye's development model within an international system of power and dependency organised around agrarian production. Yet by the late 1950s, deepening macroeconomic imbalances and political turmoil, combined with shifts in the global division of labour, generated the structural and institutional

¹ *An examination of mechanisation during the Democrat Party era reveals a dramatic surge in the number of tractors: from just 220 in 1924 to 2,000 in 1930, 1,756 in 1948, 9,905 in 1950, and an extraordinary 43,727 by 1956. This rapid mechanisation was accompanied by a massive expansion of cultivated land, which grew from 9.5 million hectares in 1948 to 14.6 million hectares in 1956, an increase of nearly 50%, underscoring the scale of the agricultural transformation in this period (Tetik, 2023: 125).*

preconditions for a transition toward an import-substitution industrialisation (ISI) strategy. The military coup of May 27, 1960, which removed the DP from power, the execution of Prime Minister Adnan Menderes, and the promulgation of the 1961 Constitution collectively created the legal and political framework for this strategic reorientation. Within this new context, Türkiye's integration into the capitalist world economy was reconfigured through the establishment of assembly industries and the development of close trade linkages with the United States, inaugurating an accumulation regime premised on import-substitution industrialisation throughout the 1960s² (Akçay & Türel, 2022). A defining characteristic of import-substitution strategies is their orientation toward the domestic market, that is, toward the scale and institutional boundaries of the nation-state (Balassa, 1983: 429-447). Import-substitution industrialisation (ISI) is commonly defined as a development strategy that fosters the domestic production of goods previously imported, thereby reducing external dependency and nurturing an indigenous industrial base.

While the 1950-1960 period was dominated by policies privileging the agricultural sector and the interests of the agrarian bourgeoisie, the post-1960 era marked a decisive shift toward privileging the industrial sector and the emergent industrial bourgeoisie. This reorientation reflected the consolidation of a new class fraction whose economic and political weight grew in this period, compelling the state to recalibrate its economic policies in line with the imperatives of industrial accumulation. The first analytical conclusion to be drawn is that the class composition underpinning the liberal, agriculture-centred policies of the 1950s differed significantly from that which drove the ISI strategy under the new post-1960 conditions.

From this perspective, it is not surprising that the state formulates economic policy in ways that reflect the interests of the dominant class coalition. As Poulantzas (1978: 239) theorises, "The power bloc constitutes a contradictory unity of the ruling classes or factions directed by the hegemonic class or faction". This conceptualisation highlights the structural necessity of the capitalist state, which, in Poulantzas's (1980) formulation, is primarily tasked with reproducing the conditions under which labour is subordinated to capital, thereby crafting policy instruments that safeguard the interests of the ruling classes that form the power bloc. It is important to note, however, that this represents Poulantzas's analytical perspective rather than a universally accepted or empirical definition of the capitalist state. Alternative approaches in the literature, such as those emphasising the relative autonomy of state institutions from specific class interests (Jessop, 2008; Skocpol, 1985), provide a

² *The global intellectual climate of the early 1960s significantly shaped Türkiye's development discourse, aligning it with theoretical currents emphasising state-led growth. In his seminal work, Gerschenkron (1962) famously posited that the later a country embarks on the path of industrialisation, the less it can rely on spontaneous market forces, and the more indispensable state intervention becomes to initiate and accelerate economic transformation. The historical experiences of late-industrialising countries such as Germany and France confirmed this argument: industrial take-off was achieved not through laissez-faire, but through deliberate and coordinated state action. Similarly, in East Asian late developers Japan, Taiwan, and South Korea, the decisive role of the state in orchestrating industrialisation has been demonstrated beyond dispute (Shapiro & Taylor, 1990).*

counterpoint by arguing that the state can occasionally act to mediate between competing social forces or pursue broader policy objectives beyond immediate class imperatives. Seen through the lens of these debates, Türkiye's post-1960 development model can be understood as a historically specific configuration in which the state both mediated among competing class interests and contributed to the long-term reproduction of capitalist accumulation, while retaining a degree of relative autonomy that permitted the selective incorporation of diverse social and economic objectives.

3. In the Shadow of Industry: Class Realignments, State Power, and the Making of a Neoliberal Agrarian Order in Türkiye, 1960-1980

After the May 27, 1960, coup d'état, planned development formally began with the First Five-Year Development Plan of 1963, which institutionalised the import-substitution industrialisation strategy (DPT, 1963). The Plan outlined objectives, basic policies, production, and investment targets across sectors, including agriculture, aiming to increase industrial inputs while simultaneously expanding agricultural production to support exports (DPT, 1963: 147-148). Within this framework, the Plan highlighted agricultural reform not merely through land reform, which remained largely absent from the policy agenda (Barbaros & Yildirim, 2013: 89-90; Yerasimos, 1980: 765) but via targeted measures to strengthen the sector, such as supporting agricultural cooperatives, subsidizing select agricultural products, maintaining low-interest loans, and providing price supports for inputs that enhance soil fertility.

The Plan also facilitated the establishment and expansion of public institutions to support agriculture, including the Meat and Milk Board, Dairy Industry Corporation, Feed and Fertiliser Industries, State Production Farms, and agricultural credit cooperatives, alongside Ziraat Bank's increased lending to farmers and agricultural sales cooperatives (DPT, 1963: 147-148). These initiatives reflect a developmental logic in which the agricultural sector was actively supported rather than relegated to a residual or passive supplier role³. Consequently, attributing the emergence of the industrial bourgeoisie as a dominant fraction solely to the Plan's production and investment targets in agriculture or agricultural exports is methodologically unsound. Instead, the evidence indicates that agricultural policy was conceived as a central mechanism to stabilise production, channel agrarian surplus, and integrate the sector into the broader national development strategy, rather than as an exceptional or temporary intervention.

Specifically, the First Five-Year Development Plan treated the subsidisation of agricultural products as a fundamental and structured instrument of state support. The Plan explicitly stated: "The prices of agricultural products should be protected mainly by subsidising the elements that enter the costs of these products" (DPT, 1963: 498). Far from

³ *Quantitatively, the scope of agricultural subsidies expanded dramatically during this period: whereas only six crops were subsidised in 1960, the number had risen to 24 by the end of the 1970s, reflecting the intensification of state intervention in the agrarian sector (Günaydin, 2002: 13).*

being an exceptional measure, this policy constitutes the core of agricultural support, designed to ensure stable production and facilitate the generation of surplus that could subsequently feed industrial accumulation and national development objectives. This interpretation aligns with the contemporaneous establishment of public enterprises and credit mechanisms that, together, reinforced the developmental role of agriculture during Türkiye's early industrialisation period.

Nevertheless, the Plan largely failed to achieve its intended objectives for the agricultural sector. The policy framework of the 1960s privileged industrial capital accumulation and, within agriculture, favoured large landowners who were perceived as potential contributors to industrial investment. As Avcıoğlu (1965: 10) observed:

"The most important reason for failure is that the village is considered a harmonious community without social differentiation. No distinction was made between poor peasants and rich peasants. When social differentiation was ignored, most of the good works undertaken benefited the rich peasants and aghas. Credit flowed to the landlords. Aghas benefited from irrigation and land utilisation projects. The poor peasant, on the other hand, saw the development of society as the development of the aghas".

This critique is corroborated by Oral's (2006: 56) empirical findings, which demonstrate the unequal distribution of agricultural credit: in 1960, roughly 88% of farmers received only 42% of total loans, whereas the wealthiest 8% captured 47%. By 1965, the imbalance had deepened 92% of farmers received just 53% of loans distributed by Ziraat Bank, and only 32% of agricultural enterprises had access to the full range of available credit. These data underscore that state-led agricultural policies in the ISI period disproportionately benefited the rural elite, thereby reinforcing existing class hierarchies rather than alleviating them.

The electoral victory of the Justice Party (JP) in 1965, widely regarded as the political heir of the Democrat Party, initiated a new phase in Türkiye's agrarian and industrial policy-making. The JP adopted a mixed economic approach that emphasised industrialisation while integrating policy leadership with cadres aligned closely with the industrial bourgeoisie. This orientation was codified in the Second Five-Year Development Plan (1968-1972), which identified the industrial sector as the driving force of economic development, while simultaneously acknowledging the role of agriculture as an essential component of the broader growth strategy (DPT, 1968: 56-66). The Plan prioritised public investment in intermediate and capital goods. It sought to strengthen private-sector capital accumulation while recognising the importance of supporting agrarian production through mechanisms such as agricultural cooperatives, subsidised inputs, low-interest credit, and price-support policies. Under the Demirel government, import-substitution policies functioned as instruments to consolidate and materially empower the domestic industrial bourgeoisie (Aydın & Taşkın, 2020: 146). National income data for 1960-1970 (see Table 1) suggest a relative decline in agriculture's share of GDP. Yet, these figures should be interpreted cautiously, as they do not cover the final two years of the Plan period. Consequently, while

agriculture’s share appears to have declined, it remained integrated into a development strategy that balanced industrial growth with the stabilisation and modernisation of agrarian production.

Table: 1
Sector Shares in National Income (%)

Years	Agriculture	Industry	Service
1960	44.3	16.7	39.0
1961	42.7	16.2	41.1
1962	42.6	16.2	41.2
1963	42.6	16.1	41.3
1964	40.8	16.8	42.4
1965	38.1	17.6	44.3
1966	38.7	17.8	43.5
1967	37.0	18.7	44.3
1968	33.2	26.4	40.4
1969	31.3	27.2	41.4
1970	30.4	27.0	42.6

Source: Mücek, 2019: 402.

As Marx (1979 [1852]: 186) reminds us, “state power is not suspended mid-air”. Throughout the late 1960s and early 1970s, the Turkish state implemented policies that favoured larger, market-oriented segments of the agrarian class, particularly through credit allocation mechanisms. Necdet Oral’s (2006: 56) data illustrate this concentration: in 1969, only 3% (per thousand) of agricultural credit recipients, 697 enterprises, captured a volume of credit far greater than that utilised by 697,000 smaller borrowers, who represented nearly one-third of all recipients. By 1975, 3% of total agricultural credit went to 89% of borrowers, while the remaining 11% received a staggering 97%, revealing a dramatic imbalance in credit distribution. These figures indicate that while large farmers benefited disproportionately from state-supported credit policies, the majority of the rural population experienced comparatively declining access to financial resources.

The Third Five-Year Development Plan (1973-1977) further entrenched this trajectory, setting explicit targets that favoured industrial expansion: 35% of GNP was allocated to industry, 53.4% to services, and only 11.6% to agriculture (DPT, 1973). In substance, the Plan resembled an industrial promotion strategy rather than a balanced development framework, reflecting Justice Party policies consolidated since 1965 (Barbaros & Kozal, 2014: 165).

Import-substitution industrialisation and the breadth and dynamism of the domestic market were the determining elements of the economic policy of the period. Beyond its developmental objectives, the agricultural component of state planning also functioned as a mechanism for maintaining rural stability and reproducing existing class hierarchies. As noted by Avcıoğlu (1965: 10) and corroborated by Oral’s (2006: 56) findings, agricultural policies during this period largely favoured large landholders and local notables, thereby constraining the scope for rural political mobilisation. These policies temporarily improved the financial situation of some poor peasants, yet their benefits were unevenly distributed and structurally limited. According to Sönmez (2013: 83), assuming 1960-61 = 100, the

terms-of-trade index for agriculture reached 117 in 1976, 123 for cotton, and 190 for tobacco. These indices indicate relative price advantages for agricultural commodities over time, though the precise methodology and index calculations are outside the scope of this study. While some scholars have suggested that such market orientation increased farmers' long-term exposure to market fluctuations (Keyder & Yenal, 2011; Oral, 2015a), a detailed analysis of the socio-economic vulnerabilities created by these policies constitutes a separate research agenda.

A prominent scholar of income distribution in Türkiye summarises this structural tendency:

"We cannot support the claim that the Turkish economy successfully redistributed income between the agricultural and non-agricultural sectors in 1950-1974. Large farmers always benefited from high support prices, input subsidies, state irrigation projects, and technological developments, which tended to increase inequalities" (as cited in Ulusan, 1980: 138, 146).

The World Bank's 1977 Agriculture Report, as cited in Köymen (1988, p. 236), offered a stark diagnosis: "Public investments in rural areas have increased the inequality in rural income distribution. Support policies have favoured rich farmers to the detriment of poor peasants. Credit policies have mostly benefited large-scale agricultural enterprises and have not effectively reduced income inequality. The land policy has not reduced income inequality or increased productivity. Türkiye, Mexico, and Brazil have one of the world's most unequal rural income distributions. The top 10% of producers in the top income group receive 43% of the income, while the bottom 20% receive 2.7%".

The ISI model persisted until the deepening structural and economic crisis of the late 1970s (Akçay & Türel, 2022). The 1971 military intervention, political instability, the 1973 Oil Crisis, and the international repercussions of the 1974 Cyprus Peace Operation collectively exacerbated the downturn, producing both economic and political turbulence. After 1976, relative prices turned decisively against agriculture, favouring industry. When 1976 is indexed to 100, the agricultural terms of trade fell to 69 by 1979, representing a 31% deterioration (Günaydın, 2014). Agriculture's share of GDP contracted sharply, dropping from 28.9% in 1977 to just 20.7% in 1979 (Çölaşan, 1984: 274).

During this period, the Turkish economy came under severe strain, besieged by soaring prices, a surge in imports, a contraction of exports, and a mounting external debt burden⁴. Reversing the structural imbalances of the 1970s required radical measures to restore the economy's capacity for self-sustained accumulation. In this context, the January 24th Decisions announced by the last Justice Party government marked a decisive turning

⁴ Between 1973 and 1979, Türkiye's export prices rose by 82.4%. Yet at current prices, imports skyrocketed by 1,772% between 1950 and 1979, outpacing export growth of 859% over the same period. Consequently, the export-to-import coverage ratio collapsed from 91.9% in 1950 to just 38% by 1980, highlighting the deepening structural imbalance in Türkiye's external trade (Başkaya, 1986: 177).

point in Türkiye’s political economy. They inaugurated a new era of market-oriented restructuring.

The Fourth Five-Year Development Plan (1979-1983) heralded a paradigmatic shift in economic policy, signalling profound transformations in the agricultural sector. The Plan explicitly acknowledged that state-led support purchases had distorted production patterns and exacerbated income inequalities:

“The practice has adversely affected the composition of production and income distribution. As the enterprises grow, the amount of benefit from the price support by the state increases with the expansion of the marketed quantities, and in products such as wheat, which is also subject to domestic consumption, self-sufficient enterprises that must buy these products partially from the market may be adversely affected by the support price” (DPT, 1979).

This diagnosis reflected an ideological repositioning: agricultural supports were reframed not as instruments of rural development but as distortions that had to be disciplined to align agriculture with the imperatives of market liberalisation.

Table: 2
Shares of Production Sectors in Gross National Product (%)

Year	Agriculture	Industry	Service
1968	37.6	17.4	45.0
1973	29.4	17.7	52.9
1977	27.3	19.1	53.6
1980	23.6	20.1	56.3

Source: Turkish State Institute of Statistics, Statistical Indicators, 1923-1991.

IMF deeply shaped the economic and political trajectory constructed around the January 24th Decisions- and World Bank-sponsored stabilisation and structural adjustment programs, embedding Türkiye into the global neoliberal project. The discourse of economic liberalisation gained momentum in this period and would find its full institutional expression after the September 12, 1980, military coup (Köymen, 2017: 145). For agriculture, the implications were severe: sharp reductions in support policies, liquidation of public agricultural institutions, and large-scale privatisation measures, developments that will be analysed in the subsequent sections. Seen through a political economy lens, the January 24th Decisions and the 1980 military coup did not merely inaugurate a new set of economic policies. Still, they reconfigured the very form of the Turkish state, restructuring class relations and consolidating a neoliberal accumulation regime whose implications for agriculture were both far-reaching and irreversible.

4. The Neoliberal Reconfiguration of Agriculture: January 24th Decisions, Class Power, and the Making of a Market-Mediated Agrarian Order in Türkiye

The January 24th Decisions functioned as the *midwife* of a new orientation in Turkish capitalism, the memorandum of capital, inaugurating a new accumulation regime that entrenched the hegemony of capital. These decisions marked Türkiye's transition from an inward-looking, import-substitution model toward an export-oriented development strategy rooted in neoliberal prescriptions. As in Chile's neoliberal experiment, the liberalisation process in Türkiye was consolidated under authoritarian rule, beginning with the September 12, 1980, military coup. The primary function of the coup was to dismantle the institutional architecture of the ISI era and replace it with a new set of institutions designed to privilege market logics. The intellectual genealogy of the January 24th program can also be traced to the global ascendancy of the New Right following the rise of Margaret Thatcher in the United Kingdom (1979) and Ronald Reagan in the United States (1981) (Şener & Çolak, 2019: 400).

The post-1980 Turkish state pursued a developmental strategy focused on export promotion, providing financial privileges and tax incentives to export-oriented industries (Karadağ, 2010: 17). This state strategy coincided with the objectives of domestic capital accumulation. IMF standby agreements and policy conditionalities further shaped the implementation of neoliberal-oriented economic policies. Unlike the period between 1960 and 1980, when elements of welfare policy mediated class tensions, the post-1980 policy framework emphasised market liberalisation and export-oriented industrial growth, with limited mechanisms for incorporating labour interests into policy-making.

The January 24th Decisions incorporated elements characteristic of IMF-imposed stabilisation packages of the 1970s and World Bank structural adjustment programs, including currency devaluation, price adjustments of State Economic Enterprises' products, removal of price controls, privatisation, gradual liberalisation of financial markets, and deregulation of foreign capital inflows (Koç, 2014: 227). These measures inevitably affected the agricultural sector, marking a departure from the broadly supportive agricultural policies of 1960-1980, which featured widespread input subsidies, high support prices, and low-interest agricultural loans (Baray & Ergun, 1990: 88-89). Unlike the previous period, the post-1980 stabilisation measures sought to minimise state intervention in agriculture, transferring the sector increasingly to market mechanisms while retaining only limited targeted support.

The first concrete manifestation of this new stabilisation regime was the dramatic hike in fertiliser prices in January 1980, which drove the share of fertiliser costs in grain production from 7% in 1979 to 17% in 1980 (Şahinöz, 2014: 427). Access to credit was simultaneously tightened: interest rates on medium-term loans provided by Ziraat Bank to agriculture were doubled from 11% to 22% in 1980, while support prices were reduced and the number of crops covered by support was halved. These measures combined to depress

agricultural output growth, reducing the sector's annual growth rate from roughly 3% in the pre-1980 period to below 2% thereafter (Şahinöz, 2014: 427). The share of agricultural goods in total exports fell precipitously, from 59.4% in 1979 to 47.2% by 1981 (Mücek, 2009: 156).

TÜSİAD's 1981 Agricultural Report, representing the voice of Türkiye's organised industrial and financial capital, openly articulated the desired reconfiguration of agriculture:

"The necessary harmony between agriculture and industry in the market economy model can be likened to the optimum speed of a two-horse carriage. The speed of one constantly affects the other; the slower one becomes a burden on the faster one, and the faster one tries to drag the slower one. In closed economies, agriculture and industry cannot develop beyond a certain point because the economy is not open to exports; the economy slows and stops, as if it has hit a hill or even a wall. If the economy is not open to exports, both agriculture and industry slow down at the limits of domestic demand, and the surpluses produced by chance or out of habit are exported, which is not enough for the economy to make the necessary move" (TÜSİAD, 1981: 75-76).

With the full institutionalisation of the January 24th program and the consolidation of stability and structural adjustment policies, agriculture was fully subordinated to the logic of export-oriented industrialisation. This shift became even more apparent following the 1983 return to civilian rule and the rise to power of the Motherland Party (ANAP) under Turgut Özal, the chief architect of the January 24th program (Oral et al., 2015: 76).

Table: 3
Terms of Trade in Agriculture

Years	Terms of Trade	Years	Terms of Trade	Years	Terms of Trade
1966	100	1972	107,3	1978	87,9
1967	103,1	1973	111,8	1979	68,2
1968	103,4	1974	111,2	1980	62,9
1969	105,4	1975	108,3	1981	70,1
1970	109,0	1976	100,4	1982	65,7
1971	112,1	1977	96,9	1983	60,7

Source: Akad, 2015: 102.

From 1971 to 1984, agriculture's share of GNP plunged from 35% to 21% (Korkut, 1984: 23). The ratio of agricultural to industrial prices fell from 107.6 in 1977 to 73.5 in 1984, indicating a dramatic deterioration in relative prices to the detriment of agriculture (Başkaya, 1986: 303). In short, the neoliberal turn systematically eroded the economic position of agriculture, deepened rural income inequalities, and accelerated the transition toward a fully market-mediated agrarian order.

5. Neoliberal Counter-Revolution in Agriculture: The Motherland Party, Class Power, and the Dismantling of State Support

The 1983 electoral victory of the Motherland Party, led by Turgut Özal, the architect of the January 24th Decisions, paved the way for the neoliberal state model to gain

prominence and for a more pronounced market-oriented restructuring of agriculture. During this period, the scope of agricultural support was progressively narrowed, and prices of key agricultural products were suppressed. Comparing the post-1980 period with the 1960-1980 period, when broad input subsidies were prevalent, the reduction in support becomes evident. Terms of trade for agriculture, indexed to 100 for 1976-1979, fell to 53% by 1988, highlighting a sharp deterioration; for context, the same index stood at 27% during the Great Depression (Günaydın, 2014: 520). By juxtaposing the broadly subsidised agricultural framework of 1960-1980 with the post-1980 policy contraction, it becomes evident that the reduction in state support constitutes a structural departure from the previously established developmental logic, signalling a deliberate reorientation of agrarian policy toward market-mediated accumulation.

Gülten Kazgan's (1999: 33) assessment of the transformation of Turkish agriculture between 1980 and 1990 offers a striking summary:

"The difference in approach that became more evident in the second half of the period can be summarised as follows: First, the protective and regulatory state attitude towards agriculture changed, and a policy change emerged to ensure that agricultural production was subject to market conditions. Foreign trade protectionism was greatly reduced, input subsidies were abolished except for a small subsidy for chemical fertilisers, and product price support was almost eliminated, and its scope was narrowed. Secondly, towards the end of the period, public institutions regulating agricultural markets lost the advantages they had previously enjoyed, especially credit advantages, and, like other public institutions, they were privatised, and the monopoly power of some of them ended. Thirdly, the seed sector, which had previously been closed to foreign capital, was opened almost entirely to domestic and foreign capital, and the trend toward ending the public sector's role in this field was completed. Finally, the tendency to use agriculture to boost the competitiveness of the manufacturing industry and services in an economy fully opened to foreign competition became evident".

Under ANAP, neoliberal discourse became the official language of economic policy, framing development as the natural outcome of market forces. As stated in the party program:

"To ensure the development of the economy within its natural laws, our economic system preference is the implementation of a free market economy in which the conditions of competition prevail by minimising interventions and restrictions in line with the interests of the country" (ANAP, 1983: 19).

This ideological orientation was fully reflected in the development plans of the period. The Fifth Five-Year Development Plan (1985-1989) explicitly recommended keeping agricultural support prices low and, if necessary, raising industrial goods prices to adjust the terms of trade against agriculture (Sönmez, 1982: 51).

Within this framework, state-mediated subsidies and price-support mechanisms underwent a profound contraction rather than a mere continuation of prior policies (Pamuk, 2008: 288). By 1984, the real purchasing power of agricultural support payments had declined to approximately half of its 1977 level (Başkaya, 1986: 304). The number of products eligible for support purchases fell from 18 in 1985 to 10 by 1990. Between 1980 and 1989, the proportion of tobacco production covered by support purchases decreased from 71.5% to 39.3%, while fresh tea leaves, hazelnuts, and cotton were excluded from the support system in 1986 and 1988, respectively (Oral, 2020: 51). Concomitantly, the share of agricultural support in total value added dropped from 14.7% in 1976 to 5.5% in 1988, and Central Bank loans earmarked for agricultural support fell from 27% to 5% in the same period (Oral, 2020: 51). This evidences the onset of a decisive contraction in state support, marking a structural reorientation of agrarian policy toward market-mediated mechanisms and away from the protective frameworks that had underpinned agriculture in previous decades.

The terms of trade, indexed to 1976 = 100, fell to 51.8 by 1989, indicating a 48% shift against agriculture (Oral, 2015a: 421). As a result, farmers' purchasing power declined by nearly 35% during the 1980s (Oral, 2020: 52). Resource transfers from agriculture to non-agricultural sectors also increased dramatically, rising from 2.19% of GDP in 1975-1978 to as high as 9% by 1986 (Baray & Ergun, 1990: 93). Per capita income disparities between industry and agriculture widened: industry's per capita income, which was 4.6 times higher than agriculture's in 1980, rose to 5.7 times by 1988 (Oral et al., 2015: 79). Functional income distribution data likewise reveal a sharp decline in agriculture's share of national income from 23.9% in 1980 to 16.6% in 1988 while the combined share of profit, interest, and rent incomes surged from below 50% to nearly 70% over the same period (Oral, 2015a: 422) (see Table 4).

Table: 4
Functional Distribution of National Income in Türkiye

Years	Share of Agricultural Income (%)	Share of Wage-Salary* (%)	Profit-Interest-Rent** Share (%)
1967	34.53	28.51	36.95
1968	32.44	29.31	38.25
1969	31.58	31.38	37.05
1970	31.08	31.15	37.77
1971	31.31	31.33	37.37
1972	30.32	31.57	38.11
1973	29.13	31.56	39.31
1974	30.20	29.77	40.04
1975	30.76	31.51	37.73
1976	31.28	33.11	35.60
1977	29.12	36.81	34.07
1978	26.66	35.19	38.15
1979	24.33	32.79	42.88
1980	23.87	26.66	49.47
1981	23.06	24.57	52.36
1982	21.82	24.62	53.55
1983	20.52	24.78	54.69
1984	20.44	21.57	57.99
1985	19.08	18.84	62.08
1986	18.09	17.70	64.21

Source: Özmucur, 1987: 79; Mücek, 2009: 205.

* Non-agricultural, wage and salary income; ** Non-agricultural, non-wage, and non-salary income.

Privatisation represented one of the central pillars of ANAP's development strategy. In 1984, the private sector was granted the right to establish facilities for the purchase, processing, and packaging of fresh tea, while ÇAYKUR was prohibited from making new investments, effectively privileging private investors (Oral et al., 2015: 78). Seed imports were liberalised in 1985 under a World Bank loan agreement, opening the sector to foreign capital (Oral, 2020: 61). The privatisation of the General Directorate of Agricultural Enterprises (TİGEM) accelerated, with its assets leased to the private sector. In 1984, TEKEL was permitted to import foreign cigarettes. By 1990, the share of foreign brands in domestic consumption had risen from 6% to 25% (Oral et al., 2015: 78). Finally, after 1989. The adoption of Decree No. 32 on the Protection of the Value of Turkish Currency, Türkiye, shifted from an export-led growth model to a capital-inflows-driven accumulation regime, further exacerbating structural vulnerabilities and deepening the agrarian crisis.

6. Disciplining Agriculture: Financial Liberalisation, IMF-World Bank Conditionalties, and the Restructuring of Türkiye's Agrarian Economy

The enactment of Decree No. 32 on the Protection of the Value of the Turkish Currency in 1989 marked a decisive rupture in Türkiye's political economy, fully liberalising financial transactions and rendering the Turkish lira convertible. This legal-institutional shift opened the floodgates for foreign capital inflows, fueling a cycle of rising interest rates and embedding a growth strategy predicated on short-term portfolio flows, which came to be known as the "hot money" model. In this context, the conditions for the reproduction of first real, and subsequently financial, capital were institutionalised, mobilising new opportunities for expanded capital accumulation through enhanced profit rates. Crucially, this reorientation signalled an explicit attempt to reorganise the economic surplus in favour of the financial bourgeoisie, inaugurating a period of class realignment and redefining the state's relationship with the dominant fractions of capital.

The 1990s unfolded as a decade of macroeconomic volatility, political fragility, and deepening social disintegration. Internationally, Iraq's 1990 invasion of Kuwait and the dissolution of the Soviet Union in 1991, along with the economic and political turbulence generated by the transition of post-Soviet republics, further destabilised Türkiye's external environment. Domestically, the consequences of financial liberalisation became increasingly apparent: the economy was progressively decoupled from the productive sphere and diverted toward speculative circuits of accumulation (Altıok, 2002: 104). In effect, financial flows began to eclipse productive investment, undermining the development of the real economy.

This model, grounded in volatile capital inflows, perpetual external borrowing, and consumption-driven growth, proved unsustainable and culminated in a severe balance-of-payments and confidence crisis in early 1994. The April 5th Decisions⁵, framed by then-

⁵ *The core of this program endorsed by the IMF through a stand-by agreement and incorporating the principal components of orthodox stabilization packages can be distilled into three interrelated pillars: (1) the*

Prime Minister Tansu Çiller as a "war of economic liberation," constituted a comprehensive stabilisation package designed under IMF auspices and incorporating the canonical instruments of structural adjustment. For agriculture, however, these measures amounted to a de facto mortgage: the sector was further subjected to market discipline, and its already diminished state support mechanisms were eroded further, deepening rural precarity.

The agricultural implications of the April 5th Decisions were far-reaching, restructuring the sector along explicitly neoliberal lines. Policy measures included pegging agricultural product prices to world market levels, narrowing the scope of state procurement, curtailing input subsidies, restricting the cultivation of crops with structural surpluses, and accelerating the privatisation of state agricultural enterprises (Oral, 2006: 87). The number of supported crops, which had stood at 26 in 1992, was reduced to just nine under the new regime, including cereals, sugar beet, poppy, and tobacco (Günaydın, 2014: 521). Farmers' access to subsidised, low-interest loans became increasingly restricted, while the prices of critical production inputs surged by up to 300%, significantly raising cultivation costs (Aysu, 2023: 63).

Privatisation remained a defining feature of the period, with agricultural state-owned enterprises dismantled under the mandate of Law No. 3291 on Privatisation (1986) (Günaydın, 2006: 19). Core institutions, including the Dairy Industry Corporation (SEK), Feed Industry (YEMSAN), Forest Products Industry (ORÜS), and Turkish Agricultural Equipment Corporation (TZDK), were privatised between 1990 and 2000, profoundly affecting agricultural production, animal husbandry, and rural livelihoods. The liquidation of these entities contributed to a dramatic contraction in livestock numbers: from approximately 87 million in 1980 to 68.5 million in 1984, and to roughly 52 million by 1997 (Mücek, 2019: 430). Similarly, the Meat and Fish Institution, which once held 60% of the domestic market share, saw its 16 combine facilities transferred to private ownership between 1995 and 1999; output collapsed from 14,000 tons before privatisation to a mere 1,300 tons (Yörük, 2021: 71-72). With the dismantling of these institutional pillars, producers were left without a public safety net, leading to declining production, growing import dependence, and widening inequalities in agricultural income distribution (Yörük, 2021: 72).

The 1994 Household Income Distribution Survey starkly illustrates this inequality: the poorest 20% of agricultural households captured only 5.6% of agricultural income, while the wealthiest 20% accounted for a disproportionate 47.7% (Köymen, 2017: 146-147).

A further milestone of this era was Türkiye's accession to the Customs Union with the European Union, effective December 31, 1995. Notably, high-value-added products in which Türkiye held a clear ecological advantage, such as canned fruits, vegetables, and

compression of wages, salaries, and agricultural subsidies; (2) the reduction of public sector deficits through fiscal austerity; and (3) the large-scale privatization of state assets and the radical retrenchment of the state's economic role, particularly in the production of goods and services.

tomato paste, were excluded from the agreement's coverage, while processed agricultural products (e.g., chocolate, confectionery, pasta, ice cream), heavily subsidised under the EU's Common Agricultural Policy, were included (Oral et al., 2015: 81). This asymmetrical arrangement accelerated the deterioration of Türkiye-EU trade balances, with Türkiye's trade deficit rising from USD 5.8 billion in 1995 to USD 28.8 billion by 2011 (Oral et al., 2015: 81).

International financial institutions played a crucial role in deepening this transformation. The IMF and World Bank continued to prescribe policies aimed at accelerating the de-agrarianization process. A telling moment occurred on May 29, 1996, when Martin E. Hardy, Deputy Director of the IMF's European Department, addressed the Confederation of Turkish Trade Unions. Responding to concerns about unemployment and internal migration, Hardy bluntly stated:

"In Türkiye, 45% of the active labour force is employed in agriculture. However, the contribution of agriculture to national income is only 15%. Employment in agriculture should be reduced to 10%" (as cited in Koç, 2014: 186).

Even political elites embraced this logic. Then-President Süleyman Demirel repeatedly emphasised the need to reduce the rural labour force, declaring at the 1997 Agricultural Council:

"The 40-44% of this country's population working in agriculture should be reduced to 10% or even below" (as cited in Koç, 2014: 186).

By late 1997, a World Bank mission visited Türkiye to evaluate agricultural support policies. Its 1998 report diagnosed the system as fiscally unsustainable and economically inefficient, urging sweeping reforms:

"Prices of agricultural products should be brought down to the level of world prices. A system of direct income support should replace price supports or subsidies. Fertiliser and credit subsidies should be eliminated. Agricultural state-owned enterprises, which have become redundant with the transition to direct income support, should be privatised" (as cited in Aysu, 2023: 49).

The liberalisation trajectory initiated in the 1980s was reinforced with the IMF stand-by agreement of 1999 and institutionalised through the Agricultural Reform Implementation Project (ARIP) signed with the World Bank in 2001 (Yıldırım, 2022: 54-55). Under these conditionalities, Türkiye implemented sweeping legal and policy reforms to align its agricultural sector with the requirements of global capital accumulation. By the early 2000s, the commodification of agriculture was not merely a policy tendency but a structural imperative, embedding Turkish agriculture within a transnational regime of market discipline dictated by IMF-World Bank orthodoxy (Kendir, 2003: 281).

7. The Global Script for Agriculture: Washington Consensus, Structural Adjustment, and the Restructuring of Türkiye's Agrarian Order

The acceleration of economic globalisation since the 1990s, intensifying further in the 2000s, was propelled by the dissolution of traditional geopolitical blocs, the ascendancy of liberal and neoliberal paradigms, rapid technological innovation, and the transnationalization of goods and financial markets (Kutlu, 1998: 369). This transformation was not merely the "natural" outcome of liberalising trade and capital flows but was actively institutionalised through the growing power of supranational organisations such as the World Trade Organization, the International Monetary Fund (IMF), and the World Bank, which came to operate as global decision-making and enforcement bodies alongside nation-states (Ataç, 2000: 96). The collapse of the Cold War order further consolidated the influence of these institutions, particularly in the economic sphere, allowing them to dictate the terms of market integration for peripheral economies. By the 1990s, the Washington Consensus, built around the policy triad of macroeconomic stabilisation, privatisation, and trade liberalisation, had become the hegemonic development paradigm (Ruger, 2005: 60). The structural adjustment programs (SAPs) and conditionalities designed by the IMF and World Bank under this paradigm systematically dismantled protectionist regimes and exposed agriculture to the discipline of global markets, leaving producers in many countries, including Türkiye, vulnerable to price volatility and intensified competition.

One of the most visible economic consequences of globalisation has been the homogenization of national policy frameworks: economic strategies increasingly became "carbon copies" of one another, converging around neoliberal orthodoxy. For decades, agricultural policy retained a degree of national specificity due to its strategic nature, but in recent decades it, too, has been subsumed into the circuits of globalisation. As Berthelot (2001) famously remarked, "Agriculture is the Achilles' heel of globalisation," capturing the sector's structural vulnerability within liberalised markets. Countries seeking IMF assistance during financial crises were required to adopt pre-packaged agricultural policy blueprints as integral components of SAPs. These prescriptions, driven primarily by fiscal austerity imperatives and neoliberal dogma, left little room for considerations of long-term development, social equity, or food security. Türkiye's 1999 Letter of Intent to the IMF, which laid out the policy trajectory for the 2000s, effectively reiterated and deepened the liberalisation agenda initiated two decades earlier, underscoring the continuity of external conditionality over domestic policy space.

Perhaps the most far-reaching intervention in Turkish agriculture was the Agricultural Reform Implementation Project (ARIP), executed between 2000 and 2008 under World Bank auspices. ARIP marked a decisive rupture with the state-led agricultural support regime: price supports and input subsidies were dismantled, crop production decisions were handed over to market forces, and the protective institutional infrastructure that had shielded smallholders was systematically dismantled (Keyder & Yenal, 2013). The Eighth Five-Year Development Plan (2001-2005) rationalised these reforms by arguing that support prices historically set above world market levels had generated excessive production

surpluses, led to costly stockpiling, and destabilised farm incomes. As a corrective, the plan advocated expanding the Direct Income Support (DIS) system, which was initially piloted as a mechanism to replace price supports with direct transfers to farmers (DPT, 2001: 132-136).

The eruption of the 2001 financial crisis, which triggered the collapse of Türkiye's banking sector (Gorvett, 2001), further entrenched the role of international financial institutions in steering domestic policy. The appointment of Kemal Derviş, brought directly from the World Bank to head the economy for a critical 17-month period, marked a pivotal juncture. Under his leadership, the Transition to a Strong Economy Program was launched, constituting the second roadmap of Türkiye's neoliberal restructuring. In agriculture, this program entailed a significant intensification of structural adjustment policies, accelerating a profound, largely irreversible transformation of the sector's institutional, economic, and social foundations in alignment with global neoliberal imperatives.

8. The Deep Restructuring of Turkish Agriculture: Neoliberal Legislation, De-Agrarianization, and the Crisis of Agrarian Self-Sufficiency

The first decades of the twenty-first century marked a critical juncture in Türkiye's agrarian trajectory, characterised by growing fragility and an increasing dependence on external markets. Rather than indicating a complete reversal in trade balances, developments in this period reflected cyclical fluctuations and structural vulnerabilities within agricultural production and trade. These dynamics pointed to a gradual weakening of agrarian self-sufficiency and a deepening exposure to global price volatility outcomes rooted in neoliberal state policies that systematically privileged the interests of large capital and the hegemonic class fraction. Under this reconfigured accumulation regime, the agricultural sector, once celebrated as a cornerstone of national economic sovereignty, was progressively restructured, tethering Türkiye's food system more closely to global market dynamics. The Transition to a Strong Economy Program (2001), the Sugar Law (2001), the Tobacco Law (2001), the Agriculture Law (2006), and the Seed Law (2006) collectively entrenched a new institutional architecture for neoliberal restructuring in agriculture. The Transition Program, a more aggressively market-oriented version of the 1999 IMF stabilisation package, explicitly sought to terminate the post-war regime of state-mediated agrarian support and replace it with a system of direct income support (DIS) narrowly targeted at small and medium producers. In practice, this translated into the abolition of state procurement schemes, the withdrawal of fertiliser and credit subsidies, and the privatisation of agricultural state economic enterprises, modifying the institutional framework that had supported rural production and agrarian self-sufficiency for decades.

The Sugar Law introduced a quota regime that not only paved the way for the privatisation of state-owned sugar factories but also opened Turkish markets to surplus sugar stocks from the U.S. and the EU, undermining domestic production and crippling livestock-based molasses feed chains (Konyalı & Gaytancıoğlu, 2002: 310). Likewise, the Tobacco Law facilitated the dismantling of TEKEL, which was ultimately sold to British American

Tobacco in 2008, ceding the market to multinational firms (Oral, 2015a: 425). These reforms devastated producer bases: the number of sugar beet growers collapsed from 492,000 in 2002 to 124,000 by 2014, while the number of tobacco-farming households plummeted by more than 80%, leaving barely 55,000 by 2016 (Değirmenci, 2017: 773).

The Agriculture Law (2006) codified a vision of a "non-interventionist" state, restricting itself to regulatory functions and guaranteeing agricultural budget allocations of "at least 1% of GNP" (Art. 21). In reality, allocations never reached this threshold, remaining around 0.5-0.6% (Şengül & Sarıbal, 2015: 150), meaning that producers received less than half of the statutory amount: TL 121 billion instead of TL 269 billion between 2006 and 2019 (Yıldırım, 2022: 92).

The cumulative effect of these policies was starkly summarised by Oral (2015a: 425):

"Public support to agriculture decreased from USD 6.2 billion in 2000 to USD 4.2 billion in 2011. Support fell from 3% of national income to 0.5%, agricultural input use declined, and production growth lagged behind population growth. Livestock populations dwindled, and even basic feed, live animals, and hay became import-dependent. The privatisation or liquidation of state agricultural enterprises was largely completed, and agriculture was transformed into a net importing sector".

The social costs were equally severe: agricultural employment contracted by 1.6 million between 2000 and 2011 (TÜİK), with agriculture's share in total employment dropping from 36% to 25%. Rural poverty, far from being alleviated, deepened, rising from 35.5% in 2002 to 38.7% by 2009 (TÜİK).

Global factors compounded this structural transformation. The 2008 global food crisis, triggered by rising commodity prices, pushed international organisations to revisit their development discourse. The World Bank's 2008 World Development Report, titled *Agriculture for Development*, marked a rare admission that earlier structural adjustment programs had exposed smallholders to market failures and unsustainable risks:

"Incomplete markets and institutional gaps imposed costs and welfare losses on small farmers ... threatening their competitiveness and, in many cases, their very existence" (World Bank, 2007: 138).

Yet, rather than reversing neoliberal orthodoxy, the report reframed the state's role as a market facilitator rather than a developmental agent, consolidating the regulatory state model. Domestic elites echoed this orientation: TÜSİAD's 2008 Agricultural Report called for the complete abandonment of protectionist policies, legitimising a class project that redistributed income upward to large-scale landowners and agribusiness (TÜSİAD, 2008).

Empirical evidence corroborates this polarisation. İslamoğlu et al. (2008: 56) show that small family farms were liquidated at alarming rates: holdings under 50 decares shrank

from 65% of the total in 2001 to 32% in 2008, while farms above 500 decares increased sixfold from 1% to 6%, consolidating a new agrarian oligopoly.

The macroeconomic outcomes were equally telling: the value-added of agriculture fell by 24% between 2012 and 2017, while per capita agricultural value-added declined by nearly 20% in the same period (Oral, 2020: 33). Agriculture's share in exports halved from 5.95% in 2000 to 2.7% in 2019, while its share in imports rose from 3.5% to 4.8% (Yıldırım, 2022: 52), indicating a deepening structural trade deficit.

The diagnosis offered by Mahmut Eskiörük, President of the Tire Milk Cooperative, captures the political economy of this transformation:

"During the Özal era, a dangerous idea was injected into our veins: 'Why produce if it is cheaper abroad?' ... Today, we import wheat, cotton, and lentils. Our self-sufficiency has been sacrificed. Without a stable, long-term agricultural policy, Turkish agriculture is doomed to remain trapped in this spiral of dependency" (Yörük, 2021: 128).

This spiral has become particularly visible in the context of recent global disruptions, including the COVID-19 pandemic and the Russia-Ukraine war, which have affected global supply chains and international agricultural markets. These events may have influenced Türkiye's import patterns, price volatility, and market stability, highlighting the structural vulnerabilities of an agrarian economy increasingly integrated into global production and trade circuits.

9. Crisis upon Crisis: COVID-19, the Russia-Ukraine War, and the Exposure of Türkiye's Agrarian Vulnerabilities

The emergence of the COVID-19 pandemic in Wuhan, China, on November 17th, 2019, and its rapid spread across the globe triggered profound disruptions in nearly all spheres of life, including agriculture, which became a litmus test for national resilience (Kayabaşı, 2020: 40). United Nations Secretary-General António Guterres warned world leaders that the pandemic could precipitate a "triple crisis" of food, energy, and finance, placing the specter of hunger and global food insecurity at the top of the agendas of the G-7, G-20, World Bank, and IMF meetings. In this sense, the pandemic marked a historical juncture in which the very notion of self-sufficiency was tested worldwide, reviving debates over food sovereignty and national capacity for provisioning.

Türkiye entered the pandemic era with a structurally fragile economy and a highly import-dependent food system. Given the indeterminate duration and scale of the pandemic, the country faced intensified food security risks and deepened vulnerabilities in agricultural production. Türkiye ranks among the world's leading importers and exporters of grains. In the case of wheat, domestic production has generally been sufficient to meet internal consumption, and imports primarily serve export-oriented processing and trade purposes. Although wheat production in April 2020 increased by roughly 20% compared to 2019, rising prices reflected structural insufficiencies in certain commodities and crisis-induced

market pressures: wheat prices rose by 35.95% in 2021, red lentils, barley, and potatoes followed suit, and even basic vegetable staples such as tomatoes, eggplants, and green peppers saw double-digit price increases. Similarly, chickpea and bean prices climbed by 12% and 27.1%, respectively, in 2020, while durum wheat, barley, rye, and corn experienced sharp year-on-year hikes, symptoms of an agricultural system under strain from extraordinary global conditions rather than absolute domestic scarcity (Gevher & Acet, 2023: 115-117).

It is important to note, however, that these price increases cannot be interpreted as evidence of systemic insufficiency in Türkiye's agricultural production. Price dynamics are influenced by a combination of demand pressures, cost fluctuations, and broader structural conditions, and should not be taken as a direct measure of domestic scarcity. Türkiye's agricultural system, operating within a historically de-agrarianised framework shaped by decades of neoliberal restructuring, remains highly sensitive to global market volatility. From this perspective, although the COVID-19 pandemic and the Russia-Ukraine war highlighted the vulnerabilities of the system, domestic production, particularly for staple commodities such as wheat, has generally been sufficient to meet internal consumption, with imports primarily facilitating export-oriented trade and processing (Ministry of Trade, 2023: 8). These dynamics underscore the need to distinguish between price-induced stress and actual supply insufficiency when evaluating Türkiye's agrarian system's resilience.

The post-pandemic period revealed structural vulnerabilities in Türkiye's agricultural trade. Between 2009 and 2021, crop export values increased from USD 4.2 billion to USD 6.6 billion, while imports grew even more sharply, from USD 4.4 billion to USD 11.2 billion (Kılıç & Babayiğit-Sunay, 2023: 120). Wheat imports rose from 4.8 million tons in 2011 to 9.8 million tons in 2020, whereas exports increased from 3.9 to 7.5 million tons, indicating a structural trade imbalance and a growing reliance on international grain markets.

Despite its geographical advantages, diverse agroecological zones, and rich crop portfolio, Türkiye's agricultural sector has been steadily losing its share of GDP and employment. This decline cannot be viewed as a "natural" by-product of structural transformation alone; it also reflects deliberate policy choices that subordinated agriculture to industrial and service sector priorities. Historically, agriculture has served as a countercyclical stabiliser, absorbing labour during economic crises, yet its capacity to play this role has eroded.

Rescuing Türkiye's agricultural sector from its current vulnerabilities requires a paradigmatic reorientation: a production-centred policy designed to meet domestic needs while accounting for the country's ecological realities (Oral, 2020: 35). This entails abandoning externally imposed policy blueprints, re-establishing effective state intervention mechanisms, and strengthening public agricultural enterprises to stabilise prices, support producer incomes, and safeguard food sovereignty. While state-owned enterprises (SEEs) that engage in intervention purchases have historically played an important role in mitigating market volatility, their effectiveness cannot be assumed as absolute. The case of TEKEL,

which was compelled to destroy excess stocks, stands as a stark reminder of the limits of these interventions. Without comprehensive measures, import dependence is likely to deepen, rural disintegration may accelerate, and the agricultural base will remain acutely exposed to systemic shocks. The COVID-19 pandemic has already revealed the fragility of an economy structured under decades of neoliberal restructuring, highlighting how global supply chain disruptions can rapidly affect domestic markets. Preliminary assessments suggest that geopolitical developments, such as the Russia-Ukraine war, may further exacerbate global commodity volatility; however, the specific impacts on Türkiye's domestic production and trade remain to be empirically quantified. Hence, policy prescriptions must remain grounded in verifiable data and structural realities rather than extrapolations from external crises.

10. Conclusion

This study has traced the *longue durée* transformation of Türkiye's agricultural sector, arguing that its trajectory from 1960 to the present is inseparable from the shifting regimes of accumulation, the successive metamorphoses of state form, and the evolving articulation of Türkiye within the hierarchies of the global capitalist order. A historical-political economy approach reveals that agricultural policy is not merely a technocratic instrument of production management but a privileged site where class power is organised, contested, and reproduced. The state, far from a neutral arbiter, has functioned as the "collective organiser" of the ruling bloc, calibrating policy to secure the reproduction of capital accumulation and to stabilise the hegemony of the dominant agrarian, industrial, and later financial bourgeoisie.

Between 1960 and 1980, agriculture was instrumentalised as a reservoir of surplus for industrialisation under the ISI paradigm. Interventionist measures, such as price supports, input subsidies, and cooperative promotion, were not ends in themselves but mechanisms for extracting and redirecting agrarian surplus toward the circuits of industrial capital formation. These measures, while appearing developmentalist, disproportionately benefited large landholders and deepened class differentiation in the countryside.

The late 1970s crisis marked the exhaustion of this accumulation model and paved the way for the neoliberal turn inaugurated by the January 24th 1980 Decisions. Under IMF tutelage and with the enthusiastic support of domestic capital, the institutional edifice of ISI was dismantled. Agriculture was stripped of its protective scaffolding and subjected to market discipline, with the state reconstituted as the guarantor of market rationality rather than a developmental agent.

Neoliberal restructuring unfolded in successive waves: the Motherland Party era, characterised by privatisation and subsidy retrenchment; the financial liberalisation of 1989, which reoriented accumulation toward rentier and financial capital; and the 1994 crisis, which further entrenched IMF-World Bank stabilisation orthodoxy. From the 2000s onward, the Transition to a Strong Economy Program, the Agriculture Law (2006), and other

neoliberal legislative frameworks reinforced these transformations. While Türkiye's agricultural sector experienced increased integration into global markets and heightened import activity for certain commodities, aggregate data indicate that the country maintained a net-exporter status for key agricultural products (See Ministry of Trade, 2023: 8). These trends reflect structural adjustments and selective vulnerabilities rather than an outright "liquidation" of the agricultural sector or the wholesale dismantling of smallholder production. Nevertheless, the policies did contribute to a reconfiguration of the agrarian economy, with transnational capital and large-scale agribusiness increasingly shaping market dynamics and sectoral priorities.

This historical trajectory demonstrates that agriculture has been recast as a fully market-mediated sector, structurally dependent on global value chains, and increasingly stripped of its social, ecological, and strategic functions. Employment contraction, deepening rural poverty, rising import dependence, and the erosion of food sovereignty have emerged as structural outcomes of this neoliberal reordering.

Yet agriculture is not infinitely malleable. Its embeddedness in ecological systems, its centrality to food security, and its socio-political significance as a locus of rural life constitute enduring limits to commodification. While the COVID-19 pandemic and the Russia-Ukraine war highlighted potential vulnerabilities in global food supply chains, there is currently no conclusive data indicating that these events directly caused widespread disruptions in Türkiye's domestic agricultural production. Nevertheless, these global shocks underscore the structural sensitivity of agriculture to international market volatility, illustrating the importance of policies that enhance domestic resilience and safeguard food security.

Thus, the future of Turkish agriculture necessitates careful reconsideration of its policy framework. Strengthening the link between the state and producers through measures that stabilise rural incomes, maintain strategic support mechanisms, and promote sustainable production remains essential for enhancing the resilience and stability of the sector. While Türkiye has historically implemented support policies both directly via central government programs and indirectly through State Economic Enterprises, the long-term effectiveness of these measures has varied across crops and regions. Consequently, future policy interventions should be grounded in empirical assessments of past support programs, aiming to balance market incentives with the structural needs of domestic agriculture and broader food security goals.

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Energy Consumption in the EU: The Role of Productivity and Efficiency-Driven Technology¹

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AB’de Enerji Tüketimi: Üretkenlik ve Verimlilik Odaklı Teknolojinin Rolü²

Abstract

This study investigates how productivity and productivity-intensive technologies affect energy consumption in selected EU countries from 1996 to 2021. Despite technological progress, fossil fuels still dominate, posing environmental and economic concerns. Using the AMG method, results show that multifactor productivity significantly reduces energy use, while productivity-intensive technologies offer smaller but meaningful reductions. In contrast to prior research linking technology to higher energy demand, this study highlights the importance of efficiency-focused innovation. Findings support the EU’s 2030 energy reduction target and suggest policymakers should prioritise productivity-intensive technologies, on-the-job training, and digital tools to decouple growth from energy consumption.

Keywords : Productivity, Productivity Intensive Technology, Energy Consumption, Economic Growth, European Union.

JEL Classification Codes : E20, O47, J24, O11.

Öz

Bu çalışma, 1996-2021 döneminde seçilmiş AB ülkelerinde verimlilik ve verimlilik odaklı teknolojilerin enerji tüketimine etkisini incelemektedir. Teknolojik ilerlemelere rağmen fosil yakıtlar hâlâ baskın kalmakta ve çevresel ile ekonomik sorunlara yol açmaktadır. AMG yöntemiyle elde edilen sonuçlar, çok faktörlü verimliliğin enerji tüketimini önemli ölçüde azalttığını, verimlilik odaklı teknolojilerin ise daha sınırlı ama anlamlı katkılar sağladığını göstermektedir. Teknolojinin enerji talebini artırdığı yönündeki önceki çalışmalardan farklı olarak, bu çalışma verimliliğe odaklanan yeniliklerin önemini vurgulamaktadır. Bulgular, AB’nin 2030 enerji azaltım hedefini desteklemekte ve politika yapıcılara verimlilik odaklı teknoloji, hizmet içi eğitim ve dijital araçlara öncelik verilmesini önermektedir.

Anahtar Sözcükler : Verimlilik, Verimlilik Yoğun Teknoloji, Enerji Tüketimi, Ekonomik Büyüme, Avrupa Birliği.

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1. Introduction

Technological progress and increased productivity have largely been seen as the drivers of the world's rapid economic growth. Several studies, Bahrini and Qaffas (2019), Nguyen et al. (2020) and Zafar et al. (2019) have found a strong correlation between economic growth and frontier technologies and concluded that technology is one of the main drivers of economic growth. As widely expected, economic growth and technological development are accompanied by increased energy use (Gorus & Aydin, 2019; Rahman & Velayutham, 2020). Similarly, the Energy Information Administration (EIA, 2023) reports that total energy consumption is essentially driven by economic growth, whereas energy consumption per capita is linked to changes in technology policy. As a result, for more than a century, the world's economies have been facing a major challenge: technological and economic development that drives energy consumption.

Besides, though Naimoglu (2021) and Zhang et al. (2020) show the effectiveness of energy-saving technologies in reducing energy consumption, the EIA (2023) report indicates that total energy consumption has been trending upwards. Even though there are many reasons for the dichotomy between the effectiveness of energy-saving technologies and the increase in overall energy consumption, Liu et al. (2019), Safarzadeh et al. (2020), and Stern (2020) have explained it through the rebound effect. Although technological innovation may contribute to long-term efforts to reduce energy use, it may increase short-term pressure on energy use through the rebound effect. Given the dependence of economies on fossil fuels, the upward trend in energy consumption has accelerated the negative impacts of energy use (Khan et al., 2021; Abbasi et al., 2022; Onifade, 2023). Therefore, achieving the net-zero emission target of the Paris Agreement with the help of technology is crucial.

Technological progress is driving the globalisation of industries and fostering international trade, while global integration and trade, in turn, accelerate the diffusion of technology (Grossman & Helpman, 2015). An increase in trade inevitably leads to higher energy consumption due to increased production of goods and transport (Al-mulali & Sheau-Ting, 2014; Topcu & Payne, 2018). Trade has a significant impact on urbanisation, transforming cities into centres of attraction and production (Blaydes & Paik, 2021). As a result, trade, production processes, urbanisation, and the diffusion of technology all impact energy consumption. For the period 2021-2024, the EU allocated 15.1% of its total budget, around €208.1 billion, to digital technologies within the framework of the Horizon Europe Programme (European Commission, 2025a). Also, the Digital Europe report (2024) states that Europe is losing competitiveness in technology, particularly against the USA and China, and that the most immediate risk is missing out on productivity gains. Likewise, Bergeaud (2025) highlights that the EU has experienced productivity weaknesses since 1995, which have widened the productivity gap between the EU and the USA. If the EU ignores productivity losses and focuses solely on technology, energy consumption may increase, making it unlikely that the EU's 2030 11.7% reduction target will be achieved (European Commission, 2023). Therefore, the study will clarify the overlooked linkage between energy consumption, productivity, and technology.

Figure: 1
Diagram of the Impact of Technology and Productivity on Energy Consumption

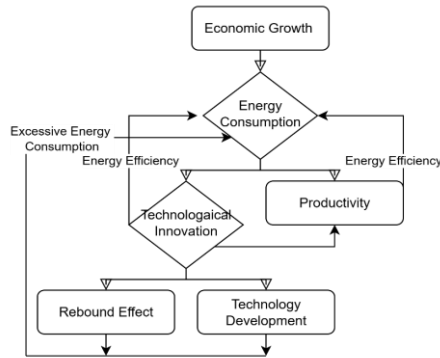
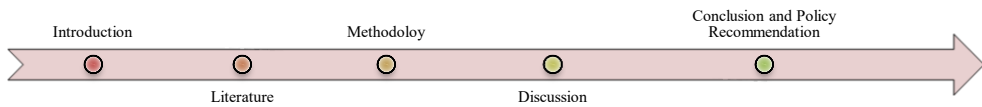


Figure 1 shows the basic relationship between energy and productivity and how they affect energy consumption in an economy. While productivity has a direct effect on energy consumption through energy efficiency, the impact of technological innovation is less straightforward. Technological innovation can lead to energy efficiency. However, the technology development process and the rebound effect may also result in excessive energy consumption. At the same time, technology can boost productivity. Technology and productivity share a complex, inseparable relationship: any increase in productivity intricately influences economic growth, yet energy-efficiency studies have mostly focused on technology. However, studies such as Santos et al. (2021) show that productivity improvements can lead to both economic growth and greater energy efficiency. Considering this perspective, productivity is highly valued for its ability to minimise not only energy input but also other resources such as labour, capital, and raw materials, while maintaining equivalent economic outcomes in production processes (Hasanov & Mikayilov, 2021). Ultimately, this will reduce energy consumption and, in turn, environmental pollution. Due to mixed and conflicting results, further investigation is necessary in this field. Hence, this study aims to investigate how technological advancements and shifts in productivity influence energy consumption across specific EU countries. Changes in energy consumption from 1996 to 2021 have been examined using the Augmented Mean Group (AMG) approach, with technology, productivity, trade, urbanisation, and economic growth rate as explanatory variables.

The literature contains numerous studies on energy efficiency and use. However, the study is intended to fill several gaps in the literature. The first contribution clarifies how technology and productivity drive energy consumption. Instead of prior studies that focused on innovation, communication, transportation, and renewable technologies, this study has focused on total technology spending. Also, by multiplying technology by productivity, a productivity-intensive technology variable has been created to compare technology and productivity in terms of energy usage. Technological innovation is a controversial topic in

the literature. Developing new technologies with excessive resources may result in innovations that are never used or that provide benefits lower than their investment costs. Therefore, this study suggests focusing on productivity when developing new technologies to allocate investment budgets and enhance energy efficiency effectively. This method helps fill a gap in the literature by addressing the overlooked role of productivity in maximising the impact of technological investments. Another expected contribution is to focus on a new sample. The literature has been overwhelmingly supportive of studies on China, Japan, and the USA. However, studies on technology and productivity in the EU have generally been overlooked. To conclude, the findings of this study on energy consumption will make significant contributions to the literature by clarifying mixed results, comparing technology and productivity, and focusing on EU economies. The study's structure is illustrated in Fig. 2.

Figure: 2
Structure of the Study



2. Literature

Energy is a widely debated topic that intersects with all areas of economics, and, as a finite resource, researchers focus on extending its availability. Basically, there are two ways to overcome this hurdle: discovering new energy sources and using existing ones more efficiently. From a general perspective, while technology plays a role in both approaches, productivity is primarily associated with efficiency. Hence, existing literature tends to focus mainly on technology and its impact on energy consumption. For example, information communication technology (ICT) is one of the most widely covered topics in the literature regarding energy consumption, and some milestone studies have been explained, such as Ishida (2015), who has focused on the contributors to energy consumption in Japan from 1980 to 2010, applying Autoregressive Distributed Lag (ARDL). The results show that ICT can reduce energy consumption in Japan. He has emphasised that an increase in ICT developments does not lead to an increase in real GDP, but it does lead to energy efficiency, especially fuel efficiency in transport. This relationship has been approved by Han et al. (2016) for China from 1985 to 2014, only for the short term. The Partial Least Squares (PLS) results indicate a U-shaped relationship between ICT and energy consumption in China. It has been stated that the reason for this relationship may be the use of high-skilled workers, enabled by ICT, rather than low-skilled workers. A similar study has been conducted by Dehghan Shabani and Shahnazi (2019) for the Iranian economy from 2002 to 2013 using the Dynamic Ordinary Least Squares (DOLS) method. They indicate that while ICT increases energy consumption in the industrial sector due to a weaker substitution effect, it improves energy efficiency in the transportation sector through dematerialisation. Usman et

al. (2021) have researched the same phenomena in a broader country sample, Bangladesh, India, Pakistan, and Sri Lanka, from 1990 to 2018 using the ARDL technique. Interestingly, India is the only country to achieve both energy efficiency and economic growth thanks to ICT. However, ICT causes energy consumption in Sri Lanka. Unlike most of the literature, Ren et al. (2021) concluded that ICT increases energy consumption through economic growth in China, using Ordinary Least Squares (OLS) for the period 2006-2017. Verma et al. (2022) concluded that ICT enhances energy consumption in the South Asian Association for Regional Cooperation, using the Driscoll-Kraay method.

In addition to ICT, environmental technology is another technology proxy commonly used in the literature. Paramati et al. (2022) have addressed the subject using environmental technology as a proxy. They have focused on OECD countries from 1990 to 2014 using the AMG method. The findings indicate that environmental technology mitigates energy consumption, because the majority of economies depend on high-energy-intensive sectors. However, the findings of Paramati et al. (2022) have not been confirmed by Shinwari et al. (2024) for Belt and Road Initiative countries during 2000-2021. The Driscoll-Kraay method shows that green environment-related technology increases energy consumption. They suggest that this may be due to the rebound effect and technological developments that increase energy demand. Wang et al. (2023) investigated the causal relationship between energy consumption and technological innovation in the EU from 1995 to 2020 using the Dumitrescu-Hurlin test. The findings indicate a bidirectional causality between energy consumption and technology. Likewise, using generalised least squares (GLS) regression, Alofaysan et al. (2024) found that green technology innovation is associated with energy efficiency in the EU during 2011-2020.

Anser et al. (2024) have also focused on the same problem using a different technology proxy, patent applications. The GMM method shows that technological improvements have increased energy efficiency in BRIC economies over the period 1990 - 2023. However, these findings are contrary to those of Jiang and Khan (2023) for Belt and Road Initiative countries from 1995 to 2019. They have also used patent applications and the GMM method, but they indicated that technological improvements cause more energy consumption. They indicate that innovation needs more energy sources.

The literature has primarily focused on technology as a solution to energy problems. It is widely accepted that technology can address these issues on both demand and supply sides. For example, developing new energy sources such as solar power can help solve supply-side problems, while enhancing energy efficiency through innovations like energy-efficient vehicles can address demand-side challenges. However, it must be remembered that both solutions offer more energy or materials. Therefore, developing solutions to the energy problem that do not rely on increased material consumption could represent a significant advancement. Studies such as Román-Collado and Colinet (2018), Hasanov and Mikayilov (2021), and Qianqian et al. (2025) have strictly suggested that productivity mitigates energy consumption. Román-Collado and Colinet (2018) have investigated the link between labour productivity and energy consumption in Spain from 2000 to 2013 using the LMDI-I method.

The show that labour productivity mitigates energy consumption in Spain. They suggested that this may be related to reduced working hours. However, during a low-unemployment-rate situation, an increase in productivity has an adverse effect on energy consumption. Given the close relationship between technology and productivity, this study proposes productivity-intensive technology as a solution to energy problems and seeks to fill a gap in the literature. The other contribution is that, while most existing research has focused on the role of technology in energy consumption, the specific relationship between productivity and energy consumption has received much less attention, particularly in Europe. Unlike previous studies that primarily investigate Asian, Middle Eastern, or global samples, this research specifically examines the European region, thereby filling a geographical gap in the literature. By highlighting the overlooked link between productivity, technology, and energy efficiency, the study provides a more comprehensive understanding of how Europe can achieve its energy and environmental targets and fill the gap in the literature.

3. Data, Methodology and Findings

3.1. Data

This study includes 13 EU countries for which 'Total Productivity' (MFP) data is available in the OECD database: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Luxembourg, the Netherlands, Portugal, Spain, and Sweden. Although these countries have different levels of development, they share similar characteristics in terms of energy consumption, the dependent variable, and can be considered homogeneous. Although Eurostat provides data for all EU countries, its MFP data was not used because it is still in a raw and experimental format, making it less reliable. The study covers the period from 1996 to 2021, providing a consistent and complete dataset. Details on the data sources and variables are in Table 1.

Table: 1
Definitions and Sources of the Variables

Variables	Symbol	Unit of Measurement	Source
Total Energy Consumption	lnTEC	Fossil, nuclear, and renewable energy consumption per capita (kWh)	Our World in Data
Economic Growth	lnGDP	GDP per capita (US \$)	World Bank-WDI
Multifactor Productivity	lnMFP	Overall efficiency (labour and capital) 2015=100	OECD
Trade	lnTRD	Trade (% of GDP)	World Bank-WDI
Urbanization	lnURB	Urban population to rural population ratio	World Bank-WDI
Patent Applications	lnPAT	Total (residents+ nonresidents)	WIPO statistics database
Productivity*Patent Applications	lnMFP*lnPAT	Numeric	Author's Calculations

To demonstrate the influence of productivity-intensive technology, 2 models have been created. Model 1 in equation (1) is used to show the relationship between total energy consumption (TEC), economic growth (GDP), urbanisation (URB), trade (TRD), and total productivity (MFP). In Model 2 (equation 2), the number of patent applications is added to test whether technological change affects total energy use. In both models, i stands for the country, and t stands for the year. The symbol ε shows the error term in the equations.

Model: 1

$$\ln TEC_{it} = \alpha_0 + \alpha_1 \ln GDP_{it} + \alpha_2 \ln URB_{it} + \alpha_3 \ln TRD_{it} + \alpha_4 \ln MFP_{it} + \varepsilon_{it} \quad (1)$$

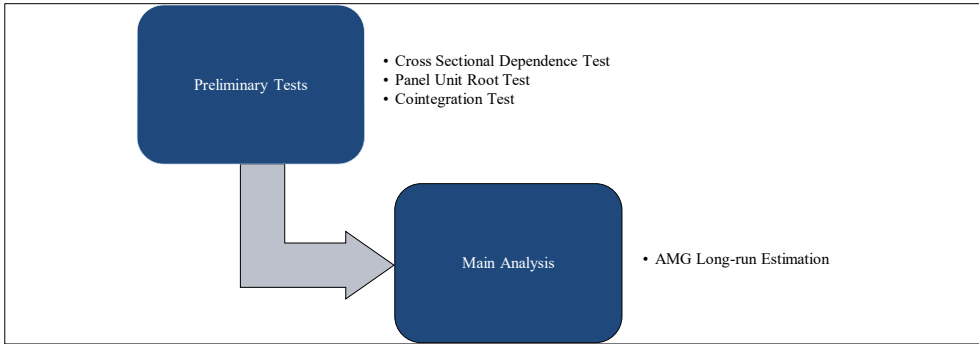
Model: 2

$$\ln TEC_{it} = \alpha_0 + \alpha_1 \ln GDP_{it} + \alpha_2 \ln URB_{it} + \alpha_3 \ln TRD_{it} + \alpha_4 \ln MFP * \ln PAT_{it} + \varepsilon_{it} \quad (2)$$

3.2. Methodology and Findings

Before applying econometric tests to examine the relationships among the variables, preliminary tests must be conducted to ensure more reliable results. These tests help determine the most appropriate econometric method for the study. The study's methodological framework is shown in Figure 2.

Figure: 3
Framework of the Methodology



3.2.1. Cross-Sectional Dependency (CSD) Test

The CSD test is one of the most important diagnostic tests for determining whether events or shocks in one unit affect other units in the dataset. Analysing data without accounting for CSD leads to biased or inconsistent estimates in panel data models. In this study, BP_{LM} and CD_{LM} tests have been used to assess CSD. For improved readability, we have provided a detailed explanation of the tests in the Appendix. The null hypothesis of the tests states that there is no CSD in the series. The findings indicate the presence of CSD in the model. Therefore, second-generation panel unit root tests need to be applied. Table 2 shows both BP_{LM} and CD_{LM} test results.

Table: 2
CSD Test Results

Variables	BP_{LM}	CD_{LM}
lnTEC	394.368***	25.330***
lnMFP	145.801***	5.428***
lnTRD	140.191***	4.979***
lnURB	190.432***	9.002***
lnPAT	117.892***	3.194***
lnMFP*lnPAT	127.828***	3.989***

*** represents 1% significance level.

3.2.2. PANIC Unit Root Test

Based on the CSD test findings, the PANIC unit root test has been applied as a second-generation unit root test. The null hypothesis is that all units are non-stationary, and the alternative hypothesis is that some units are stationary. A detailed explanation of the tests has been included in the Appendix to enhance readability. The unit root test results are shown in Table 3.

Table: 3
PANIC Test Results

Variables	Test	Level	1 st Difference
lnTEC	Z_k^c	-2.3704	8.8651***
	p_k^c	8.9068	89.9271***
lnMFP	Z_k^c	-1.8710	5.0037***
	p_k^c	12.5080	62.0823***
lnTRD	Z_k^c	-1.6621	5.5672***
	p_k^c	14.0142	66.1453***
lnURB	Z_k^c	0.7199	1.5972*
	p_k^c	31.1914	37.5175*
lnPAT	Z_k^c	-2.2115	6.0102***
	p_k^c	10.0529	69.3401***
lnMFP*lnPAT	Z_k^c	-1.5780	7.0496***
	p_k^c	14.6212	76.8351***

***, **, and * indicates 1 %, 5%, and 10 % significance level.

3.2.3. LM Panel Cointegration Test

To continue the long-run econometric analysis in the study, it is necessary to check whether the series are cointegrated. For this purpose, the LM bootstrap panel cointegration test can be applied in the case of CSD. The presence of cointegration across all cross-sectional units is the null hypothesis, and the absence of cointegration across some cross-sectional units is the alternative hypothesis. To improve readability, we have added a detailed explanation of the tests in the Appendix. The results presented in Table 4 indicate that the variables in the models exhibit a long-run cointegrating relationship.

Table: 4
Panel Cointegration Test Results

Test	Model 1			Model 2		
	Statistic	Asymp. p-value	Bootstrap p-value	Statistic	Asymp. p-value	Bootstrap p-value
LM ⁺	4.959	0.000	0.994	4.565	0.000	0.998

Bootstrap p-values are based on 10,000 bootstrap replications.

3.2.4. Augmented Mean Group (AMG) Long-Run Estimation

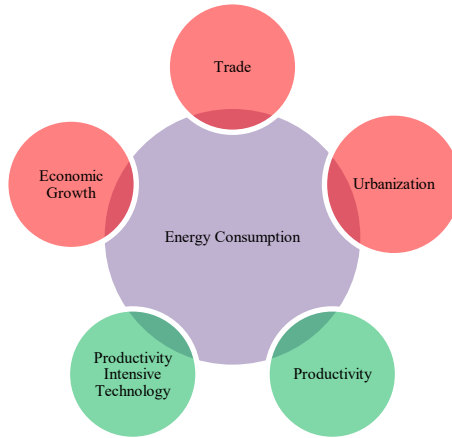
AMG estimation has been designed for use in CSD models and heterogeneous models. We have applied the AMG test since our series exhibits CSD. For improved readability, we have provided a detailed explanation of the tests in the Appendix. The AMG estimation results are presented in Table 5, and the p-value from the Wald test, which assesses the overall significance of the models, indicates that both Model 1 and Model 2 are statistically significant.

Table: 5
AMG Long-run Estimation Results

Variables	Model 1		Model 2	
	$\ln TEC_{it} = \alpha_0 + \alpha_1 \ln GDP_{it} + \alpha_2 \ln URB_{it} + \alpha_3 \ln TRD_{it} + \alpha_4 \ln MFP_{it} + \varepsilon_{it}$		$\ln TEC_{it} = \alpha_0 + \alpha_1 \ln GDP_{it} + \alpha_2 \ln URB_{it} + \alpha_3 \ln TRD_{it} + \alpha_4 \ln MFP + \ln PAT_{it} + \varepsilon_{it}$	
	Values	P-value	Values	P-value
lnGDP	0.713	0.000	0.558	0.000
lnURB	0.349	0.072	0.485	0.006
lnTRD	0.372	0.010	0.264	0.018
lnMFP	-1.488	0.000	-	-
lnMFP*lnPAT	-	-	-0.086	0.071
Wald chi2	295.47	0.000	672.09	0.000

The results of Models 1 and 2 are presented in Table 5. While Model 1 states the influence of productivity on total energy consumption, Model 2 highlights the impact of productivity-intensive technology on total energy consumption. The findings of the Model 1 show that economic growth, urbanisation, and trade boost energy consumption in European Countries. More specifically, a 1% increase in lnGDP causes a 0.713% increase in lnTEC. Similarly, a 1% increase in lnURB and lnTRD increases lnTEC by 0.349% and 0.372%, respectively. However, marginal factor productivity is the only variable that mitigates energy consumption in European Countries. A 1% increase in lnMFP leads to a -1.488% decrease in lnTEC. As in Models 1 and 2, economic growth, urbanisation, and trade boost energy consumption in European Countries. To be specific, 1% increase in lnGDP, lnURB and lnTRD causes a rise in lnTEC by 0.558%, 0.485% and 0.264%, respectively. A 1% increase in lnMFP*lnPAT reduces lnTEC by 0.086%. It shows that productivity-intensive technology mitigates energy consumption in European Countries. The summary of the findings is shown in Figure 4.

Figure: 4
The Summary of the Estimation Results



4. Discussions

It is well known that global energy demand has been steadily increasing. Although innovative technologies have diversified energy sources, fossil fuels still account for the majority of global energy consumption. In energy-importing countries, this puts serious pressure on their economies. The European Commission (2025) stated that the EU paid €604 billion in 2022 for energy imports. In addition to diversifying energy sources, innovative technologies can also mitigate energy consumption by improving energy efficiency. However, this general perspective is sometimes rejected by studies such as Dehghan Shabani and Shahnazi (2019), Usman et al. (2021), Ren et al. (2021), and Verma et al. (2022). The argument in these studies is that technology increases energy consumption: either because it drives economic growth and, in turn, energy consumption, or because technological development itself generates high energy demand. Therefore, this study aims to offer alternative approaches in the literature for mitigating energy consumption by focusing on productivity, to enhance cost, material, and environmental efficiency.

According to OECD (2023), multifactor productivity also encompasses changes in management practices, brand identity, organisational changes, general knowledge, network effects, and spillovers from production factors, alongside the overall efficiency in utilising labour and capital inputs. Based on these definitions, restricting energy consumption without high energy demand in technological processes or the overall economy is achievable. To increase productivity in this case, little or no extra resources are needed. Our findings indicate that increased productivity mitigates energy consumption, and the study presents results consistent with the few studies in the literature that address this issue: Román-Collado and Colinet (2018), Hasanov and Mikayilov (2021), and Qianqian et al. (2025). There are also reservations that productivity increases may increase energy consumption in some

cases, such as a low-unemployment-rate case or a leading-excessive-growth-rate case. In such cases, our findings show that productivity-intensive technologies can mitigate energy consumption and serve as solutions to this problem. Our findings on productivity-intensive technology and energy consumption contrast with those of Dehghan Shabani and Shahnazi (2019), Usman et al. (2021), Ren et al. (2021), and Verma et al. (2022), who primarily focus on technology. In contrast, our study emphasises that technologies should also prioritise productivity to be environmentally friendly. Although this per-unit effect appears modest, its cumulative impact over time and across sectors could be substantial. Even small reductions in energy intensity, when scaled, may translate into meaningful energy and emissions savings, reinforcing the role of productivity-intensive technologies as a pathway toward sustainable energy use in Europe. In particular, energy-intensive sectors such as manufacturing, heavy industry, and transport can significantly reduce fuel consumption through digitalisation and efficiency improvements.

The report of the European Commission (2022) on energy consumption states that the EU has a plan to reduce energy consumption by 2030, providing energy efficiency by 13%. To achieve this target, the report highlights the importance of behavioural awareness, public-sector energy savings, and the adoption of digitalisation and smart technologies. Thus, the definition of multifactor productivity of OECD (2023) and the aim of the European Commission (2022) show significant overlap. In addition, the European Commission (2023) has set a target of achieving a minimum 55% reduction in CO₂ emissions by 2030. However, Çakır and Ökte (2025) indicate that while technology exacerbates environmental degradation, productivity-intensive technology improves environmental quality in the EU. Therefore, focusing on productivity-intensive technology to mitigate energy consumption in the EU has also provided positive environmental externalities. To summarise, our findings indicate that productivity mitigates energy consumption, and productivity-intensive technology can help mitigate energy consumption when productivity does not, as in cases of low unemployment rates that lead to excessive growth.

5. Conclusion and Policy Recommendations

It is widely recognised that global energy demand continues to rise. Although technological advancements have diversified energy sources, fossil fuels still dominate the global energy supply. While energy source diversification is crucial, the efficient use of energy resources is even more critical for extending the lifespan of these limited resources. In light of this, the present study offers valuable insights by focusing on selected EU countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Luxembourg, the Netherlands, Portugal, Spain, and Sweden, over the period from 1996 to 2021. Based on the AMG test results, multifactor productivity significantly reduces energy consumption. Moreover, productivity-intensive technology also contributes to reducing energy use, though to a lesser extent than multifactor productivity alone. Nevertheless, economic growth emerges as the main driver behind increasing energy demand in both models. Urbanisation and trade are also found to positively influence energy consumption.

The models show that economic growth, urbanisation, and trade have a positive effect on energy consumption. Thus, policymakers should be boosting renewable energy, as outlined in the REPowerEU plan of the European Commission (2022). By replacing excessive energy demand with renewable energy sources, Europe can reduce its dependence on Russian energy supplies. This shift will directly weaken the connection between energy and trade. Policymakers should develop policies to decouple economic growth from energy consumption. In light of our findings, productivity-intensive technology can help decouple economic growth from energy consumption. The EU should prioritise productivity-intensive technologies to achieve the same output with less energy. Policymakers should monitor and evaluate each technological innovation, and if it is productivity-intensive, it can be supported with a grant or tax reduction. Policymakers should encourage productivity-intensive innovation in high-energy-demand sectors such as transport, manufacturing, and construction, where marginal efficiency gains can deliver significant reductions in total energy use. Also, our findings show that productivity mitigates energy consumption in the EU. Based on these results, policymakers should centralise productivity in the policies. Those policies, energy savings and efficiency, are also in line with the REPowerEU plan objectives. Policymakers should also be aware that productivity can be increased without technological investment. As the OECD (2023) report states, management practices, brand identity, organisational changes, general knowledge, network effects, and spillovers from production factors are the main determinants of multifactor productivity. Management practices, general knowledge and organisational changes can be enhanced through in-service training. Therefore, the EU should encourage firms to provide such training by providing public funds. Brand identity, network effects, and spillovers from production factors can be enhanced through technology, such as the use of platforms and digital tools that increase in value with user participation, like customer apps or integrated service ecosystems, as well as through knowledge sharing, automation, and cross-departmental collaboration. Therefore, the EU should encourage technological investments by prioritising productivity-intensive technologies.

Data restriction is the biggest limitation in the study. Thus, future studies can modify econometric methods using machine learning techniques that can handle short-term time-series data to cover the entire sample. Further study should also focus on sectoral-level productivity and technology. Specifically, productivity-intensive technology options should be investigated in energy-intensive sectors.

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Appendix

Cross-Sectional Dependency (CSD) Test

Two different CSD tests have been applied in the study to assess whether CSD exists among the variables.

The first CSD test is BP_{LM} test, and it was developed by Breusch and Pagan (1980). The formula of the test is shown in equation (1).

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij}^2 \sim \chi^2_{\frac{N(N-1)}{2}} \quad (1)$$

In this equation, N is constant and $T \rightarrow \infty$ with χ^2 distribution and $\hat{\rho}_{ij}$ shows the sample estimate of pairwise correlation of residuals.

The second test is CD_{LM} and the difference between BP_{LM} and CD_{LM} the test is whether $N \rightarrow \infty$ or not. If $N \rightarrow \infty$, using CD_{LM} is more appropriate (Pesaran, 2004). CD_{LM} test has been calculated based on the equation (2).

$$CD_{LM} = \sqrt{\left(\frac{1}{N(N-1)}\right)} \sum_{i=1}^{N-1} \sum_{j=i+1}^N (T \hat{\rho}_{ij}^2 - 1) \sim N(0,1) \quad (2)$$

The null hypothesis for both tests is that there is no cross-sectional dependence in the series. The findings based on equations (1) and (2) show rejection of the null hypothesis and indicate the usage of second-generation panel unit root tests (Baltagi, 2008).

PANIC Unit Root Test

The PANIC unit root test, one of the second-generation unit root tests, can be used when CSD is present in at least some of the series (Bai & Ng, 2004; Reese & Westerlund, 2016). The test statistics have been formulated based on the study by Tıraşoğlu (2017), as shown below.

$$X_{it} = D_{it} + \lambda_i' F_t + e_{it} \quad (3)$$

D_{it} is the polynomial trend function, F_t is the common factor vector which has $r \times 1$ dimension, e_{it} is the error term, and X_{it} is the sum of deterministic components. Also, in the

model with N variables, there are N idiosyncratic components but a small number of common factors (Bai & Ng, 2004).

The factor model in the intercept case can be rewritten as follows:

$$X_{it} = c_i + \lambda'_i F_t + e_{it} \quad (4)$$

where, $x_{it} = \Delta X_{it}$, $f_t = \Delta F_t$, $z_{it} = \Delta e_{it}$ are the differences, so the model can be rewritten in the first-differenced shape.

$$x_{it} = \lambda'_i f_t + z_{it} \quad (5)$$

Let $ADF_{\hat{\epsilon}}^c(i)$ represent t statistic for testing $d_{i0} = 0$ in the univariate augmented autoregression without deterministic terms.

$$\Delta \hat{\epsilon}_{it} = d_{i0} \hat{\epsilon}_{it-1} + d_{i1} \Delta \hat{\epsilon}_{it-1} + \dots + d_{ip} \Delta \hat{\epsilon}_{it-p} + error \quad (6)$$

Let $r = 1$ and $ADF_{\hat{F}}^c$ t statistics for testing $\delta_0 = 0$ in the univariate augmented autoregression including intercept.

$$\Delta \hat{F}_t = c + \delta_0 \hat{F}_{t-1} + \delta_1 \Delta \hat{F}_{t-1} + \dots + \delta_p \Delta \hat{F}_{t-p} + error \quad (7)$$

The model should be rearranged for a linear trend.

$$X_{it} = c_i + \beta_i \lambda'_i F_t + e_{it} \quad (8)$$

The model can be rewritten after some arrangement.

$$x_{it} = \lambda'_i f_t + z_{it} \quad (9)$$

where, the variables express the differences which are; $x_{it} = \Delta X_{it} - \overline{\Delta X_i}$, $f_t = \Delta F_t - \overline{\Delta F}$, $z_{it} = \Delta e_{it} - \overline{\Delta e_i}$

Let $ADF_{\hat{\epsilon}}^r(i)$ represent t statistic for testing $d_{i0} = 0$ in the univariate augmented autoregression without deterministic terms.

$$\Delta \hat{\epsilon}_{it} = d_{i0} \hat{\epsilon}_{it-1} + d_{i1} \Delta \hat{\epsilon}_{it-1} + \dots + d_{ip} \Delta \hat{\epsilon}_{it-p} + error \quad (10)$$

Let $r = 1$ and $ADF_{\hat{F}}^r$ t statistics for testing $\delta_0 = 0$ in the univariate augmented autoregression including intercept and time trend. Then the model becomes in equation (11)

$$\Delta \hat{F}_t = c_0 + c_{it} + \delta_0 \hat{F}_{t-1} + \delta_1 \Delta \hat{F}_{t-1} + \dots + \delta_p \Delta \hat{F}_{t-p} + error \quad (11)$$

For the models having trend and intercept, p values combining with $ADF_{\hat{\epsilon}}^c(i)$ and $ADF_{\hat{\epsilon}}^r(i)$ have been test by $p_{\hat{\epsilon}}^c(i)$ and $p_{\hat{\epsilon}}^r(i)$.

$$p_{\hat{\epsilon}}^c = \frac{-2 \sum_{i=1}^N \log p_{\hat{\epsilon}}^c(i) - 2N}{\sqrt{4N}} \xrightarrow{d} N(0,1) \quad (12)$$

$$p_{\hat{\epsilon}}^{\tau} = \frac{-2 \sum_{i=1}^N \log p_{\hat{\epsilon}}^{\tau}(i) - 2N}{\sqrt{4N}} \xrightarrow{d} N(0,1) \quad (13)$$

The test first proposed by Maddala and Wu (1999) for fixed N and Choi (2001) has improved the test for $N \rightarrow \infty$ (Bai & Ng, 2004). The obtaining statistics values of $p_{\hat{\epsilon}}^c(i)$ and $p_{\hat{\epsilon}}^{\tau}(i)$ have been compared with the table critical values to test that null hypothesis which is all units are non-stationary against the alternative hypothesis which is some units are stationary.

LM Panel Cointegration Test

The LM bootstrap panel cointegration test developed by Westerlund and Edgerton (2007) has been used in the study. The test formulation is shown below.

$$y_{it} = a_i + x_{it}\beta_i + z_{it} \quad (14)$$

Here, $t = 1, \dots, T$ and $n = 1, \dots, N$ denote the time period and cross-sectional units, respectively. The variable x_{it} has dimension K , may follow a pure random walk process, while z_{it} represents the distributional components of the data. The test statistics of the test is calculated based on equation (15).

$$LM_N^t = \frac{1}{NT^2} \sum_{i=1}^N \sum_{t=1}^N \hat{\omega}_i^{-2} S_{it}^2 \quad (15)$$

Here, the terms S_{it} and ω_{it} represent the partial sum processes of the error term z_{it} , derived using the Fully Modified Ordinary Least Squares (FMOLS) method. The presence of cointegration across all cross-sectional units is the null hypothesis, and the absence of cointegration across some cross-sectional units is the alternative hypothesis.

AMG Long-Run Estimation

The AMG estimation introduced by Eberhardt and Bond (2009) is designed for use in CSD and heterogeneous models. The AMG estimation process begins by applying first differences to the data using time dummy variables for all but one period in a pooled regression (FD-OLS). In the second stage, the model is estimated by including each of the cross-sectional regressions $\hat{\mu}_t$ in the first stage. Alternatively, $\hat{\mu}_t$ is different from the dependent variable. This case, on the other hand, shows that a common process is applied to each unit. In the third stage, using the MG approach developed by Pesaran and Smith (1995), the estimations have been applied. The formulation of the estimation is shown below.

$$\Delta Y_{it} = b' \Delta X_{it} + \sum_{t=2}^T c_t \Delta D_t + e_t \text{ and } \hat{c}_t \equiv \hat{\mu}_t \quad (16)$$

$$Y_{it} = a_i + b' X_{it} + a_i t d_i \hat{\mu}_t + e_{it} \quad (17)$$

$$\hat{b}_{AMG} = N^{-1} \sum_i \hat{b}_i \quad (18)$$

Digitalisation and Economic Performance: The Impact of ICT on Tourism, Exports and Investments

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Dijitalleşme ve Ekonomik Performans: BİT'in Turizm, İhracat ve Yatırımlar Üzerindeki Etkisi

Abstract

This study examines the long- and short-term effects of Information and Communication Technology (ICT) investments on tourism, export, and foreign direct investment (FDI) in 12 developing economies during the period 1995-2020. To account for cross-sectional dependence, heterogeneity, and serial correlation in the panel data, the Pooled Mean Group Autoregressive Distributed Lag (PMG-ARDL) estimator developed by Pesaran, Shin, and Smith (1999) was employed. Contrary to the existing literature, empirical findings indicate that ICT expenditures have statistically significant negative long-term relationships with all three economic variables: exports (coefficient = -1,62, $p = 0,04$), tourism (coefficient = -0,56, $p = 0,00$), and FDI (coefficient = -1,55, $p = 0,00$). Notably, while the error-correction terms for exports and tourism indicate stable convergence to equilibrium (-0,78 and -0,77, respectively), the FDI model yields an error-correction coefficient of -1,83, suggesting an oscillatory, potentially unstable adjustment process. The results suggest that ICT investments may negatively affect these key indicators in the long term in the context examined, and emphasise the importance of complementary policies to unlock their positive potential.

Keywords : Information and Communication Technologies, Tourism Revenues, Export, Foreign Direct Investment, PMG-ARDL Approach.

JEL Classification Codes : C33, F21, O33, Z32.

Öz

Bu çalışma, 1995-2020 döneminde 12 gelişmekte olan ekonomide Bilgi ve İletişim Teknolojileri (BİT) yatırımlarının turizm, ihracat ve doğrudan yabancı yatırımlar (DYY) üzerindeki uzun ve kısa vadeli etkilerini incelemektedir. Panel verilerindeki kesitsel bağımlılık, heterojenlik ve seri korelasyonu hesaba katmak için Pesaran, Shin ve Smith (1999) tarafından geliştirilen Havuzlanmış Ortalama Grup Otoregresif Dağıtılmış Gecikme (PMG-ARDL) tahmincisi kullanılmıştır. Mevcut literatürün aksine, ampirik bulgular, BİT harcamalarının üç ekonomik değişkenle de istatistiksel olarak anlamlı negatif uzun vadeli ilişkiler içinde olduğunu göstermektedir: ihracat (katsayı = -1,62, $p = 0,04$), turizm (katsayı = -0,56, $p = 0,00$) ve DYY (katsayı = -1,55, $p = 0,00$). Özellikle, ihracat ve turizm için hata düzeltme terimleri dengeye doğru istikrarlı bir yakınsamayı gösterirken (-0,78 ve -0,77, sırasıyla), doğrudan yabancı yatırım modeli -1,83'lük bir hata düzeltme katsayısı vermekte olup, bu da salınımlı ve potansiyel olarak istikrarsız bir uyum sürecine işaret etmektedir. Sonuçlar, ICT yatırımlarının incelenen bağlamda uzun vadede bu temel göstergeler üzerinde olumsuz bir etkiye sahip olabileceğini ve olumlu potansiyeli ortaya çıkarmak için tamamlayıcı politikaların önemini vurgulamaktadır.

Anahtar Sözcükler : Bilgi ve İletişim Teknolojileri, Turizm Gelirleri, İhracat, Doğrudan Yabancı Yatırım, PMG-ARDL Yaklaşımı.

1. Introduction

In recent years, the profound influence of digitalisation on national economies has become a central topic of scholarly inquiry. The digital shift has emerged as a transformative force, redefining economic systems and societal norms. Among the key facilitators of this shift are Information and Communication Technologies (ICT), which are now considered not merely tools of technological advancement but strategic enablers of economic progress. ICT investments, in particular, have increased the visibility and accessibility of the tourism industry (OECD, 2017), facilitated exporters' entry into international markets, and positioned digitally advanced nations as attractive hubs for foreign direct investment (World Bank, 2020). Within this framework, digitalisation is increasingly recognised as a catalyst redirecting global trade patterns and investment streams (Brynjolfsson & McAfee, 2014). Nonetheless, the pace and depth of this transformation differ significantly across countries, raising ongoing questions regarding its uneven effects. As a result, comparative cross-country and sector-specific investigations are necessary to fully grasp the implications of digitalisation on the global economic landscape (Gereffi, 2018).

The tourism sector, known for its significant contributions to economic growth, is also highly sensitive to technological innovations. In this context, investments in Information and Communication Technologies (ICT) are a cornerstone of the sector's digital transformation, as they enhance destinations' visibility in the digital sphere, strengthen customer engagement, and support business competitiveness (Buhalis & Law, 2008). Technological advances ranging from web-based reservation systems to targeted digital campaigns, mobile platforms, and immersive virtual experiences have fundamentally changed both tourists' decision-making processes and tourism businesses' operational activities. A robust digital infrastructure enables service providers to establish more efficient connections with potential visitors, while empowering consumers with tools such as real-time reservations, price comparisons, and user reviews, thereby enhancing trust and increasing reservation rates. Ultimately, these developments lead to increased tourist numbers and per capita spending, thereby boosting total tourism revenues (Gretzel et al., 2006). Thus, ICT has evolved from a mere technological component to a strategic instrument that shapes tourism revenue, commercial expansion, and foreign investment patterns. However, studies that comprehensively assess this multifaceted dynamic and provide cross-country comparative analyses remain limited in the literature.

The concept of Foreign Direct Investment (FDI) is defined by UNCTAD (2021) as the transfer of capital by a foreign investor to an enterprise in another country to provide long-term benefits. According to Seyidoğlu (2003), FDI is realised through an enterprise's establishment of new facilities or the acquisition of existing ones in another country. In this respect, FDI is the transfer of capital by international investors to engage in economic

activity in a country outside their own borders, and investment can be made individually or through partnerships with local firms. In recent years, ICT developments have had a significant impact on the direction, form and intensity of FDI. Countries with strong digital infrastructure have become more attractive to investors, both for operational efficiency and for the level of digitalisation. Therefore, ICT is no longer seen as merely a supporting element but also as a critical factor in investment decisions (Loungani & Razin, 2001). Multinational companies prefer countries with strong ICT infrastructure to manage global production processes more flexibly and in an integrated manner. Advanced digital infrastructure accelerates data flows, enhances remote management capabilities and facilitates supply chain integration (Brouwer et al., 2003). On the other hand, FDI also contributes to the development of the host country's digital infrastructure, creating positive externalities such as knowledge transfer, increased technical skills, and strengthened innovation capacity (Borensztein et al., 1998).

In terms of exports, ICT supports trade by enabling faster, more efficient, and more secure trade between countries. Digitalisation expands the boundaries of trade and facilitates firms' access to international markets (Mann & Eckert, 2000). For exporters, ICT not only transforms marketing and sales processes but also increases efficiency in key operational areas such as logistics, supply chain management and customer relations. Digital platforms and e-commerce sites enable small and medium-sized enterprises to compete in the global market and facilitate the integration of emerging economies into the international trade system (Almeida, 2007). In particular, e-commerce enables firms to conduct their export processes in a digital environment and reach consumers worldwide without being limited to local markets.

In today's globalised economic environment, Information and Communication Technologies (ICT) have become a central driver of both economic expansion and development strategies. Over the last two decades, as digital transformation has accelerated, the influence of ICT infrastructure on critical macroeconomic components, including tourism, international commerce, and foreign direct investment (FDI), has gained significant attention in both academic research and policy discussions.

As globalisation progresses, the growth of digital platforms and changing consumer behaviours has amplified the strategic relevance of ICT across these areas. However, a careful review of the existing body of work shows that although there is substantial research on ICT's effects within the tourism sector, studies that simultaneously evaluate its connections to broader economic variables such as export volumes and FDI, particularly using cross-country data, remain limited.

Addressing this research gap, the present study examines in depth the relationships among ICT expenditures, tourism income, export levels, and FDI flows. It draws on data from 12 developing countries over the 1995-2020 period. By adopting a multi-variable and comparative perspective, the study aims to make a distinctive academic contribution by embedding these interactions within a cohesive empirical model.

The impact of Information and Communication Technology (ICT) investments on economic outcomes has been examined within the framework of the New Growth Theory and the Endogenous Technology Approach. According to these theories, technological investments contribute to economic growth by enhancing productivity (Romer, 1990; Aghion & Howitt, 1992). However, since our study's findings indicate a negative relationship contrary to general expectations in the literature, our analysis also discusses potential negative externalities, including inefficient use of ICT investments, infrastructure deficiencies, a lack of skilled human capital, and inadequate policy and institutional alignment. In this context, the study is linked to the ICT Paradox (Solow, 1988) literature, emphasising the importance of complementary reforms and institutional capacity for technological investments to generate positive effects.

2. Literature

Information and communication technologies (ICT) are at the heart of the structural transformation of the global economy, driving innovation in tourism, exports, and foreign direct investment (FDI). In tourism, ICT infrastructure contributes to the growth of sectoral revenues by optimising access to destinations, while in exports, digital tools enable SMEs to integrate into global markets by minimising geographical constraints. In the context of FDI, economies with high ICT maturity are attractive to foreign investors thanks to their infrastructure that reduces communication costs and increases productivity. However, the existing literature lacks an integrated perspective on the interrelationships among these three areas and the multiple impacts of ICT. In this study, academic findings on ICT-tourism revenues, ICT-exports and ICT-FDI relations will be detailed under separate headings, and literature will be presented.

2.1. Relationship between ICT and Tourism Revenues

Tourism has emerged as one of the earliest adopters of digital transformation, leading the way by moving services such as flight and hotel bookings online. With the rapid spread of information and communication technologies (ICT) across the globe, the sector has been at the forefront of technological developments by rapidly adopting new tools and digital innovations (unwto.org, 2025). ICT has fundamentally transformed the functioning and dynamics of the tourism industry. While travellers used to rely on printed guides or travel agencies for information, they now have instant access to destination information through search engines, websites and social media. This change has accelerated travel decision-making processes, reduced the need for intermediaries and made tourists more independent and informed. For example, international research shows that countries with high internet usage rates, secure servers and a high number of mobile subscribers experience significant increases in the number of tourists and tourism revenues. These findings suggest that destinations with strong digital infrastructure and active online presence are likely to attract more demand (Lee et al., 2021).

The economic impact of ICT on tourism is a topic frequently examined in the academic literature. However, studies examining ICT, tourism revenues, foreign direct investment and export variables together are quite limited. The general opinion is that investments in ICTs increase countries' tourism performance and revenues. However, the magnitude and form of this effect may differ depending on the level of development and tourism infrastructure of countries. Some important findings from studies conducted on different country groups in the last decade are as follows:

Tourism Demand and Internet Access: A large-scale empirical investigation utilising World Bank data has revealed that key ICT indicators, including growth in mobile phone usage, expansion of secure internet servers, and broadband access, exert a significant positive influence on international tourist inflows. Enhancements in ICT infrastructure, particularly in digital connectivity, have been found to correlate with higher volumes of international visitors.

For instance, Lee et al. (2021) demonstrated, in a panel analysis covering 189 countries between 2000 and 2018, that growth in mobile phone subscriptions significantly boosts tourist arrivals. In a similar vein, Rajan et al. (2016) noted that the proliferation of secure internet servers contributes to increased international tourism flows.

Tourism Revenues and ICT Use: A growing body of empirical evidence indicates a strong, positive association between ICT variables and tourism income. For instance, Choudhary et al. (2020), through a panel data study covering 28 nations, emphasised the significant contribution of ICT utilisation to the rise in tourism earnings. Specifically, factors such as internet penetration, mobile connectivity, and widespread access to digital platforms were associated with statistically significant, long-term increases in tourism-related inflows.

According to Kumar & Kumar (2012), the Granger causality test revealed a one-way causal relationship from capital accumulation to ICT development, and subsequently from ICT improvements to tourism income. Al-Mulali et al. (2020) also demonstrated through regression analysis that digital transformation positively influences actual tourism income across various regional clusters, excluding high-income nations. Similarly, Tsaurai & Chimbo (2019) argue that ICT development fosters tourism revenues over both the short and long term.

Differences between Developed and Developing Countries: The influence of ICT on tourism revenues can vary significantly across countries, depending on their level of digital development and overall economic context. A comprehensive international study explored the role of ICT in promoting inclusive growth within the tourism industry and highlighted regional disparities in ICT effectiveness. As outlined by Nchofoung et al. (2022), while ICT-related investments tend to boost tourism development in regions such as Europe and Asia-Pacific, where digital infrastructure and skilled labour are more abundant, they may yield more modest outcomes in regions such as Africa and Latin America, where digital competencies are generally lower.

Nevertheless, a panel data analysis covering African nations from 1996 to 2016 by Adeola & Evans (2020) found a statistically significant long-term increase in tourist arrivals and tourism revenues, driven by enhancements in telecommunications and internet accessibility. Thus, despite structural limitations, ICT investments are increasingly emerging as a catalyst for tourism development, even in less developed economies.

According to the Tourism Competitiveness Index, based on the 2021/2024 Travel and Tourism Development Index (TTDI) published by the World Economic Forum, a well-established ICT infrastructure is a fundamental determinant of a country's competitiveness in the tourism sector. The 2024 version of the report emphasises that, in the post-pandemic era, ICT readiness scores have increased by 7.2% across many economies, primarily due to the accelerated digitalisation of travel and tourism services. The report further underlines that a significant portion of the top 30 countries with the highest tourism competitiveness are advanced economies characterised by sophisticated digital infrastructure. Countries such as the United States, Spain, Japan, France, Germany, and the United Kingdom exemplify this trend, benefiting from the effective integration of their transport systems, tourism assets, and digital technologies. The fact that these countries collectively generated over 75% of global tourism GDP in 2022 is a clear indicator of the strong positive association between digital infrastructure quality and tourism revenue performance (Travel & Tourism Development Index, 2024).

In sum, academic literature and international indices show that investments in ICT and technological development generally have a positive impact on tourism revenues. Factors such as a good communication infrastructure, high internet and mobile penetration, and the prevalence of online services can both attract more tourists and increase per capita spending. There is also evidence that large-scale digital transformation projects, such as the "smart city" concept, significantly increase the attractiveness of destinations and tourism yields (e.g., the China smart city example, a +24% increase in tourism revenue) (Ji et al., 2024). In light of these findings, it is clear that both the public and private sectors should continue to invest in tourism technology.

2.2. Relationship between ICT and Export

Recent progress in information and communication technologies (ICT) has emerged as a key driver enhancing national export performance and global competitiveness. From a theoretical standpoint, well-developed communication systems and broad internet accessibility help streamline information flow and establish market connections, ultimately reducing the barriers for firms entering international trade arenas. Numerous scholarly works support a positive linkage between ICT-related metrics and foreign trade outcomes. For instance, Akhvlediani (2021) found that in Asian countries, a 10% rise in telephone subscriptions, both in exporting and importing nations, can lead to a 2.2% to 2.6% increase in bilateral trade volumes.

With the worldwide acceleration of digitalisation over the last decade. The role of ICT in export performance has become more prominent. In particular, the proliferation of e-commerce platforms and digital payment systems makes it easier for even SMEs to find international customers, increasing the number of exporting firms. Increased internet access in developing countries has facilitated their participation in global supply chains. India, for example, has become one of the world's leading exporters of software and IT services thanks to its strong telecom infrastructure and skilled human resources. By 2023, India's software and IT services exports reached approximately \$193 billion annually (Statista, 2024). In sum, countries with strong ICT infrastructure and effective use of digital technologies have gained a competitive advantage in exports in recent years. Thanks to ICT, the decline in communication and computing costs has reduced the importance of geographical barriers; access to distant markets has become possible, and the distances between producers and consumers have shortened "digitally" (Gholami et al., 2005).

2.3. Relationship between ICT and Foreign Direct Investment

The strength of a country's information and communication technology (ICT) infrastructure is a fundamental factor that directly influences its potential to attract foreign direct investment (FDI). International investors seek an advanced digital environment that reduces communication costs, improves supply chain efficiency, and enables modern, data-driven production techniques before making investments in a country. Supporting this expectation, studies have revealed a strong, positive relationship between FDI flows and digitalisation indicators, such as a country's internet usage rate, number of mobile subscribers, and telecommunications quality (Wang & Rukh, 2021; Addison & Heshmati, 2003).

The role of ICT is not limited to making a country attractive to investors by reducing costs; it also acts as a catalyst that enhances the contribution of incoming investment to economic growth. Recent studies indicate that in countries with strong ICT infrastructure and high levels of digital literacy, the positive effects of FDI on inclusive growth increase exponentially. In other words, technology and foreign capital are two complementary strategic forces that accelerate economic development (Ofori & Asongu, 2021).

In the existing literature, the effects of ICT on tourism, exports, or investments have mostly been examined separately. However, comprehensive approaches that analyse these three key macroeconomic components together using recent panel data are quite limited. Moreover, studies focusing on the digital transformation process in developing economies are notably insufficient. In this regard, our study offers a unique contribution to the literature by adopting a holistic approach to examine the multidimensional impact of ICT on economic performance.

3. Methodology and Analysis

To examine the long-term dynamic effects of ICT expenditures on tourism, exports, and FDI in developing economies, the Pooled Mean Group Autoregressive Distributed Lags (PMG-ARDL) model was used, which addresses the cross-sectional dependence, heterogeneity, and serial correlation issues commonly observed in panel data. Traditional fixed-effect/random-effect models distort parameter estimates in such data structures, leading to misleading standard errors and, consequently, erroneous conclusions. This is because traditional fixed- and random-effects models assume that the coefficients are the same across countries (slope homogeneity). If the coefficients are actually heterogeneous (which is often the case), this assumption is violated, and the parameter estimates and standard errors produced by traditional models become inconsistent and biased. This leads to completely incorrect results and policy recommendations (Pesaran et al., 1999).

To solve these problems, they developed their proposed PMG (ARDL) method. The formulation information is given below:

$$\Phi(L, p)y_t = \sum_{i=1}^k \beta_i (L, q_i)X_{it} + \delta w_t + u_t \quad (1)$$

L is a lag operator, and w_t is a $s \times 1$ vector of deterministic variables such as the intercept term, time trends, seasonal dummies, or delay lengths are predetermined deterministic/external components. $P = 0, 1, 2, \dots, m$, $q = 0, 1, 2, \dots, m$, $I = 1, 2, \dots, k$: namely a total of $(m + 1)^{k+1}$ different ARDL models. The maximum lag order, m , is determined by the researcher (Nkoro & Uko, 2016).

In this research, expenditures on Information and Communication Technologies (ICT) are used as the primary independent variable, while tourism income, export earnings, and foreign direct investment (FDI) are the dependent variables. Gross Domestic Product (GDP) serves as a control variable to account for general economic size. The empirical analysis utilises yearly data spanning 1995 to 2020, sourced from the World Bank database. Due to gaps in annual ICT expenditure records across several countries, the final sample consists of 12 developing countries with consistent data availability. All computations and statistical procedures were performed using Stata 14 software.

Table: 1
Cross-Sectional Dependence Test Result

Test Statistic	Probability Value
34.21	0.00*

Note: ***, **, * denote 1%, 5% and 10% significance levels.

Pesaran's (2004) CD test is highly effective at detecting cross-sectional dependence in panel data sets where the time dimension exceeds the cross-sectional dimension ($T > N$). According to the results presented in Table 1, the Pesaran (2004) test indicates the presence of cross-sectional dependence, as evidenced by a p-value of 0,001. Adopting this

methodology enables more robust and reliable inferences by accounting for interdependencies among cross-sectional units within the panel data structure.

Table: 2
CIPS Unit Root Test Result

Variables		Test Statistic-Fixed	Test Statistic-Fixed and Trend
ICT		-0,82	-1,61
Tourism		-1,47	-1,72
Export		-1,90	-1,66
FDI		-3,49*	-4,24*
GDP		-1,28	-1,73
CADF Critical Values	%10	-2,14	-2,66
	%5	-2,25	-2,76
	%1	-2,45	-2,96

Note: ***, **, * denote 1%, 5% and 10% significance levels.

The results of the Pesaran CIPS (2007) unit root test, as shown in Table 2, suggest that the time series is stationary when the test statistic exceeds the critical values in absolute magnitude. Among the variables examined, only FDI satisfies this condition at a level.

Therefore, for variables that do not initially exhibit stationarity, their first differences will be used in the analysis to achieve stationarity. This transformation helps ensure the robustness and statistical validity of the econometric model.

Table: 3
CIPS Unit Root Test Result (First Difference)

Variables		Test Statistic-Fixed	Test Statistic-Fixed and Trend
ICT		-3,50	-4,20
Tourism		-3,73	-3,74
Export		-3,89	-4,01
GDP		-3,68	-3,75
CADF Critical Values	%10	-2,14	-2,66
	%5	-2,25	-2,76
	%1	-2,45	-2,96

Given the panel structure with $T > N$, this study utilises the second-generation CIPS test developed by Pesaran (2007). In contrast to first-generation unit root tests, which assume cross-sectional independence, the CIPS test explicitly accounts for cross-sectional dependence, making it better suited to the dataset's characteristics. According to Pesaran's CIPS test (2007), the level values of the ICT, Tourism, Exports, and GDP variables exhibit unit roots and are therefore not stationary. However, the first differences of these variables were taken. It was concluded that they are stationary at a 1% statistical significance level.

Table 4
Variable Variance Test Result

Test Statistic	Probability Value
0,63	0,53

According to the Breusch-Pagan (1979) and Cook & Weisberg (1983) heteroskedasticity tests, the null of constant error variance cannot be rejected, as indicated

by p-values greater than 0,05. This outcome supports the assumption of homoscedasticity and, by extension, the model's statistical validity.

Furthermore, since the computed test statistic remains below the critical threshold, there is no evidence of significant heteroskedasticity within the dataset, reinforcing the robustness of the regression estimates.

Table: 5
Autocorrelation Test Result (Wooldridge Test)

Test Statistic	Probability Value
5,14	0,04

As shown in Table 5, the Wooldridge (2010) test yields a p-value below the 0,05 significance level, providing statistical evidence of autocorrelation in the model's error terms. This outcome indicates that serial correlation is present; hence, adjustments are required to address it and ensure the reliability and validity of the regression results.

Table: 6
A Model Selection (Breusch-Pagan Lagrangean Test and Hausman Test)

Tests	Test Statistic	Probability Value
Breusch-Pagan Test	116,42	0,00
Hausman Test	0,19	0,90

Table 6 presents the outcomes of the Breusch-Pagan Lagrangean Test (1979) and the Hausman specification test (1978), both conducted to determine the most suitable econometric model for the analysis. The first test produced a p-value of 0,00, indicating strong statistical support for choosing the random effects model over the pooled OLS alternative, as the result falls well below the conventional 5% significance level.

In the second test, the Hausman test yielded a p-value of 0,90, well above the 0,05 critical threshold, confirming that there is no significant difference between the random- and fixed-effects estimators. This outcome supports the selection of the random effects model as a valid specification for the panel data structure in question.

Table: 7
Pesaran, Yamagata Test Result

Delta	Probability Value
2,952	0,00
Adj. 3,38	0,01

As shown in Table 7, the Pesaran and Yamagata (2008) tests indicated heterogeneity when the p-values were less than 5%. This evidence confirms that the PMG-ARDL framework is capable of modelling heterogeneous short-term dynamics while predicting homogeneous long-term relationships, in a manner consistent with the data's structural properties.

Table: 8
PMG-ARDL Test Result

Dependent Variable	Long-Term ICT Coeff.	p-value (ICT)	Cointegration Coeff. (ec_term)	p-ec_term	Interpretation
Export	-1,62	0,04	-0,78	0,00	In the long term, ICT exports are declining but rapidly returning to equilibrium.
Tourism	-0,5593	0,00	-0,77	0,01	ICT spending is reducing tourism, but the balance is quickly being restored.
FDI	-1,5498	0,00	-1,83	0,00	ICT significantly reduces FDI; the adjustment is unstable and oscillatory.

Given detected cross-sectional dependence, heterogeneity, and serial correlation, the PMG-ARDL was adopted. It accommodates heterogeneous short-run dynamics while assuming homogeneous long-run relationships appropriate for the analysed variables. The effects of ICT on tourism, exports, and FDI were tested within this framework.

According to Table 8, ICT has a significant negative effect on export revenues (coefficient = -1,62, $p = 0,04$) and a strong return to equilibrium (cointegration coefficient = -0,78, $p = 0,00$). This indicates that ICT investments reduce exports in the long term, but the economy quickly returns to equilibrium. Tourism revenues are statistically significantly negatively affected by ICT (coefficient = -0,5593, $p = 0,00$). The speed of convergence to equilibrium is also significant (cointegration coefficient = -0,77, $p = 0,01$). ICT has the strongest negative effect on FDI (coefficient = -1,5498, $p = 0,00$).

The FDI model's error correction coefficient of -1.83 indicates an unstable, oscillatory adjustment process. While statistically significant, this coefficient suggests the system overshoots its long-run equilibrium rather than converging smoothly. In conclusion, ICT expenditures have a statistically significant inhibitory effect on all variables. While the Export and Tourism models demonstrate stable and rapid convergence to equilibrium (ec_term = -0.78 and -0.77, respectively), the FDI model exhibits an oscillatory adjustment dynamic, suggesting greater instability in foreign capital flows in response to ICT shocks.

4. Conclusion and Recommendations

Information and communication technologies (ICT) expenditures refer to the total monetary value of digital products/services, such as information technology services (software development, telecommunications infrastructure), consultancy activities, data processing solutions, and similar digital products/services, that a country provides abroad. In this context, ICT expenditures are considered a critical indicator of a country's competitive capacity and technological maturity in the global digital economy.

Using the PMG-ARDL approach, the long- and short-term dynamics between ICT expenditures and key economic indicators, including tourism revenues, export revenues, and foreign direct investment (FDI) inflows, were analysed using panel data from 12 developing countries spanning 1995-2020. The PMG-ARDL approach, which is robust to cross-sectional dependence, heterogeneity, and serial correlation, revealed a consistent and statistically significant negative long-term relationship between ICT investments and the

three dependent variables. Specifically, ICT expenditures were found to have a significant negative impact on export revenues (coefficient = -1.62, $p = 0.04$), tourism revenues (coefficient = -0.5593, $p = 0.00$), and FDI inflows (coefficient = -1.5498, $p = 0.00$). These results contradict the majority of the existing literature, which generally suggests a positive link between ICT and economic performance (e.g., Kumar & Kumar, 2012; Tsaurai & Chimbo, 2019; Adeola & Evans, 2020; Choudhary et al., 2020).

The most important finding of the analysis is that the error correction mechanism ECT is significant in all models. This proves that there is a long-term equilibrium relationship between the variables. The transition to this equilibrium is quite robust in the Export and Tourism models. The coefficients are -0.78 and -0.77, respectively. These values are theoretically within the ideal range. This can be interpreted as follows: 78% of the imbalance from the previous year is corrected in exports and 77% in tourism in the following year. In short, these two sectors stably return to equilibrium after shocks. The FDI model, however, presents a very different picture. The error correction coefficient is -1.83. A coefficient below -1 does not mean a faster correction. On the contrary, it indicates an unstable, oscillatory adjustment process. The system overshoots its target and overreacts as it tries to return to equilibrium.

If interpretation is required for the observed negative long-term effects, this situation may reflect that, for Exports and FDI, the adoption of ICT in the developing economies examined during this period may have high upfront costs, skill mismatches, or disruptive effects that outweigh productivity gains. The negative impact on Tourism may indicate insufficient integration of digital infrastructure in the sector (e.g., delays in adopting dynamic pricing, data analytics, or seamless online experiences), the potential substitution effects of virtual alternatives, or increased competition eroding revenues despite the growth of digital marketing. Deviations from studies reporting positive effects highlight the context-dependent nature of ICT's impact, which can be influenced by the stage of development, sectoral structure, complementary investments, or policy frameworks in emerging example countries.

In conclusion, although ICT is widely regarded as a driving force for growth, this PMG-ARDL analysis reveals a significant negative long-term relationship between ICT expenditures and tourism, exports, and foreign direct investment in the developing economies examined. While the Export and Tourism models demonstrate stable convergence to equilibrium, the oscillatory adjustment in the FDI model highlights the fragility of foreign capital flows in developing economies, collectively necessitating a strategic reassessment of ICT investment policies. It is crucial to emphasise complementary investments, targeted sectoral support, and a robust enabling environment to unlock ICT's positive potential and mitigate the negative effects identified in this study. Future research could develop integrated metrics that assess not only economic outcomes but also the impact of ICT-driven structural changes on social welfare and environmental sustainability.

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Analysis of Firm-Specific Factors Affecting Capital Structure in Renewable Energy Firms

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Yenilenebilir Enerji Firmalarında Sermaye Yapısını Etkileyen Firmaya Özgü Faktörlerin Analizi

Abstract

The purpose of this study is to investigate firm-level determinants of capital structures of renewable energy firms. For the study, data from the world's top 10 renewable energy firms, ranked in the Reuters Energy 100 report from 2019 to 2023, were used. In the study, multiple linear regression is used to analyse associations among variables. Based on the analysis conducted in the study context, profitability, size, asset structure, tax and liquidity variables, and firm leverage showed strong negative correlations. The relationships among the variables provided evidence that the pecking-order theory holds in renewable energy companies.

Keywords : Sustainability, Capital Structure, Trade-off Theory, Pecking Order Theory, Leverage.

JEL Classification Codes : G30, G32, Q20.

Öz

Bu çalışmanın amacı yenilenebilir enerji firmalarının sermaye yapılarına etki eden firmaya özgü faktörlerin analiz edilmesidir. Çalışma kapsamında, Reuters tarafından hazırlanan Energy 100 raporunda yer alan dünyanın önde gelen 10 yenilenebilir enerji firmasının 2019-2023 yılları arasındaki verileri kullanılmıştır. Araştırmada değişkenler arasındaki ilişkilerin analiz edilebilmesi için çoklu doğrusal regresyon analizi kullanılmıştır. Araştırma kapsamında gerçekleştirilen analiz sonucunda, firma kaldıracı ile kârlılık, büyüklük, varlık yapısı, vergi ve likidite değişkenleri arasında anlamlı ve negatif bir ilişki tespit edilmiştir. Değişkenler arasında tespit edilen bu ilişkiler yenilenebilir enerji firmalarında finansal hiyerarşi teorisinin geçerli olduğuna dair kanıtlar sunmuştur.

Anahtar Sözcükler : Sürdürülebilirlik, Sermaye Yapısı, Dengeleme Teorisi, Finansal Hiyerarşi Teorisi, Kaldıraç.

1. Introduction

Financing decisions are among the key topics of corporate finance research. Financing decisions concern the optimal utilisation of equity and debt to finance firms' assets, ensuring the minimum capital cost. By this method, firm value maximisation will be achieved through liability structures that minimise capital costs. To this end, many studies are conducted, and new approaches are discovered and reported in the literature. Although many variables are covered in the literature, the treatments focus mainly on the leverage effect and liquidity. In these studies, theories of capital structure have been developed to explain firms' optimal capital structures.

Theories explaining capital structure can be classified into classical and modern approaches. Classical approaches focus on the effect of changes in the firm's debt-to-equity composition on firm value. These approaches include the net income approach (Durand, 1952), the net operating income approach (Berges, 2004), the classical approach (Baker & Wurgler, 2002), and the Modigliani-Miller (1958) approach. Some recent capital structure theories, such as this paper, highlight the determinants of capital structure. These are listed as trade-off theory (Bontempi, 2002; Stiglitz, 1972), agency theory (Harris & Raviv, 1991), pecking order theory (Frank & Goyal, 2003), signalling theory (Leland & Pyle, 1977), and asymmetric information theory (Harris & Raviv, 1991).

Among modern theories of capital structure, the trade-off theory (TOT) and the pecking order theory (POT) are among the most widely researched. TOT considers the debt used to finance firm assets by evaluating its pros and cons. According to this theory, the use of debt financing provides benefits by allowing the free flow of information and liquidity to firms and institutions within the company's group, except for its tax advantage. The managers' debt burden is also said to make them more inclined to operate at optimal levels. In line with the trade-off theory, while debt financing provides these benefits, bankruptcy costs increase when a threshold is exceeded. Therefore, TOT argues that debt is to be used optimally (Buferna et al., 2005: 7; Ar & Sakur, 2021: 749; Akkaynak, 2022: 60; Ersoy, 2022: 200). POT argues that firms are to utilise retained earnings, debt, and equity, respectively, in meeting their financing needs. As a result, POT suggests that honouring a specific financing sequence for firm assets will enhance firm value (Frank & Goyal, 2003: 219; Akkaynak, 2022: 60; Ersoy, 2022: 200).

According to TOT and POT, there must be certain relationships between firms' capital structures and the variables that determine or affect this structure. Therefore, the negative relationships among the tangible fixed asset ratio, profitability, and the leverage ratio support the POT theory (Abdioğlu & Deniz, 2015: 200; Engin et al., 2019: 690). Similarly, according to POT, there is a negative relationship between leverage and size (Titman & Wessels, 1988; Frank & Goyal, 2009; Ersoy, 2022). Another important finding for the POT theory is that firms with high liquidity will use less debt. Therefore, while POT expects a negative relationship between liquidity and leverage, TOT expects the opposite relationship (Abdioğlu & Deniz, 2015: 204; Engin et al., 2019: 690). When considering the

situation in terms of non-debt tax shields, firms with higher non-debt tax shields, both according to TOT and POT, are expected to use less debt (Cortez & Susanto, 2012: 125). This study tested the TOT and POT theories within this framework within a sample and analysed the findings within this conceptual framework.

There are many studies in the literature examining the optimal capital structures of firms. These studies are mostly focused on sectors such as the manufacturing industry and banking. Surprisingly, not many studies have examined the capital structures of renewable energy firms. In the limited number of studies on the capital structures of renewable energy firms, the issue has been examined at the country and industry levels, but firm-level factors have not been examined for similarly sized international firms. In the econometric analysis carried out within the scope of this study, firm-specific factors affecting the capital structure of the world's 10 leading renewable energy firms (First Solar, GCL-Poly Energy, Green Plains, Guodian Nanjing, Inox Wind, Motech, Pacific Ethanol, and Zhejiang Akcome) included in the Energy 100 report published by Reuters (<<https://www.thomsonreuters.com/en/products-services/energy/top-100>>, 04.02.2025) are used as the data set. Given the scale and capacity of traditional energy companies today, it is extremely important to expand government incentives and financing options to enable renewable energy companies to gain a competitive advantage. This situation becomes even more important given the high initial investment costs of clean and renewable energy. Therefore, it is necessary to analyse the firm-specific factors affecting the capital structures of renewable energy firms.

This study will enable a comparison of whether the TOT or the POT theorem is applicable for driving large-sized companies in this sector. TOT assumes that larger firms use more leverage, whereas POT assumes a negative size-leverage relationship (Titman & Wessels, 1988; Frank & Goyal, 2009; Ersoy, 2022). Therefore, the research seeks to fill a research gap by investigating the capital structures of large renewable energy companies and presenting econometric evidence.

In the second part of the study, the relevant literature is reviewed and the theoretical basis established. In the third part of the study, the data set and methodology are presented, and in the fourth part, the findings are discussed. In the conclusion, the study's results will be discussed.

2. Literature

There are literature review papers that outline firms' capital structures, taking into account macroeconomic and firm-specific determinants. Among the research papers, most explain the capital structures of firms in the energy sector. Research on renewable energy companies has been published in the literature in recent years, however. The majority have chosen country indices or renewable energy companies as their topics. This study differs from others in that it includes the world's leading renewable energy companies featured in

Reuters' Energy 100 report. In this section, the relevant literature on the capital structures of renewable energy companies is reviewed.

Samour et al. (2024) attempted to surface the effects of COVID-19 and capital structure on Chinese listed non-renewable and renewable energy companies. COVID-19 has had unfavourable consequences for non-renewable energy firms, according to the research. With respect to the other situation, financial leverage negatively affects equity and return on assets for both non-renewable and renewable energy companies. Therefore, based on these observations, it is certain that these findings follow the POT method. Irawan and Okimoto (2021) empirically examined the capital structures of renewable and non-renewable energy companies. TOT, POT, and market-timing theorems have been tested using macroeconomic variables in this research. The research concludes that the POT and market-timing theorems hold in describing the capital structures of energy companies. Zhang et al. (2021) examined the relationship between the capital structures of renewable energy companies and Chinese economic performance. The conclusions established from the study are the same as those of Irawan and Okimoto (2021) and Samour et al. (2024).

In Doğan and Erdoğan's (2024) research, capital structure variables of energy companies showed negative correlations with other variables, including the current ratio, return on assets, and the ratio of tangible fixed assets to total assets. In their research, Doğan and Erdoğan (2024) also provided evidence supporting the POT method. In the study by İskenderoğlu et al. (2017) on energy companies in Türkiye, the determinants of capital structure were examined. According to the study, profitability and leverage were negatively related. Evidence from studies supports POT. In Grabinska et al.'s (2021) study, the influence of corporate governance on capital structure in the energy industry was studied. Three proxies for corporate governance were utilised: institutional investors, board size, and government holdings. As the study indicates, institutional investors positively influence debt levels among Polish energy companies. In addition, some studies in the literature focused on the financial performance of electricity companies and examined the impact of capital structure variables on financial performance (Tekin, 2022).

Osiichuk (2023) conducted a comparative study of the financial positions and funding needs of traditional and renewable energy companies in EU countries. The study finds that the financial performance of renewable energy companies is improving over time. The study also offers evidence that renewable energy companies can access cheaper equity capital and easier debt financing. Morina et al. (2021) conducted a study to examine the determinants of profitability of renewable energy companies in European Union member states. The study analyses the profitability of listed renewable energy companies in European Union countries, accounting for firm-, country-, and macroeconomic factors. The research found that firm-specific drivers explain profitability more than macroeconomic factors. The firm size also influences profitability, as the study finds. Leverage also has a direct positive correlation with profitability, as the study finds. The study's findings validate the TOT theorem.

Zhang et al. (2016) reported significant findings in their article for testing both the capital structure and overinvestment hypotheses of Chinese renewable energy companies. The findings of this research showed that there has been overinvestment in China, primarily in the biomass and wind power sectors. The study found that companies' capital structures are funded by corporate bonds and long- and short-term commercial loans. The conclusion stated above follows the TOT model. Wei et al. (2020) examined the effect of capital structure on the performance of Chinese renewable energy firms. Even though the study supported an inverse relationship between profitability and financial leverage among renewable energy firms, it also found that profitability was positively related to sustainable growth.

In general, the literature on the capital structure of renewable energy companies is quite limited. While a significant part of the studies focuses on China (Samour et al., 2024; Zhang et al., 2021; Wei et al., 2020; and Zhang et al., 2016), another part focuses on the EU countries (Osiichuk, 2023; Grabinska et al., 2021; Morina et al., 2021, and Irawan & Okimoto, 2021). Another important finding from the literature review is that studies generally provide supporting evidence for the POT theorem in explaining the capital structures of renewable energy firms. This study contributes to the literature by explaining the capital structures of the world's leading renewable energy companies featured in the Energy 100 report using firm-specific factors. In the next part of the study, six models developed during the research will be introduced, with a focus on the data and methodology.

3. Data & Methodology

3.1. Data

This study aims to determine the firm-specific factors that affect the capital structures of the world's 10 leading renewable energy companies (First Solar, GCL-Poly Energy, Green Plains, Guodian Nanjing, Inox Wind, Motech, Pacific Ethanol, and Zhejiang Akcome), as included in the Energy 100 report published by Reuters. To do this, a multiple regression analysis was performed using financial ratios from the published financial reports of the target firms for the period 2019-2023. Financial statement information for the companies under the study scope was sourced from the Refinitiv Eikon database.

Under the research umbrella, 15 independent variables were used to estimate the effects on 6 dependent variables. Dependent variables, leverage ratios, were used to describe the firm's capital structure. In this study, short-term debt/total asset ratio (S/TA), long-term debt/total asset ratio (L/TA), total debt/total asset ratio (D/TA), short-term debt/equity ratio (S/E), long-term debt/equity ratio (L/E), and total debt/equity ratio (D/E) are utilised as the dependent variables. The independent variables incorporated into the models developed in this study are presented in Table 1.

Table: 1
Dependent and Independent Variables

Variable	Ratios
Profitability	Operating Profit / Sales (O/S) for S/TA, L/TA and L/E models Net Profit / Total Asset (ROA) for D/TA and S/E models Operating Profit / Total Assets (O/TA) for the D/E model
Size	Natural logarithm of capital (LOG _{CAP}) for S/TA, S/E and D/TA models Natural logarithm of sales (LOG _S) for the L/TA model Natural logarithm of total assets (LOG _{TA}) for L/E and D/E models
Asset Structure	Tangible Fixed Assets / Total Assets (TANG)
Growth Opportunities	R&D Expenses/Sales (R&D/S)
Tax	Paid Tax / Profit Before Tax (T/PBT)
Borrowing Cost	Financing Expenses / Total Debt (FE/D)
Liquidity	Current Ratio (CR)
Non-debt tax shields	The ratio between total depreciation expenses and total assets (NDTS)

3.2. Methodology

Multiple linear regression was preferred for the research analysis. Panel data analysis is not used in the research because the sample size is more suited to regression analysis. According to Sekaran (2013), to obtain optimal results from regression analysis, the sample size should be between 30 and 500. According to Baldwin (1989), at least 200 observations are needed in panel data analysis. Given the sample size of 50 in this research, the regression analysis yields optimal results. In this context, 6 models were created and analysed in the study. While creating the models, the firms' asset structures, growth opportunities, taxes, borrowing costs, firm liquidity, and non-debt tax-shield variables were held constant across all models. Model differentiation was achieved using the profitability and firm size variables that most significantly impact capital structure and financial performance. In contrast to this study, many prior studies used different variables for profitability and firm variables in their models (Demirhan, 2009; Dsouza et al., 2023; Gill et al., 2011; Yıldırım & Karabayır, 2024).

$$(S/TA)_{i,t} = \beta_0 + \beta_1 (O/S)_{i,t} + \beta_2 (LOG_{CAP})_{i,t} + \beta_3 (TANG)_{i,t} + \beta_4 (R\&D/S)_{i,t} + \beta_5 (T/PBT)_{i,t} + \beta_6 (FE/D)_{i,t} + \beta_7 (CR)_{i,t} + \beta_8 (NDTS)_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$(L/TA)_{i,t} = \beta_0 + \beta_1 (O/S)_{i,t} + \beta_2 (LOG_S)_{i,t} + \beta_3 (TANG)_{i,t} + \beta_4 (R\&D/S)_{i,t} + \beta_5 (T/PBT)_{i,t} + \beta_6 (FE/D)_{i,t} + \beta_7 (CR)_{i,t} + \beta_8 (NDTS)_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$(D/TA)_{i,t} = \beta_0 + \beta_1 (ROA)_{i,t} + \beta_2 (LOG_{CAP})_{i,t} + \beta_3 (TANG)_{i,t} + \beta_4 (R\&D/S)_{i,t} + \beta_5 (T/PBT)_{i,t} + \beta_6 (FE/D)_{i,t} + \beta_7 (CR)_{i,t} + \beta_8 (NDTS)_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$(S/E)_{i,t} = \beta_0 + \beta_1 (ROA)_{i,t} + \beta_2 (LOG_{CAP})_{i,t} + \beta_3 (TANG)_{i,t} + \beta_4 (R\&D/S)_{i,t} + \beta_5 (T/PBT)_{i,t} + \beta_6 (FE/D)_{i,t} + \beta_7 (CR)_{i,t} + \beta_8 (NDTS)_{i,t} + \varepsilon_{i,t} \quad (4)$$

$$(L/E)_{i,t} = \beta_0 + \beta_1 (O/S)_{i,t} + \beta_2 (LOG_{TA})_{i,t} + \beta_3 (TANG)_{i,t} + \beta_4 (R\&D/S)_{i,t} + \beta_5 (T/PBT)_{i,t} + \beta_6 (FE/D)_{i,t} + \beta_7 (CR)_{i,t} + \beta_8 (NDTS)_{i,t} + \varepsilon_{i,t} \quad (5)$$

$$(D/E)_{i,t} = \beta_0 + \beta_1 (O/TA)_{i,t} + \beta_2 (LOG_{TA})_{i,t} + \beta_3 (TANG)_{i,t} + \beta_4 (R\&D/S)_{i,t} + \beta_5 (T/PBT)_{i,t} + \beta_6 (FE/D)_{i,t} + \beta_7 (CR)_{i,t} + \beta_8 (NDTS)_{i,t} + \varepsilon_{i,t} \quad (6)$$

Explanations regarding the variables included in the six models established here are provided in Table 1. Therefore, explanations regarding the variables will not be repeated. In the next part of the study, the findings will be presented and discussed.

4. Findings and Discussion

Before presenting the findings from time-series analyses, it is necessary to examine descriptive statistics to make a general assessment and remove unsuitable time series from the dataset. In this context, descriptive statistics regarding the variables used in the research are included in ANNEX-1.

The average ratio of total debt to total assets for renewable energy firms' financing is 0.53, as shown in the descriptive statistics in ANNEX-1. However, an examination of the standard deviation of the ratio's volatility shows it is 0,17. As a result, the debt utilisation rate varies across the industry. When analysing debt-to-equity ratios, the industry shows lower volatility. Within these ratios, only the long-term debt-to-equity ratio varies among companies. But this can be considered normal due to the cost of long-term lending.

When the descriptive statistics for the profitability ratios (O/S, ROA, and O/TA) of renewable energy companies are examined, the average values are close to zero, but the volatility is high. The high initial investments and the long time required to turn a profit may affect the sector's average profitability. However, as shown in ANNEX-1, the companies' high profitability rates also indicate the sector's profitability potential.

Another piece of information from ANNEX-1 is that companies have high levels of tangible fixed asset investments (TANG). This situation can also be seen when depreciation is accounted for as a share of total assets. In addition, the sector's average current ratio is quite acceptable at 1,76. Therefore, companies can meet their due liabilities on time.

After the descriptive statistics, the data were subjected to correlation analysis. The correlation results are presented in ANNEX-2. Going through ANNEX-2, it is realised that there exists a strong and significant relationship among capital structure ratios, particularly profitability, asset structure, cost of borrowing, and tax shield ratios, for Models I, II, and III. When the variable for growth opportunities is included, a significant, positive relationship is observed only with short-term debt. In Models IV, V, and VI, strong correlations are observed with profitability, asset structure, debt cost, and non-debt tax shield variables. But there was no correlation between growth opportunity variables and the debt-to-equity ratio. Therefore, based on the initial results of the correlation analysis, it is possible to conclude that the short-term debt ratio variable affects the growth prospects of renewable energy companies. A possible reason is that most of the money spent on R&D is sourced through short-term debt.

In multiple linear regression, stationarity tests are required to assess whether variables are spurious. For this purpose, the Generalised Dickey-Fuller (ADF) test was applied to the time series of the models used in the research (Dickey & Fuller, 1979: 427-431).

Table: 2
ADF Test Results

Variable	Stat.	Prob.	Variable	Stat.	Prob.	Variable	Stat	Prob.
S/TA*	-6,55	0,0000	O/S	-3,46	0,0132	TANG*	-7,21	0,0000
L/TA	-3,31	0,0194	ROA	-4,64	0,0004	R&D/S*	-5,66	0,0000
D/TA*	-6,51	0,0000	O/TA	-4,65	0,0004	T/PBT	-5,97	0,0000
S/E*	-6,47	0,0000	LOG _S *	-7,31	0,0000	FE/D	-4,23	0,0000
L/E	-3,70	0,0069	LOG _{CAP} *	-7,25	0,0000	CR*	-6,65	0,0000
D/E	-3,20	0,0254	LOG _{TA} *	-7,29	0,0000	NDTS	-4,70	0,0004

* Since they are not stationary at the level, their first differences are taken.

Table 2 reports the outcome of the ADF tests. For the series within the scope of application to possess no stationarity, the $p < 0,05$ hypothesis must be fulfilled. As noted in Table 2, all series fulfil the null hypothesis of no unit root. For variables that lacked stationarity at the level, the analysis continued by taking first differences of the series.

For the models established in multiple linear regression analysis to yield accurate results, certain assumptions must be met. These assumptions are: no multicollinearity, no deviation from normality, constant variance assumption, and no autocorrelation in the models (Güriş et al., 2013: 165). For this purpose, the variance inflation factor test was applied to assess multicollinearity in the models developed for the application. When the results of the multiple linear correlation test were examined, the “Centred VIF” values for all models ranged from 1 to 5, indicating no multicollinearity among the variables.

The Jarque-Bera test was used to check the normality assumption of the models examined in the research. For the models to meet the normality assumption, the p-value of the statistic must be greater than 0,05 (Chen & Kuan, 2003:7). It has been determined that Model III and Model VI, among the models within the scope of the study, meet this assumption. However, when the sample sizes of other models are taken into account, there is no problem with performing regression analysis under the central limit theorem. *“The central limit theorem states that the arithmetic mean of a large number of independent and identically distributed random variables, if they have finite variance values, will exhibit an approximately normal distribution; Gaussian distribution.”* Based on this theorem, it is concluded that it is possible to use parametric tests even if the normality assumption is not met in series with 30 or more samples (Artstein et al., 2004: 975-982; Rempala & Wesolowski, 2002: 47-54; Marasinghe et al., 1996).

To test for heteroscedasticity in the models utilised by the study, the Breusch-Pagan-Godfrey test was applied, and to test for autocorrelation, the Breusch-Godfrey test was applied (Yan & Su, 2009: 196, 262-263). The tests showed no evidence of heteroscedasticity in any of the models. It is observed that there is autocorrelation in Models II, V, and VI. To eliminate autocorrelation, the “iterative Cochrane-Orcutt” method was applied to the models (Cochrane & Orcutt, 1949).

Table: 3
Regression Results

	Model (I)	Model (II)	Model (III)	Model (IV)	Model (V)	Model (VI)
O/S	-0,0084 (0,1340)	0,0432 (0,9975)			-0,0801 (0,3925)	
O/TA						-1,3034 (-1,8607)***
ROA			-0,2291 (-1,6931)***	-0,3237 (0,3949)		
LOG _S		0,0191 (1,2276)				
LOG _{CAP}	-0,0313 (-2,0706)**		0,0144 (0,7347)	-0,1848 (-1,5527)		
LOG _{TA}					0,0261 (0,3606)	0,1756 (1,4595)
TANG	-0,6129 (-8,3799)*	0,1420 (1,6814)	-0,2376 (-2,1816)**	-1,9562 (-2,9653)*	0,5761 (1,7329)	-0,9948 (-1,0203)
R&D/S	-0,4588 (0,5842)	0,4358 (0,5835)	-0,8277 (-1,0527)	-2,8050 (0,5889)	1,7163 (0,5979)	-8,3921 (-1,5346)
T/PBT	-0,0239 (-1,1212)	-0,0260 (0,8125)	-0,0889 (-2,4301)**	-0,2826 (-1,2748)	-0,0043 (0,0430)	-0,3537 (-2,3824)**
FE/D	-0,2279 (0,7161)	1,2307 (1,9063)	-0,6445 (-1,2921)	-1,2218 (0,4043)	3,1963 (1,1682)	-3,2318 (-1,3196)
CR	-0,1282 (-7,9413)*	-0,0358 (-3,9345)*	-0,1435 (-9,3204)*	-0,5685 (-6,0952)*	-0,1852 (-3,5019)*	-0,7142 (-4,8042)*
NDTS	0,1312 (0,2754)	1,9345 (2,7188)*	0,8569 (1,3876)	3,1855 (0,8515)	5,2946 (2,0417)**	7,6453 (1,6495)
Constant	0,0021 (0,1082)	0,0679 (1,9162)	-0,0143 (0,5894)	-0,0773 (0,5241)	0,1474 (1,5138)	-0,1709 (0,9210)
Breusch- Pagan-Godfrey	0,6509	0,9689	0,3241	0,5802	0,9975	0,9030
R ²	0,8092	0,4465	0,7432	0,5673	0,4110	0,6056
F-Stat.	(0,0000)	(0,0000)	(0,0000)	(0,0000)	(0,0000)	(0,0000)

* Indicates statistically significant relationship at 1%, ** 5%, *** 10% level.

Table 3 exhibits the outcome of six other models in the context of the research. The regression analysis was carried out using ordinary least squares (OLS). O/S, O/TA, and ROA variables were used to investigate the effect of profitability on the firm's leverage. Results from Models III and VI indicate negative, significant relationships between profitability and firm leverage. These results would indicate that successful firms derive less advantage from borrowing. Yet, if one examines the significance levels of the results, it is evident that they should be supported by other research. Analysis of other studies in the literature revealed an inverse correlation between profitability and firm leverage, consistent with the findings of this research (Samour et al., 2024; Doğan & Erdoğan, 2024; Irawan & Okimoto, 2021; Zhang et al., 2021; İskenderoğlu et al., 2017).

Within the scope of the study, the relationship between firm leverage and size was analysed using the variables sales (LOGS), capital (LOGCAP), and total assets (LOGTA). When the empirical findings in Table 3 are examined, a negative relationship between leverage and size is detected only within Model I. This provides evidence that firms need less short-term debt as their capital size increases. The findings of the model established within the scope of the research regarding the relationship between leverage and size align with those in the literature (Samour et al., 2024; Osiichuk, 2023; Zhang et al., 2021; Grabinska et al., 2021).

Firm asset structure and leverage were investigated through the ratio of tangible fixed assets to total assets. The variable has to be analysed due to its high installation cost for renewable energy companies and their high tangible fixed assets. Negative and strong relationships between firms' leverage and asset structure were found in Models I, III, and IV of this study. This setting provides evidence that renewable energy firms with higher levels of tangible fixed assets are likely to rely on equity capital components rather than short-term debt. These findings are corroborated by Osiichuk (2023) and Grabinska et al. (2021).

In the empirical analysis conducted in this study, the sales-to-research-and-development-expenses ratio was used as the growth-opportunity variable across all models. However, no model supports the contention that leverage is related to growth opportunities. The relationship between leverage and tax was also explored in the study. Here, a negative relationship between firm leverage and tax was found under the scope of Models III and VI. It is important in the context of showing the tax effect of leverage. It is uncommon in the literature to find research on the tax variable for renewable energy firms. However, findings on the leverage-tax relationship are as much as those of Irawan and Okimoto (2021).

In this study, the association between the leverage levels of renewable energy companies and their cost of borrowing was investigated. However, in this study, no significant association was found between these two variables. The current ratio variable was used to investigate the association between leverage and liquidity. The findings reveal negative, significant relationships between leverage and liquidity. There is a negative relationship between leverage and liquidity across all models constructed within the study's framework. This situation shows that firms with less liquid assets tend to borrow more. These findings align with the literature (Osiichuk, 2023; Grabinska et al., 2021). In addition, the negative and robust correlation between liquidity and leverage across all specifications indicates that renewable energy firms prefer to utilise internal sources of funds rather than debt, thereby reducing their external financing requirements by maintaining high liquidity.

Throughout the research, the relationship between leverage and the non-debt tax shield was also investigated. Empirical results confirmed a positive relationship between leverage and the non-debt tax shield. The findings indicate a relationship between non-debt tax shields and high leverage. The positive impact of the non-debt tax shield on leverage indicates that components such as depreciation have a significant financial leverage effect, alongside the tax benefit of firms' debt utilisation. The literature review found that prior research had not examined the impact of non-debt tax shields and leverage on renewable energy firms. Nevertheless, in other sectors, results have been similar to those of this paper (Ersoy, 2022; Söylemez, 2019; Mirza et al., 2017).

After determining the relationships among all variables and leverage, it would be appropriate to draw a general conclusion about the regression outcome. In this study, the analysis found negative relationships between leverage and profitability, size, asset structure, tax variables, and liquidity variables among renewable energy companies. These findings between the variables indicate the relevance of the POT theorem in this sector.

Moreover, for the first time in this study, the relationship between leverage and non-debt tax shields in renewable energy firms was examined, and a positive relationship was found. Conversely, in the research topic, no relationship was observed among the leverage, growth opportunities, and financing cost variables.

5. Conclusion

The world's need for clean, renewable energy is increasing by the day. However, the relative cost advantage of traditional energy sources necessitates subsidies and other credit incentives for investments in renewable energy. Looking at the development of the energy sector, the number and size of renewable and clean energy companies are increasing. In this regard, the literature discusses the capital structures of renewable energy firms.

This study investigates firm-level determinants of the capital structure of renewable energy firms. In the context of the study, the world's top 10 renewable energy firms, as presented in the Reuters Energy 100 report, were used as the dataset. The study differs from other studies found in the literature in terms of the variables and scope. The analysis revealed that firm leverage and profitability, size, asset structure, tax variables, and liquidity variables were strongly negatively correlated. This correlation between variables provided evidence that the POT theorem holds for renewable energy companies.

The study's findings indicate that internal financial factors, including profitability, size, asset structure, and liquidity, influence the leverage ratios of renewable energy companies. It would therefore be beneficial to establish tax incentives, policy support for the use of equity, and low-cost green financing programs to improve firms' internal financing options. Additionally, long-term fixed-rate credit lines must be offered to firms with high levels of tangible fixed asset investment. The tax burden on firms can be reduced by encouraging practices that create non-debt tax shields, such as depreciation. Existing asset-based support policies must be put in place with the consideration that firms with high liquidity need to minimise their borrowing requirements. Lastly, instruments such as publicly supported green bonds and credit guarantees must be scaled up to mitigate sector-specific risks, and sectoral data collection and monitoring mechanisms must be put in place. Within the scope of this study, no relationship was found between leverage, growth opportunities, and financing costs. The reason for this may be the variables used or the data set. Therefore, it is recommended that future studies expand the dataset and test unused variables to yield new findings.

This research has significant findings on identifying capital structure factors for renewable energy companies, but it also faces limitations. Firstly, the investigation relies only on financial ratios and the OLS regression method. This reduces the information about the direction of causality and dynamic impacts. Secondly, the study dataset is restricted to a particular period and sample, making it difficult to generalise to other geographical locations or timeframes. Further research could develop the impact of macroeconomic and institutional factors in cross-country comparative studies. Comparing with other sectors

would provide a better understanding of the dynamics of the renewable energy sector. Moreover, the model could be expanded by integrating variables such as institutional governance structures, environmental performance metrics, and the extent of green finance use.

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ANNEX-1

Descriptive Statistics

Variable	Obs.	Mean	Median	Maximum	Minimum	Standard Deviation	Skewness	Kurtosis
S/TA	50	0,3729	0,3974	0,6668	0,0980	0,1804	0,0079	1,5851
L/TA	50	0,1614	0,1614	0,3675	0,0197	0,0913	0,3823	2,2236
D/TA	50	0,5343	0,5852	0,7614	0,1961	0,1744	-0,5232	1,9541
S/E	50	1,0465	0,9431	2,7680	0,1219	0,7461	0,4047	1,9426
L/E	50	0,4088	0,3270	1,3315	0,0560	0,3028	0,9573	3,3217
D/E	50	1,4553	1,4109	3,1924	0,2440	0,8825	0,3217	1,9703
O/S	50	-0,0080	0,0407	0,5132	-0,6812	0,2085	-0,9907	5,2754
O/TA	50	0,0082	0,0235	0,2422	-0,4012	0,0980	-1,0457	7,9777
ROA	50	-0,0080	0,0057	0,1877	-0,4364	0,0971	-1,5401	9,0664
LOG _S	50	6,9718	7,0958	8,9376	4,4091	1,2147	-0,5914	2,4921
LOG _{CAP}	50	6,6666	6,4338	8,8079	4,6424	1,2154	0,3090	2,0600
LOG _{TA}	50	7,4988	7,2775	9,7022	5,6017	1,2120	0,3648	1,8823
TANG	50	0,3596	0,3414	0,6311	0,0906	0,1530	0,0315	1,9883
R&D/S	50	0,0197	0,0103	0,0684	0,0000	0,0214	0,8920	2,4307
T/PBT	50	0,0359	0,0196	1,4428	-0,6274	0,3020	1,8159	11,1053
FE/D	50	0,0228	0,0144	0,0991	-0,0271	0,0239	0,8049	3,5857
CR	50	1,7627	1,2865	4,3901	0,5243	0,9525	0,9065	2,8047
NDTS	50	0,0342	0,0323	0,1039	0,0083	0,0191	1,1863	5,0311

ANNEX-2 Correlation Coefficients

Model I

	S/TA	O/S	LOG _{CAP}	TANG	R&D/S	T/PBT	FE/D	CR	NDTS
S/TA	1,00								
O/S	-0,31**	1,00							
LOG _{CAP}	-0,17	0,53*	1,00						
TANG	-0,73*	0,14	0,17	1,00					
R&D/S	0,29**	0,31**	0,37*	-0,36*	1,00				
T/PBT	-0,05	0,30**	0,12	-0,08	0,06	1,00			
FE/D	0,04	-0,48*	-0,23	0,30**	-0,35**	-0,35**	1,00		
CR	-0,85*	0,29**	0,16	0,38*	-0,13	0,04	-0,26**	1,00	
NDTS	-0,51*	-0,04	-0,11	0,63*	-0,27	0,07	0,21	0,31**	1,00

Indicates statistically significant relationship at * 1%, ** 5%, *** 10% level.

Model II

	L/TA	O/S	LOG _S	TANG	R&D/S	T/PBT	FE/D	CR	NDTS
L/TA	1,00								
O/S	-0,12	1,00							
LOG _S	0,12	0,61*	1,00						
TANG	0,55*	0,14	0,32**	1,00					
R&D/S	-0,21	0,31**	0,15	-0,36*	1,00				
T/PBT	-0,17	0,30**	0,21	-0,08	0,06	1,00			
FE/D	0,38*	-0,48*	-0,24**	0,30**	-0,35**	-0,35**	1,00		
CR	-0,01	0,29**	0,18	0,38*	-0,13	0,04	-0,26**	1,00	
NDTS	0,47*	-0,04	0,21	0,63*	-0,27	0,07	0,21	0,31**	1,00

Indicates statistically significant relationship at * 1%, ** 5%, *** 10% level.

Model III

	D/TA	ROA	LOG _{CAP}	TANG	R&D/S	T/PBT	FE/D	CR	NDTS
D/TA	1,00								
ROA	-0,43*	1,00							
LOG _{CAP}	-0,21	0,41*	1,00						
TANG	-0,46*	-0,04	0,17	1,00					
R&D/S	0,18	0,14	0,37*	-0,36*	1,00				
T/PBT	-0,14	0,26***	0,12	-0,08	0,06	1,00			
FE/D	0,24***	-0,47*	-0,23	0,30**	-0,35**	-0,35**	1,00		
CR	-0,88*	0,31**	0,16	0,38*	-0,13	0,04	-0,26**	1,00	
NDTS	-0,28**	-0,42*	-0,11	0,63*	-0,27	0,07	0,21	0,31**	1,00

Indicates statistically significant relationship at * 1%, ** 5%, *** 10% level.

Model IV

	S/E	ROA	LOG _{CAP}	TANG	R&D/S	T/PBT	FE/D	CR	NDTS
S/E	1,00								
ROA	-0,25***	1,00							
LOG _{CAP}	-0,10	0,41*	1,00						
TANG	-0,57*	-0,04	0,17	1,00					
R&D/S	0,23	0,14	0,37*	-0,36*	1,00				
T/PBT	-0,09	0,26***	0,12	-0,08	0,06	1,00			
FE/D	0,10	-0,47*	-0,23	0,30**	-0,35**	-0,35**	1,00		
CR	-0,80*	0,31**	0,16	0,38*	-0,13	0,04	-0,26**	1,00	
NDTS	-0,38*	-0,42*	-0,11	0,63*	-0,27	0,07	0,21	0,31**	1,00

Indicates statistically significant relationship at * 1%, ** 5%, *** 10% level.

Model V

	L/E	O/S	LOG _{TA}	TANG	R&D/S	T/PBT	FE/D	CR	NDTS
L/E	1,00								
O/S	-0,20	1,00							
LOG _{TA}	0,14	0,41*	1,00						
TANG	0,31**	0,14	0,04	1,00					
R&D/S	-0,04	0,31**	0,43*	-0,36*	1,00				
T/PBT	-0,13	0,30**	0,07	-0,08	0,06	1,00			
FE/D	0,34**	-0,48*	-0,16	0,30**	-0,35**	-0,35**	1,00		
CR	-0,36*	0,29**	-0,09	0,38*	-0,13	0,04	-0,26**	1,00	
NDTS	0,33**	-0,04	-0,19	0,63*	-0,27	0,07	0,21	0,31**	1,00

Indicates statistically significant relationship at * 1%, ** 5%, *** 10% level.

Model VI

	D/E	O/TA	LOG _{TA}	TANG	R&D/S	T/PBT	FE/D	CR	NDTS
D/E	1,00								
O/TA	-0,38*	1,00							
LOG _{TA}	0,20	0,28**	1,00						
TANG	-0,38*	0,01	0,04	1,00					
R&D/S	0,18	0,10	0,43*	-0,36*	1,00				
T/PBT	-0,12	0,28**	0,07	-0,08	0,06	1,00			
FE/D	0,20	-0,40*	-0,16	0,30**	-0,35**	-0,35**	1,00		
CR	-0,80*	0,31**	-0,09	0,38*	-0,13	0,04	-0,26**	1,00	
NDTS	-0,21	-0,35**	-0,19	0,63*	-0,27	0,07	0,21	0,31**	1,00

Indicates statistically significant relationship at * 1%, ** 5%, *** 10% level.

ANNEX-3 Variance Inflation Factors Test Results

MODEL I		MODEL II		MODEL III	
Variable	VIF	Variable	VIF	Variable	VIF
O/S	1,475	O/S	1,475	ROA	1,840
LOG _{CAP}	1,321	LOG _S	1,321	LOG _{CAP}	1,364
TANG	1,714	TANG	1,714	TANG	1,729
R&D/S	1,828	R&D/S	1,828	R&D/S	1,902
T/PBT	1,275	T/PBT	1,275	T/PBT	1,297
FE/D	1,610	FE/D	1,610	FE/D	1,524
CR	1,079	CR	1,079	CR	1,115
NDTS	1,374	NDTS	1,374	NDTS	1,491
C	NA	C	NA	C	NA
MODEL IV		MODEL V		MODEL VI	
Variable	VIF	Variable	VIF	Variable	VIF
ROA	1,840	O/S	1,440	O/TA	1,593
LOG _{CAP}	1,364	LOG _{TA}	1,557	LOG _{TA}	1,581
TANG	1,729	TANG	1,741	TANG	1,763
R&D/S	1,902	R&D/S	1,767	R&D/S	1,838
T/PBT	1,297	T/PBT	1,324	T/PBT	1,371
FE/D	1,524	FE/D	1,593	FE/D	1,413
CR	1,115	CR	1,278	CR	1,344
NDTS	1,491	NDTS	1,330	NDTS	1,410
C	NA	C	NA	C	NA

ANNEX-4

Autocorrelation Test Results

Date: 07/31/25 Time: 14:38

Sample (adjusted): 2 50

Included observations: 49 after adjustments

Date: 07/31/25 Time: 14:54

Sample (adjusted): 2 50

Included observations: 49 after adjustments

Autocorrelation	Partial Correlation	AC	PAC	Q-Stat	Prob	Autocorrelation	Partial Correlation	AC	PAC	Q-Stat	Prob
		1 -0.118	-0.118	0.7195	0.396			1 -0.214	-0.214	2.3881	0.122
		2 -0.028	-0.043	0.7619	0.683			2 0.072	0.027	2.6638	0.264
		3 -0.079	-0.089	1.1048	0.776			3 0.078	0.103	2.9923	0.393
		4 -0.144	-0.170	2.2618	0.688			4 -0.173	-0.146	4.6548	0.325
		5 0.151	0.108	3.5618	0.614			5 0.088	0.014	5.0913	0.405
		6 -0.193	-0.194	5.7305	0.454			6 0.072	0.115	5.3934	0.494
		7 -0.129	-0.209	6.7220	0.458			7 -0.139	-0.095	6.5366	0.479
		8 0.051	-0.010	6.8785	0.550			8 -0.021	-0.124	6.5642	0.584
		9 0.018	0.002	6.8999	0.648			9 -0.076	-0.085	6.9231	0.645
		10 0.226	0.134	10.159	0.427			10 -0.036	-0.015	7.0049	0.725
		11 -0.094	-0.054	10.739	0.465			11 -0.081	-0.136	7.4364	0.763
		12 -0.036	-0.031	10.825	0.544			12 -0.006	-0.062	7.4387	0.827
		13 -0.046	-0.096	10.974	0.613			13 0.110	0.148	8.2750	0.825
		14 0.020	0.023	11.003	0.686			14 -0.106	-0.052	9.0781	0.826
		15 0.036	-0.013	11.097	0.746			15 0.083	-0.011	9.5850	0.845
		16 -0.005	0.074	11.099	0.803			16 -0.089	-0.090	10.189	0.857
		17 -0.041	-0.012	11.232	0.844			17 -0.071	-0.072	10.588	0.877
		18 0.067	0.049	11.596	0.867			18 0.106	0.007	11.502	0.872
		19 -0.011	-0.039	11.606	0.902			19 -0.047	-0.040	11.688	0.899
		20 0.113	0.095	12.701	0.890			20 0.099	0.095	12.528	0.897

Date: 07/31/25 Time: 14:58

Sample (adjusted): 2 50

Included observations: 49 after adjustments

Date: 07/31/25 Time: 14:54

Sample (adjusted): 2 50

Included observations: 49 after adjustments

Autocorrelation	Partial Correlation	AC	PAC	Q-Stat	Prob	Autocorrelation	Partial Correlation	AC	PAC	Q-Stat	Prob
		1 -0.108	-0.108	0.6017	0.438			1 -0.214	-0.214	2.3881	0.122
		2 -0.089	-0.102	1.0208	0.600			2 0.072	0.027	2.6638	0.264
		3 0.079	0.059	1.3570	0.716			3 0.078	0.103	2.9923	0.393
		4 -0.151	-0.148	2.6270	0.622			4 -0.173	-0.146	4.6548	0.325
		5 0.057	0.039	2.8094	0.729			5 0.088	0.014	5.0913	0.405
		6 -0.144	-0.176	4.0206	0.674			6 0.072	0.115	5.3934	0.494
		7 -0.044	-0.049	4.1333	0.764			7 -0.139	-0.095	6.5366	0.479
		8 -0.061	-0.146	4.3631	0.823			8 -0.021	-0.124	6.5642	0.584
		9 0.017	0.021	4.3818	0.885			9 -0.076	-0.085	6.9231	0.645
		10 0.144	0.082	5.7150	0.839			10 -0.036	-0.015	7.0049	0.725
		11 -0.133	-0.104	6.8845	0.808			11 -0.081	-0.136	7.4364	0.763
		12 -0.005	-0.063	6.8865	0.865			12 -0.006	-0.062	7.4387	0.827
		13 -0.091	-0.164	7.4554	0.877			13 0.110	0.148	8.2750	0.825
		14 -0.078	-0.112	7.8930	0.895			14 -0.106	-0.052	9.0781	0.826
		15 0.098	-0.002	8.6059	0.897			15 0.083	-0.011	9.5850	0.845
		16 -0.081	-0.065	9.1086	0.909			16 -0.089	-0.090	10.189	0.857
		17 0.135	0.097	10.523	0.880			17 -0.071	-0.072	10.588	0.877
		18 0.065	0.040	10.865	0.900			18 0.106	0.007	11.502	0.872
		19 -0.034	-0.043	10.962	0.925			19 -0.047	-0.040	11.688	0.899
		20 0.146	0.066	12.797	0.886			20 0.099	0.095	12.528	0.897

Date: 07/31/25 Time: 14:38

Sample (adjusted): 2 50

Included observations: 49 after adjustments

Date: 07/31/25 Time: 14:38

Sample (adjusted): 2 50

Included observations: 49 after adjustments

Autocorrelation		Partial Correlation		AC	PAC	Q-Stat	Prob	Autocorrelation		Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.118	-0.118	0.7195	0.396				1	-0.118	-0.118	0.7195	0.396	
		2	-0.028	-0.043	0.7619	0.683				2	-0.028	-0.043	0.7619	0.683	
		3	-0.079	-0.089	1.1048	0.776				3	-0.079	-0.089	1.1048	0.776	
		4	-0.144	-0.170	2.2618	0.688				4	-0.144	-0.170	2.2618	0.688	
		5	0.151	0.108	3.5618	0.614				5	0.151	0.108	3.5618	0.614	
		6	-0.193	-0.194	5.7305	0.454				6	-0.193	-0.194	5.7305	0.454	
		7	-0.129	-0.209	6.7220	0.458				7	-0.129	-0.209	6.7220	0.458	
		8	0.051	-0.010	6.8785	0.550				8	0.051	-0.010	6.8785	0.550	
		9	0.018	0.002	6.8999	0.648				9	0.018	0.002	6.8999	0.648	
		10	0.226	0.134	10.159	0.427				10	0.226	0.134	10.159	0.427	
		11	-0.094	-0.054	10.739	0.465				11	-0.094	-0.054	10.739	0.465	
		12	-0.036	-0.031	10.825	0.544				12	-0.036	-0.031	10.825	0.544	
		13	-0.046	-0.096	10.974	0.613				13	-0.046	-0.096	10.974	0.613	
		14	0.020	0.023	11.003	0.686				14	0.020	0.023	11.003	0.686	
		15	0.036	-0.013	11.097	0.746				15	0.036	-0.013	11.097	0.746	
		16	-0.005	0.074	11.099	0.803				16	-0.005	0.074	11.099	0.803	
		17	-0.041	-0.012	11.232	0.844				17	-0.041	-0.012	11.232	0.844	
		18	0.067	0.049	11.596	0.867				18	0.067	0.049	11.596	0.867	
		19	-0.011	-0.039	11.606	0.902				19	-0.011	-0.039	11.606	0.902	
		20	0.113	0.095	12.701	0.890				20	0.113	0.095	12.701	0.890	

Sustainability in the Skies: A Tri-Dimensional Performance Evaluation of Global Airlines with Hybrid MCDM Methods

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Gökyüzünde Sürdürülebilirlik: Küresel Hava Yolu İşletmelerinin Melez ÇKKV Yöntemleriyle Üç Boyutlu Performans Değerlendirmesi

Abstract

This study proposes a hybrid multi-criteria decision-making (MCDM) framework that combines entropy and TOPSIS to evaluate the corporate sustainability performance of ten global airlines, utilising 22 GRI-based economic, environmental, and social criteria. Using 2020 data, the analysis identifies China Southern, China Eastern, and American Airlines as top performers, while Qatar Airways ranks lowest due to weak social indicators. Key drivers include available seat kilometres, cargo volume, and water use, while gender metrics and fleet age contribute less. The findings provide data-driven insights for sustainable aviation strategies, bridging theoretical and empirical approaches in the sustainability performance literature.

Keywords : Sustainability, Corporate Sustainability, Corporate Sustainability Performance, Airlines, Logistics, MCDM, Entropy, TOPSIS.

JEL Classification Codes : L93, Q56, C44, M14.

Öz

Bu çalışma, ekonomik, çevresel ve sosyal 22 GRI tabanlı kriter üzerinden küresel hava yolu işletmelerinin kurumsal sürdürülebilirlik performansını değerlendirmek amacıyla entropi ve TOPSIS yöntemlerini birleştiren melez birçok kriterli karar verme (ÇKKV) çerçevesi sunmaktadır. 2020 verilerine dayalı analizde, China Southern, China Eastern ve American Airlines en yüksek performansı gösterirken, sosyal göstergelerdeki zayıflıklar nedeniyle Qatar Airways en düşük sırada yer almıştır. Öne çıkan belirleyici unsurlar koltuk-kilometre kapasitesi, taşınan kargo hacmi ve su tüketimidir. Bulgular, sürdürülebilir havacılık stratejileri geliştirmek isteyen politika yapıcılar ve sektör paydaşları için veri temelli yol gösterici bilgiler sunmaktadır.

Anahtar Sözcükler : Sürdürülebilirlik, Kurumsal Sürdürülebilirlik, Kurumsal Sürdürülebilirlik Performansı, Hava Yolları, Lojistik, ÇKKV, Entropi, TOPSIS.

1. Introduction

Civil aviation serves as a cornerstone of the global economy, driving cross-border trade, tourism, and business collaboration while fostering interconnectedness among nations. Its role extends beyond facilitating the movement of people and goods; it underpins economic growth by enabling international commerce, labour mobility, and cultural exchange. In 2024, the aviation industry supported 65.5 million jobs, generated \$2.7 trillion in economic activity, and accounted for 35% of global trade by value (The Air Transport Action Group, 2024; Kiracı & Bakır, 2019). This industry's contributions to tourism are equally profound, as air travel stimulates destination economies through tourist expenditures, hotel stays, and local businesses "tap into diverse talent pools and optimise productivity, thereby catalysing economic growth.

However, the industry's environmental footprint presents a pressing challenge. Aviation contributes approximately 2% of anthropogenic CO₂ emissions (The Air Transport Action Group, 2024), with non-CO₂ effects elevating its total impact on global warming to 3.5% (Zieba & Johansson, 2022). These emissions exacerbate climate change, disrupt ecosystems, and degrade air quality, underscoring the urgent need to adopt sustainable practices. Strategies such as fuel-efficient technologies, emission-reduction protocols, and waste-management innovations are critical to reconciling aviation's economic benefits with ecological stewardship (Yılmaz & Atmanlı, 2016; Akdemir, 2020). Achieving this balance is vital not only for mitigating environmental harm but also for securing societal acceptance and long-term industry viability. In addition to reducing environmental damage, ensuring social acceptance and securing the long-term sustainability of industry necessitate measuring holistic sustainability performance in the skies. In this context, this study comprehensively analyses the corporate sustainability performance of ten global airlines using an integrated assessment framework based on a total of twenty-two criteria, comprising economic (8), social (7), and environmental (7) aspects. The primary purpose of this study is to evaluate the sustainability performance of these airline businesses, both objectively and systematically, using multi-criteria decision-making (MCDM) methods. In this context, the airlines' performances are comparatively presented using the Entropy method, which provides objective weighting, and the TOPSIS method, which focuses on ranking. This methodological approach aims to enhance the measurability of sustainability strategies and to inform decision-makers in policy development processes.

Utilising the Entropy-TOPSIS methodology, the research employs the entropy method to assign criterion weights and the TOPSIS technique to rank airlines. The entropy method objectively weights sustainability criteria by analysing data dispersion, minimising subjective bias. The subsequent TOPSIS ranking compares airlines to ideal solutions, prioritising those closest to optimal performance across all dimensions. This dual-method approach ensures robust, data-driven insights, enabling stakeholders to identify best practices and allocate resources effectively. A literature review contextualises the concepts and applications of sustainability and multicriteria decision-making in aviation. By bridging theoretical frameworks with empirical analysis, this study advances understanding of

aviation sustainability and offers actionable pathways for industry leaders to align operational strategies with global sustainability imperatives. The findings aim to guide industry stakeholders in refining sustainability strategies, aligning operational practices with global standards, and enhancing transparency in reporting.

2. Literature

2.1. Corporate Sustainability Performance

Corporate sustainability performance (CSP) refers to a business's ability to operationalise sustainable development principles by balancing economic viability, social equity, and environmental stewardship. Rooted in the Triple Bottom Line (TBL) framework (Elkington, 2000), CSP emphasises that businesses must transcend profit-centric models to address their impacts on people and the planet. This holistic approach integrates long-term value creation with ethical governance, resource efficiency, and stakeholder engagement (Dyllick & Hockerts, 2002; Montiel, 2008). Scholars define Corporate Social Responsibility (CSR) as the measurable outcomes of a business's strategies to mitigate negative externalities, enhance societal well-being, and maintain ecological integrity while ensuring economic resilience (Hahn et al., 2018). It extends beyond regulatory compliance to encompass initiative-taking such as reducing carbon footprints, fostering inclusive labour practices, and optimising resource efficiency (Eccles & Krzus, 2010; Linnenluecke & Griffiths, 2013).

The Environmental, Social, and Governance (ESG) criteria complement the TBL framework by providing standardised metrics to evaluate ethical practices, climate resilience, and social responsibility (Friede et al., 2015; Khan et al., 2016). While TBL guides the strategic integration of sustainability, ESG enables quantifiable benchmarking, together offering a holistic view of corporate responsibility (Eccles & Krzus, 2010). For instance, in the aviation industry, CSP entails optimising fuel efficiency, reducing emissions, engaging communities, and ensuring equitable labour practices, all while maintaining profitability (Karaman et al., 2018; Tsai et al., 2020). By aligning with global frameworks such as the Sustainable Development Goals (SDGs), businesses can systematically track and communicate their Corporate Social Responsibility (CSR) progress, thereby fostering accountability and stakeholder trust (Bansal & Song, 2017; Roszkowska-Menkes et al., 2024).

CSP, viewed as a strategic imperative, enables businesses to mitigate risks, enhance brand reputation, and secure competitive advantages in sustainability-conscious markets (Porter & Kramer, 2006; Schaltegger & Burritt, 2018). This multidimensional perspective highlights CSP as a dynamic, context-dependent construct that bridges corporate strategy with sustainable development imperatives, ensuring organisational resilience in the face of ecological and socio-economic uncertainties.

The theoretical basis of this study is grounded in the potential of Elkington's Triple Bottom Line (TBL) approach and multi-criteria decision-making (MCDM) methods to

provide a holistic analysis for evaluating sustainability performance. The TBL approach suggests that corporate success should be evaluated not only in terms of economic output but also in terms of sustainability dimensions, including social responsibility and environmental impact. In this context, CSP refers to the extent to which businesses simultaneously demonstrate environmental sensitivity, social inclusiveness, and economic durability. The framework in question has served as a fundamental guide in determining the criteria addressed in this study and in structuring the evaluation method. Determining the objective weights of the criteria using the Entropy method minimises the effect of subjective judgments in the evaluation process and provides an analytical basis for decision-making. Then, ranking airlines based on their proximity to the ideal solution using the TOPSIS method enables a comparative assessment of CSP levels. Thus, the combined use of the TBL approach and objective MCDM techniques provides theoretical and methodological integrity in industrial sustainability analyses.

2.2. Corporate Sustainability Performance Measurement in the Aviation Industry

Assessing CSP in the civil aviation industry poses a multifaceted challenge, requiring robust frameworks that reconcile economic, social, and environmental dimensions. While MCDM models have gained prominence in evaluating CSP, existing literature often prioritises defining industry-specific criteria over advancing mathematical methodologies, despite the critical role of quantitative analysis in driving global sustainability progress (Searcy, 2012). Scholars have proposed diverse indicators and indices, such as the Dow Jones Sustainability Index (DJSI) and Global Reporting Initiative (GRI) standards, to benchmark performance. However, the heterogeneity of criteria across studies underscores the need for standardised, transparent measurement systems to enhance comparability and credibility.

2.3. Country-Specific Analyses

The regional and national contexts influence the selection of corporate sustainability performance (CSP) metrics, as presented in Table 1 in chronological order. For Chinese airlines, criteria such as return on equity (ROE), accident rates, environmental investments, and fleet composition have been evaluated using entropy and grey relational analysis (Wang et al., 2014). Similarly, fuel consumption, CO₂ emissions, fleet age, and ownership status are applied to assess 13 Chinese carriers through network data envelopment analysis (DEA) (Hadi-Vencheh et al., 2018). Chen et al. (2021) extend this approach by incorporating a slack-based network DEA to account for operational and environmental factors, such as kerosene consumption, available seat kilometres (ASK), and revenue ton-kilometres (RTK). In India, technical efficiency studies focus on operational costs, non-passenger revenue, and ASK (Jain & Natarajan, 2015), while Iranian airline evaluations emphasise fleet size, RTK, and carbon emissions using TOPSIS and fuzzy network models (Omran et al., 2022; Heydari et al., 2020). In addition, Kılıç and Şimşek (2023) apply the fuzzy analytic hierarchy process (AHP) and fuzzy TOPSIS to assess the ground operations of Turkish low-cost

carriers, integrating service-oriented criteria such as ticketing efficiency, counter service quality, and personnel responsiveness.

Table: 1
Chronological Literature Review on Country-Specific Corporate Sustainability Performance in Aviation

Study	Method	Criteria	Dimensions	Scope	Region / Country
Wang et al. (2014)	Entropy, Grey Relational Analysis	ROE, net profit growth, accident rate, on-time performance, tax performance, employee income growth, CSR	Economic and Social	Corporate sustainability	China (8 Airlines)
Jain & Natarajan (2015)	DEA	ASK, operational costs, total revenue, non-passenger revenue	Technical Efficiency	Efficiency evaluation	India (2006-2010)
Hadi-Vencheh et al. (2018)	MCDM	Fuel consumption, fleet size, CO ₂ emissions, ownership status, M&A activity	Economic and Environmental	Sustainability assessment	China (13 Airlines)
Heydari et al. (2020)	Fully Fuzzy Network DEA-Range Adjusted Measure	Employees, ASK, ATK, scheduled flights, fleet size, passenger/ton kilometres performed.	Operational Efficiency	Sustainability performance	Iran (14 Airlines)
Chen et al. (2021)	Slacks-Based Measure Network DEA	Kerosene consumption, ASK, ATM, RPK, CO ₂ emissions	Operational and Environmental	Operational, Environmental performance	China (9 Airlines)
Omrani et al. (2022)	TOPSIS	Fleet size, ASK, ATK, employees, CO ₂ emissions, RTK	Economic and Environmental	Sustainability performance	Iran (16 Airlines)
Kılıç & Şimşek (2023)	Fuzzy AHP, Fuzzy TOPSIS	Ticketing, online services, counter services, flight schedule, service personnel	Social and Operational	Ground Operations Performance of 3 LCCs	Türkiye (3 Airlines)

2.4. Regional and Global Perspectives

Broader analyses extend these frameworks to regional and global contexts, as referred to in Table 2. In East Asia, eco-efficiency studies integrate CO₂ emissions, energy usage, and passenger data with principal component analysis (Elhmod et al., 2021). For the Asia-Pacific region, the decision-making trial and evaluation laboratory (DEMATEL) methodologies incorporate governance, supply chain efficiency, environmental policies, and labour practices (Chang et al., 2015). Latin American studies prioritise fleet size and operational efficiency by dynamic data envelopment analysis (Wanke & Barros, 2016).

Table: 2
Chronological Literature Review on Regional and Global Corporate Sustainability Performance in Aviation

Study	Method	Criteria	Dimensions	Scope	Region / Country
Arjomandi & Seufert (2014)	Bootstrapped DEA	Workforce size, TKA, CO ₂ emissions	Technical and Environmental	Technical and Environmental performance	Global (48 Airlines)
Chang et al. (2014)	DEA	ATK, RTK, employee count, profit, carbon emissions	Economic and Environmental	Economic and Environmental efficiency	Global (27 Airlines)
Chang et al. (2015)	DEMATEL	Corporate governance, risk management, and environmental policies, fleet efficiency, labour practices	Economic, Social, and Environmental	Sustainability assessment of Asia-Pacific airlines	Asia-Pacific
Wanke & Barros (2016)	Virtual Frontier Dynamic DEA & Simplex Regression	Number of flights, employees, and aircraft	Operational Efficiency	Sustainability performance	Latin America (19 Airlines)
Bakır et al. (2019)	Entropy, WASPAS	Passenger reviews (legroom, comfort, cleanliness, value for money)	Social	Service quality of European low-cost carriers (LCCs)	Europe (13 Airlines)
Kıraç & Bakır (2019)	CRITIC, EDAS	ASM, CASM, RASM, RPM	Financial and Operational	Ranking	Global [13 Airlines (2005-2012)]
Chowdhury & Paul (2020)	Systematic Literature Review	MCDM applications, enablers/barriers of sustainability	Economic, Social, and Environmental	Broad analysis across industries (including aviation)	Global
Elhmod et al. (2021)	PCA	CO ₂ emissions, electricity/fuel/water usage, waste generation, revenue, passengers, cargo	Eco-Efficiency	Eco-efficiency	East Asia (7 Airlines)
Asker (2021)	Two-Stage DEA	ASK, employees, aircraft, RPK, load factor, net profit/net sales	Economic Efficiency	Efficiency evaluation	Global (36 Airlines)
Alkhatib & Migdadi (2021)	DEMATEL, AHP, TOPSIS	Greenhouse gas emissions, fuel efficiency, noise pollution, and water usage	Environmental	Sustainability ranking	Global (20 Airlines)
Sarkis & Zhu (2021)	Fuzzy TOPSIS	Fuel efficiency, waste management, labour rights, and community engagement	Economic, Social, and Environmental	Sustainability trade-offs in global low-cost carriers	Global
Kyriakou & Psaropoulos (2023)	AHP, WSM, TOPSIS	Technological performance, environmental impact, costs, circularity	Environmental and Economic	Sustainability assessment of 4 passenger aircraft with different fuels	Global
Current Study (2025)	Entropy + TOPSIS	22 criteria: Economic (8), Social (7), Environmental (7)	Economic, Social, and Environmental	Sustainability ranking	Global (10 Airlines)

On a global scale, Arjomandi and Seufert (2014) employ bootstrapped DEA to evaluate 48 international airlines based on workforce size, ton-kilometres available (TKA), and emissions. Chang et al. (2014) and Asker (2021) assess economic-environmental efficiencies using variables such as ASK, RTK, profit margins, and CO₂ emissions. Kiracı and Bakır (2019) utilise the criteria importance through intercriteria correlation (CRITIC) and evaluation based on distance from the average solution (EDAS) methods to rank airlines across continents based on financial and operational metrics, such as available seat miles (ASM) and revenue per available seat mile (RASM). Alkhatib and Migdadi (2021) advanced global assessments by combining DEMATEL, AHP, and TOPSIS to evaluate the green operations of 20 airlines, focusing on greenhouse gas emissions, fuel efficiency, and environmental compliance.

Chowdhury and Paul (2020) contribute a systematic literature review that maps MCDM applications across various industries, including aviation, to address sustainability enablers and barriers. Bakır et al. (2019) assess the service quality of European low-cost carriers using the entropy and weighted aggregated sum product assessment (WASPAS) methods, with an emphasis on customer-centric criteria such as seat comfort, cleanliness, and staff service. Lastly, Kyriakou and Psarropoulos (2023) evaluate the sustainability of four aircraft types using the AHP and TOPSIS methods, with an emphasis on technological performance, circularity, and environmental impact.

2.5. Research Gaps and Methodological Advancements

Despite this proliferation of studies, a critical gap persists: no prior research holistically integrates economic, social, and environmental dimensions using combined weighting and ranking methodologies. Existing approaches often isolate specific criteria or regions, which limits cross-industry comparability. To address this, the present study employs the Entropy method, a data-driven weighting technique that minimises subjectivity, to assign criterion weights. This is followed by the TOPSIS method, which ranks airlines based on their proximity to ideal sustainability performance. This dual-method framework not only enhances methodological rigour but also provides actionable insights to help stakeholders prioritise sustainability initiatives, align with global standards, and foster industry-wide accountability.

By synthesising fragmented criteria and advancing an integrated evaluation model, this research contributes to bridging the gap between theoretical frameworks and practical implementation, offering methodological transparency, minimising subjective bias, and enhancing the interpretability of results for policymakers, regulators, and industry stakeholders aiming to create a scalable tool for the aviation industry's transition toward sustainable development.

3. Methodology

The mathematical notation for the entropy and TOPSIS methods used in the study is outlined in this section.

3.1. Entropy Method

Entropy, initially defined as a measure of system disorder and uncertainty (Heng et al., 2023), has emerged as a cornerstone of information-entropy weighting methodologies. Rooted in Shannon's (1948) pioneering work on information theory, this approach quantifies the relative informational utility of empirical data by assessing the dispersion and variability within decision matrices (Gazel et al., 2021; Wu et al., 2011). By deriving weights directly from dataset variability, entropy-based methods minimise subjective biases inherent in expert-driven weighting approaches, offering a robust framework for MCDA (Karakaş et al., 2016; Pekkaya & Dökmen, 2019). The Shannon entropy method, operationalised through a structured computational process (Aytekin & Karamaşa, 2017; Gazel et al., 2021), involves the following systematic steps:

Step 1. The decision matrix is formed as follows:

$$X = \begin{matrix} & \begin{matrix} X_1 & X_2 & \cdots & X_j & \cdots & X_n \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \end{matrix} \quad \text{Equation (1)}$$

where x_{ij} denotes the success value of i^{th} alternative per the criterion j^{th} in the matrix being $i = 1, 2, 3 \dots m$ and $j = 1, 2, 3 \dots n$ while m is the number of alternatives and n is the number of criteria.

Step 2. A normalisation process is required to evaluate the criteria, as they have different scales (Aytekin & Karamaşa, 2017). Equation (2) used for the normalisation process is as follows:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^m x_{ij}} \quad \text{Equation (2)}$$

Step 3. Entropy (e_j) values are calculated in accordance with Equation (3) where the k value expresses the entropy constant and is calculated with the formula of $k = \frac{1}{\ln(m)}$ (Bahadır & Türkmençalıkoğlu, 2021):

$$e_j = -k \sum_{i=1}^m r_{ij} \ln r_{ij} \quad \text{Equation (3)}$$

Step 4. The degree of differentiation (d_j) is calculated (Aytekin & Karamaşa, 2017) through Equation (4):

$$d_j = 1 - e_j \quad \text{Equation (4)}$$

Step 5. Weights (w_j) for the importance level of each criterion is computed with Equation (5) (Aytekin & Karamaşa, 2017):

$$w_j = \frac{d_j}{\sum_{j=1}^m d_j} \quad \text{Equation (5)}$$

3.2. TOPSIS Method

Developed by Hwang & Yoon (1981), the TOPSIS method is a multi-criteria decision-making approach that ranks alternatives based on their proximity to an ideal solution, effectively incorporating both quantitative and qualitative criteria (Madanchian & Taherdoost, 2023). The method aims to determine the distance of each alternative from the ideal and negative ideal solutions, with the ideal solution defined by the best available values and the negative ideal by the worst available values (Hwang & Yoon, 1981). In this process, criteria are evaluated according to whether they represent a benefit or a cost; for a benefit criterion, the ideal is characterised by the maximum value, whereas for a cost criterion, it is represented by the minimum value. Conversely, the negative ideal solution is defined using the reverse approach. The applicability of the TOPSIS method is well supported by an extensive body of expert literature (Behzadian et al., 2012), which outlines the following steps.

Step 1. The decision matrix is formed to capture the alternatives across criteria (Hwang & Yoon, 1981) as follows:

$$X = \begin{matrix} & \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} X_1 & X_2 & \cdots & X_j & \cdots & X_n \\ x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \end{matrix}_{mxn} \quad \text{Equation (6)}$$

where x_{ij} denotes the success value of i^{th} alternative per the criterion j^{th} in the matrix being $i = 1, 2, 3 \dots m$ (number of alternatives) and $j = 1, 2, 3 \dots n$ (number of criteria).

Step 2. A normalisation process using the Euclidean norm is required to ensure comparability across criteria, as emphasised by Yoon & Hwang (1995), who stress the importance of scaling values to a uniform range. Thus, the normalised decision matrix is created using Equation (7) for the normalisation process, as indicated below.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^n x_{ij}^2}} \quad \text{Equation (7)}$$

Step 3. The weighted normalised decision matrix is created with the use of Equation 8, presented as follows:

$$v_{ij} = w_j \times r_{ij} \quad \text{Equation (8)}$$

Step 4. The distances of the alternatives to the ideal (A^+) and negative ideal (A^-) solutions (as defined as "best conceivable" and "worst conceivable" outcomes by Hwang & Yoon (1981)) are calculated using Equations (10) and (11) presented below:

$$A^+ = \{\max(v_{ij}) \text{ for benefit criteria; } \min(v_{ij}) \text{ for cost criteria}\} \quad \text{Equation (9)}$$

$$A^- = \{\min(v_{ij}) \text{ for benefit criteria; } \max(v_{ij}) \text{ for cost criteria}\} \quad \text{Equation (10)}$$

Step 5. The ideal (A^+) and negative ideal (A^-) separation measures are calculated with Equation (11) and Equation (12):

$$S_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2} \quad \text{Equation (11)}$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \quad \text{Equation (12)}$$

Step 6. The relative closeness value of the alternatives is computed, and the alternatives are ranked as in Equation (13), as validated by Chen (2000) for robustness in ranking:

$$C_i^+ = \frac{S_i^-}{S_i^+ + S_i^-}, 0 < C_i^+ < 1 \quad \text{Equation (13)}$$

3.3. Case Study

Building on a systematic review of the existing literature, industry reports from leading airlines, and insights from an aviation sustainability consultancy, this study integrates a rigorous methodological framework to define corporate sustainability performance criteria within the civil aviation industry. Through a collaborative expert consensus process involving scholars and practitioners specialising in air transportation sustainability, twenty-two criteria are systematically identified and categorised into the tripartite pillars of sustainability: economic (8), social (7), and environmental (7) criteria (see Table 3). These criteria are subsequently applied to evaluate and rank ten globally recognized airlines -selected for their extensive international operations, market prominence, and high-revenue performance- including Turkish Airlines (ALT1), Lufthansa (ALT2), Qatar Airways (ALT3), American Airlines (ALT4), Delta Air Lines (ALT5), Southwest Airlines (ALT6), China Eastern Airlines (ALT7), British Airways (ALT8), Emirates (ALT9), and China Southern Airlines (ALT10).

Table: 3
Main and Sub-Criteria of Evaluation for Corporate Sustainability Performance

Economic Criteria	Social Criteria	Environmental Criteria
Number of countries flown to (EC1)	Total number of employees (SC1)	Annual electricity consumption amount (Million kWh) (ENC1)
Number of aircraft (EC2)	Total number of female employees (SC2)	Annual natural gas consumption (Million m ³) (ENC2)
Number of passengers carried (Million) (EC3)	Female employee rate (%) (SC3)	Amount of water consumed annually (Tons) (ENC3)
Amount of cargo transported (Tons) (EC4)	Labor turnover rate (%) (SC4)	Annual ton fuel savings (Tons) (ENC4)
Average fleet age (EC5)	Training/hour value per employee (SC5)	Tons of CO ₂ released annually (Tons) (ENC5)
Net profit (\$ Million) (EC6)	The rate of female managers in the manager profile (%) (SC6)	Avoided CO ₂ (Tons) (ENC6)
Revenue (\$ Million) (EC7)	Number of new employees (SC7)	Annual fuel usage (Tons) (ENC7)
Available seat kilometres (ASK) (EC8)		

Having provided the basic information on the criteria used, the airlines included, and the steps to be followed for each MCDM method, the following sections begin by weighing the criteria using the entropy method and proceed to rank the airlines using the TOPSIS method to evaluate their corporate sustainability performance.

3.3.1. Descriptive Statistics of Criteria

The descriptive statistics of the criteria used in the study are analysed, and, in this regard, the distribution of each criterion is assessed in terms of the minimum, maximum, mean, and standard deviation. The degree of variability of the criteria serves as the foundation for the weighting process, which is conducted using the Entropy method. This method objectively quantifies the information conveyed by the criteria using these distributional characteristics, assigning greater weight to criteria with higher variability. Consequently, the criteria are categorised into three groups: high, medium, and low weight potential, based on their descriptive statistics. The descriptive statistics of the criteria are presented in Table 4.

Table: 4
Descriptive Statistics for Criteria

Criteria Code	Min	Max	Average	Standard Deviation	Variance
EC1	35	170	98	48	2.292
EC2	250	1.399	632	364	132.654
EC3	6	138	56	44	1.948
EC4	246.310	1.383.000.000	164.249.662	431.746.061	186.404.661.230.505.000
EC5	7	15	10	3	9
EC6	-12.385	-836	-5.036	3.677	13.522.174
EC7	2.152	17.337	10.462	5.099	25.996.893
EC8	214.722	152.070.000.000	15.283.254.772	48.061.977.964	2.309.953.725.795.310.000.000
SC1	28.688	125.207	67.580	33.676	1.134.063.764
SC2	13.128	47.744	28.663	13.594	184.789.016
SC3	37	58	44	6	42
SC4	2	24	6	6	40
SC5	18	134	38	34	1.180
SC6	12	43	28	10	107
SC7	534	21.716	4.333	6.302	39.720.795
ENC1	15.832	152.380	60.776	46.248	2.138.861.354
ENC2	1.410.000	9.500.000	4.321.264	2.277.752	5.188.155.863.629
ENC3	36.501	5.260.000	884.858	1.621.820	2.630.299.305.451
ENC4	11.300	600.000	138.184	208.723	43.565.214.993
ENC5	7.250.236	41.969.334	16.958.764	10.730.377	115.140.988.090.828
ENC6	26.800	2.000.000	436.717	674.502	454.952.521.552
ENC7	1.273.000	7.845.300	4.237.896	2.178.265	4.744.836.539.498

Criteria with High Weight Potential: The criteria in this group exhibit wide value ranges and high standard deviations, resulting in significant information diversity within the dataset. Therefore, the Entropy method assigned high weights to these criteria. High variance indicates that these criteria provide more decisive contributions to the decision-making process.

- EC4 - Cargo Amount Carried (Ton): Transportation capacity varies greatly depending on the fields of activity of airline businesses. Since some businesses focus on cargo while others focus on passenger transportation, the variance of this criterion is relatively high.
- EC8 - Available Seat-Kilometre (ASK): Differences in fleet size and flight distance between businesses cause significant changes in this capacity indicator. Since the ASK value is much higher in businesses with long-range and high-frequency flights, the variance increases.
- ENC5 - Annual CO₂ Emission (Tons): There are significant differences between airline businesses' activity volumes, fleet efficiency, and operational intensity. This causes some businesses to produce much higher levels of emissions and creates a wide range of CO₂ emissions.
- ENC2 - Annual Natural Gas Consumption (Million m³): There are significant differences in natural gas consumption among businesses depending on heating, air conditioning, and energy needs. While some businesses do not utilise this resource at all, others consume large amounts; this is the primary factor that increases the variance.
- ENC7 - Annual Fuel Consumption (Tons): The fuel consumption of different aircraft types, fleet age, and operational efficiency levels has a direct impact. Businesses with long-haul operations and large fleets have significantly higher fuel consumption, which substantially increases the criterion's variance.

Criteria with Low Weight Potential: The value ranges for these criteria are narrow, and their standard deviations are low. The entropy method yields low weights because it assesses the information content of these criteria in a limited manner. These criteria play a less decisive role in explaining the decision-making process in the dataset.

- EC5 - Average Fleet Age: The average fleet age of airline businesses typically falls within a similar range. The similarity in aircraft purchasing policies and the fact that the industry is subject to similar regulations have kept the variance of this criterion low.
- SC6 - Number of Newly Hired Employees: Human resources mobility does not show significant differences between airlines. Growth strategies at similar scales and limited employment trends in the post-COVID-19 period have led to this criterion carrying limited information with low variance.
- SC3 - Female Employee Rate: Female employment rates are comparable in most businesses. Since policies regarding gender representation have developed at a

similar level, the variance of this criterion has remained low, and its contribution to the decision-making process has been limited.

3.3.2. Weighting Criteria with the Entropy Method

Criterion weighting is integral to multi-criteria decision analysis, as weights directly determine the relative influence of each metric on the evaluation outcomes. In this study, the 22 sustainability criteria, stratified into economic (8), environmental (7), and social (7) dimensions, are weighed using the entropy method, as explained in the subsection 'Entropy Method'. Data for the year 2020, sourced from authoritative and publicly accessible records (e.g., audited annual reports, regulatory filings, and corporate sustainability disclosures), are processed algorithmically in MS Excel 2023 to derive objective weights before applying the TOPSIS framework.

The criteria are classified into two distinct groups to align with their inherent objectives:

- Maximisation criteria (EC1, EC2, EC3, EC4, EC6, EC7, EC8, SC2, SC3, SC5, SC6, ENC4, ENC6), which reflect positive sustainability outcomes (e.g., efficiency gains, social equity).
- Minimisation criteria (EC5, SC1, SC4, SC7, ENC1, ENC2, ENC3, ENC5, ENC7), which correspond to adverse impacts (e.g., emissions, operational risks).

The decision matrix, provided in Appendix 1, is normalised using the entropy method and presented in Appendix 2. The entropy method assigns criterion weights based on the information each criterion contributes to the decision-making process, prioritising those with greater variability in their data distributions. In this framework, the initial step is to normalise criterion values to eliminate scale discrepancies. For instance, Turkish Airlines emerges as the most advantageous option in terms of Aircraft Flown and Female Employee Ratio (%). At the same time, Lufthansa outperforms in Annual Electricity Consumption (kWh) and Annual Fuel Usage (tons).

The entropy values computed for each criterion are detailed in Appendix 3. A critical consideration when interpreting these values is the inherent variability among criterion data points. Low variability (e.g., Available Seat Kilometres and Annual Natural Gas Consumption) corresponds to reduced informational utility, resulting in lower weights. Conversely, high variability (e.g., Cargo Volume Transported (tons), Net Profit (USD), and Female Employee Ratio (%)) indicates greater informational significance and warrants higher weights. For example, the pronounced variability in Cargo Volume Transported and Net Profit underscores their pivotal role in differentiating airline performance. In contrast, minimal variability in Available Seat Kilometres reflects its limited discriminative power in the evaluation.

This variation-based weighting mechanism ensures that criteria that provide more information for the decision-making process are weighted proportionally more heavily,

thereby shaping results consistent with the empirical data structure. Although negative values are present in the net profit criterion, the column-based proportional normalisation approach yields normalised values that are transformed into positive values, with the Entropy method being consistently applied. The Entropy weights, which represent the information contribution of each criterion, are presented in Table 5.

Table: 5
Criteria for Evaluating Corporate Sustainability Performance with Entropy Values

#	Main Criteria	Sub Criteria	E_j	W_j (Entropy Values)
1	Economic	Number of Countries Flown to	0,951545302	0,011595323
2	Economic	Number of Aircraft	0,937271916	0,015010978
3	Economic	Number of Passengers Carried (Million)	0,871835947	0,030669958
4	Economic	Amount of Cargo Transported (Tons)	0,256987109	0,177804726
5	Economic	Average Fleet Age	0,983304971	0,003995159
6	Economic	Net Profit (\$ Million)	0,896680401	0,024724622
7	Economic	Revenue (\$ Million)	0,949724615	0,012031017
8	Economic	Available Seat Kilometres	0,018085279	0,234974493
9	Social	Total Number of Employees	0,951446591	0,011618945
10	Social	Total Number of Female Employees	0,954781571	0,010820876
11	Social	Female Employee Rate (%)	0,995860404	0,000990615
12	Social	Labour Turnover Rate (%)	0,874111776	0,030125347
13	Social	Training per Personnel/hour value	0,892616923	0,025697022
14	Social	Ratio of Female Managers in Manager Profile (%)	0,971322546	0,006862582
15	Social	Newly Hired Personnel	0,731273031	0,064306993
16	Environmental	Annual Electricity Consumption (Million kWh)	0,898196065	0,02436192
17	Environmental	Annual Natural Gas Consumption Amount (Million m ³)	0,949540392	0,012075102
18	Environmental	Annual Amount of Water Consumed (Tons)	0,572718276	0,102249518
19	Environmental	Annual Ton Fuel Savings (Tons)	0,648345304	0,084151793
20	Environmental	Tons of CO ₂ Released Annually (Tons)	0,933730539	0,015858437
21	Environmental	Prevented Carbon Dioxide (CO ₂) (Tons)	0,633113027	0,087796912
22	Environmental	Annual Fuel Usage (Tons)	0,948693936	0,012277661

The entropy-derived weighting results establish a quantitative hierarchy among the twenty sustainability criteria. At the aggregate level, available seat kilometres (ASK) emerges as the highest-weighted criterion, followed by freight volume (tonnage) and annual water consumption (tonnage). Conversely, the female employee ratio (%), the proportion of female managers (%), and the average fleet age are identified as the least influential metrics. However, domain-specific prioritisation reveals nuanced insights:

- **Economic Dimension:** Available seat kilometres (ASK) dominates as the most critical criterion, reflecting its direct link to operational scalability and revenue generation, while average fleet age ranks lowest, underscoring its marginal impact on short-term economic performance.
- **Social Dimension:** The new employee recruitment rate holds the highest weight, signalling its relevance to workforce dynamism and business growth, whereas the female employee ratio (%) is the least prioritised, suggesting a limited perceived influence on social equity outcomes within the current framework.
- **Environmental Dimension:** Annual water consumption (tonnage) is the most significant criterion, aligning with global water stewardship priorities, while annual fuel consumption (tonnage) - despite its ecological implications - ranks

lowest, potentially due to uniform industry-wide inefficiencies normalising its perceived variability.

These findings highlight disparities between aggregate and dimension-specific weightings, underscoring the need for contextual analysis in sustainability evaluations. Full results are catalogued in Table 5.

3.3.3. Evaluating the Compatibility Between Entropy Weights and Variance

This study examines the statistical properties of the criteria employed, specifically their variance, and the levels of information contribution derived using the Entropy method. It is generally accepted that greater variance in a criterion indicates greater discrimination within the sample, thereby contributing more significantly to the decision model. Accordingly, a positive correlation between variance and entropy weights is anticipated.

Based on the analysis conducted, the findings predominantly corroborate this assumption. For instance, both EC8 (Available Seat-Kilometre) and EC4 (Cargo Amount Carried) demonstrate considerable variability and are among the criteria assigned the highest weights using the Entropy method. Likewise, ENC6 (Prevented CO₂ Emission) and ENC4 (Fuel Savings) also display high variance and rank highly in terms of informational contribution. These results suggest that the criteria generate notable distinctions within the dataset and significantly contribute to the decision-making process.

Conversely, the criteria SC3 (Female Employee Ratio), SC6 (Number of New Hires), and EC5 (Average Fleet Age) exhibit low variance and have among the lowest Entropy weights, indicating that these criteria have similar values across businesses and contribute minimally to the decision-making process. These results largely reaffirm the anticipated correlation between the Entropy method and variance. Nonetheless, certain exceptions to this pattern are observed. For instance, criteria such as Annual CO₂ Emission (ENC5) and Annual Natural Gas Consumption (ENC2), when evaluated using the Entropy method, exhibit relatively low information contribution despite high variance. This anomaly is attributable to the asymmetric distributions evident in the structure of these variables. Such findings suggest that although a broad concordance exists between variance and entropy weights, the Entropy method is sensitive not only to the magnitude of variability but also to the distributional complexity inherent in the dataset. In this context, the Entropy method offers a comprehensive evaluation framework predicated on information content rather than solely on statistical distributions.

3.3.4. Performance Ranking with the TOPSIS Method

Following the entropy-based determination of criterion weights, these weights are integrated into the TOPSIS framework to evaluate and rank the sustainability performance of the ten global airlines under study. Appendix 4 presents the normalised decision matrix generated by the TOPSIS method for evaluating the alternatives, while Appendix 5 displays the weighted normalised decision matrix derived from the decision matrix in Appendix 1.

For instance, alternative ALT3 has a low normalised value for the SC4 criterion, indicating that Qatar Airways exhibits the lowest performance on the female employee ratio compared to the other alternatives. Conversely, Southwest Airlines demonstrates the highest performance on the female employee ratio criterion. In Appendix 5, the weighted normalised decision matrix is obtained by multiplying the normalised decision matrix by the corresponding criterion weights, thereby reflecting the relative importance of each criterion in the decision-making process. For example, the EC8 criterion (Seats Offered per Kilometre) has a high weight of 0.234974, so differences in performance on this criterion significantly influence the overall decision. In another case, the alternative ALT4 demonstrates a relative advantage of 0.17621 under the EC4 criterion, indicating that Cargo Transported is a key factor favouring American Airlines.

Table: 6
Airline Rankings under the TOPSIS Method

Businesses / Criteria	S_i^+	S_i^-	p_i	Rank
Turkish Airlines	0,9004772	0,1157593	0,113909799	5
Lufthansa	0,8995401	0,1103866	0,109301628	9
Qatar Airways	0,8993042	0,1049884	0,104539665	10
American Airlines	0,8846723	0,1886336	0,17575007	3
Delta Air Lines	0,8951308	0,1311552	0,127795929	4
Southwest Airlines	0,8968082	0,1140134	0,11279284	6
China Eastern Airlines	0,8632669	0,2611111	0,232227147	2
British Airways	0,8988269	0,1122894	0,111054903	8
Emirates	0,8975735	0,1121611	0,111079774	7
China Southern Airlines	0,3047592	0,8520801	0,736558772	1

Table 6 presents the ranking of alternatives obtained using the entropy-based TOPSIS method. In this ranking, the results show a clear hierarchy, with China Southern Airlines in first place, China Eastern Airlines in second, and American Airlines in third. Qatar Airways ranks at the bottom of the list for holistic sustainability performance. This ranking highlights operational and strategic disparities among airlines in aligning with the three key sustainability dimensions (economic, social, and environmental).

4. Conclusion and Discussion

This study proposes an integrated multi-criteria framework to evaluate corporate sustainability performance in the civil aviation industry, synthesising insights from academic literature, industry reports, and consultancy analyses. A 22-criterion taxonomy -stratified into economic (8 criteria), social (7 criteria), and environmental (7 criteria) dimensions- is developed to assess ten globally prominent airlines (Turkish Airlines, Lufthansa, Qatar Airways, American Airlines, Delta Air Lines, Southwest Airlines, China Eastern Airlines, British Airways, Emirates, and China Southern Airlines). These airlines are selected based on their adherence to the GRI framework, global operational footprint, and market dominance.

To mitigate subjective bias, the Entropy method is employed to weight the criteria objectively. Key findings include:

- **Economic Dimension:** ASK emerges as the most influential criterion, reflecting operational efficiency and revenue potential, followed by cargo volume (in tons) and net profit (in USD millions).
- **Social Dimension:** The new employee recruitment rate ranks highest, underscoring workforce expansion as a key social priority, followed by the number of training hours per employee and the workforce turnover rate (%).
- **Environmental Dimension:** Annual water consumption (in tons) is prioritised, aligned with resource stewardship imperatives, followed by prevented CO2 emissions (in tons) and annual fuel savings (in tons).

The TOPSIS-based rankings reveal significant disparities in sustainability performance:

- **Top Performers:** China Southern Airlines (1st), China Eastern Airlines (2nd), and American Airlines (3rd) demonstrate superior alignment with the tripartite sustainability benchmarks.
- **Mid-Tiers:** Delta Air Lines (4th) and Turkish Airlines (5th) exhibit moderate performance, with opportunities for improvement in environmental and social metrics.
- **Lower Tiers:** Southwest Airlines (6th), Emirates (7th), British Airways (8th), Lufthansa (9th), and Qatar Airways (10th) lag notably, particularly in environmental accountability and social equity.

Notably, while the narrow margins among the top five airlines (e.g., China Southern, China Eastern, American Airlines) suggest a comparable adoption of high-level sustainability strategies, China Southern's pronounced lead reflects operational exceptionalism in resource efficiency and governance. Conversely, European airlines (Lufthansa, British Airways) and Qatar Airways underperform, potentially attributable to regulatory fragmentation in Europe and reliance on legacy operational models that lag in environmental and social innovation. Qatar Airways' position at the bottom of the list can be attributed to its poor performance on social criteria, such as the ratios of female employees and female managers, and the average number of years of training per employee. These findings suggest that some airlines have not yet made sufficient progress on social sustainability, despite providing some level of transparency in environmental data. Qatar Airways' failure to demonstrate a competitive level in environmental indicators, such as carbon emissions, also indicates that the business's sustainability policies need to be reviewed in terms of scope and implementation.

In addition to the ranking results, the statistical properties of the sustainability criteria and the information contributions calculated using the Entropy method are evaluated together. While criteria such as EC8 (Available Seat-Kilometre) and EC4 (Cargo Amount Carried) show high variance, the Entropy method assigns high weights to these criteria; thus, the expected harmony between variance and information contribution is confirmed. Similarly, criteria such as EC5 (Average Fleet Age), SC3 (Female Employee Ratio), SC4

(Labour Turnover Rate), and SC6 (Number of New Hires) make limited contributions to the decision process with low variance and low entropy weights. However, this harmony is disrupted for criteria such as ENC5 (Annual CO₂ Emission) and ENC2 (Annual Natural Gas Consumption), and, despite high variance, low-entropy weights are observed. This situation is thought to be due to an imbalance in the distribution of the criteria in the business data. In general, the Entropy method is sensitive not only to the level of variability but also to the structural features of the data distribution; in this respect, it offers a more holistic evaluation.

4.1. Policy Implications

The findings of this study have important implications for policymakers, regulatory authorities, and industry representatives, highlighting ways to increase sustainability in the airline industry. Indicators such as seat-kilometre capacity (SKL), cargo volume, and water consumption, which carry high weight values, reveal that operational efficiency and resource management are determinants of sustainability performance. In this context, public authorities and international organisations can direct airlines to improve their performance by integrating these indicators into national reporting systems or by developing incentive and sanction mechanisms. In addition, the low performance of some airlines in social indicators, such as the female employee ratio, female representation in management, and the training period per employee, reveals the need for stronger regulations to support inclusive employment policies. In this context, it is recommended to develop policy tools that promote gender equality and employee development (e.g., employment incentives, certification programs, social compliance standards). The study's entropy- and TOPSIS-based methodology has the potential to make decision-making processes more objective and data-driven for policymakers. International aviation authorities (e.g., ICAO, IATA) and regional regulators can achieve more transparent and comparable results by integrating such multi-criteria assessment models into their sustainability monitoring mechanisms. As a result, the findings not only assess the current situation but also provide a data-based basis for policy reforms aimed at building a more sustainable and accountable governance structure across the industry. These recommendations can contribute to the development of policy sets that support industrial transformation and align with the SDGs.

4.2. Limitations

Despite its contributions, this article has some limitations.

Limitations 1: Exclusion of Non-GRI Compliant and Low-Cost Carriers (LCCs)

The sample of this study comprises solely large-scale airlines that adhere to the sustainability reporting standards set forth by the GRI framework and submit consistent data. Consequently, LCCs and regional- or developing-country-based airlines that do not publish GRI reports are excluded from the study. This exclusion, driven by data availability constraints, limits the generalizability of the findings to the entire aviation industry. Notably, given that the sustainability performance of LLCs may differ in their emphasis on service

quality or cost objectives, this exclusion diminishes the model's applicability across airline categories. Future research endeavours can address this inclusivity gap by incorporating alternative data sources or employing hybrid models supported by qualitative analyses.

Limitations 2: Data Constraints due to COVID-19

The data analysed in this study pertain to 2020, a year when the unique effects of the COVID-19 pandemic on the aviation industry are most intensely felt. The suspension of international flights, fleet reductions, a sudden decrease in passenger demand, and operational restrictions due to COVID-19 caused structural changes in both economic, environmental, and social indicators. Therefore, this year's data may have led to unusual deviations in some criteria and may not reflect long-term trends. This situation limits the generalizability of sustainability performance findings to their true potential and requires careful interpretation of the findings beyond COVID-19 conditions. The use of multi-year datasets in future studies will help mitigate the effects of such periodic shocks and enable more robust comparisons.

4.3. Future Research Directions

This study exclusively utilises data from 2020, representing a unique period characterised by the extraordinary impact of COVID-19 on the global aviation industry. Consequently, future research endeavours should include analyses based on multi-year (panel) data. Such an approach would facilitate a more precise understanding of the evolution of sustainability strategies employed by airline businesses over time, their crisis management capacities, and long-term recovery trajectories. Additionally, it would enable more comprehensive inferences by accounting for the effects of periodic shocks on the analysis outcomes.

In the current study, only quantitative data from GRI-compliant businesses are utilised. This circumstance constrains the evaluation framework with respect to data comprehensiveness. Future research endeavours may consider developing multidimensional data sets by integrating alternative reporting standards (e.g., SASB, TCFD, CDP, ISO 26000). Such an approach would facilitate a more comprehensive assessment of sustainability performance, encompassing not only environmental aspects but also sub-dimensions such as governance quality, human rights, and supply chain responsibility.

Furthermore, the present study relies exclusively on quantitative results and does not include stakeholders' viewpoints. Nonetheless, corporate sustainability is inherently a multi-stakeholder and perception-oriented phenomenon. Future research may integrate stakeholder perspectives, including those of passengers, employees, investors, regulatory authorities, and others, into the decision-making process using methodologies such as the Delphi technique, the Analytic Network Process (ANP), fuzzy decision models, and Multi-Stakeholder Decision-Making (MSDM). Consequently, this would facilitate not only performance ranking but also stakeholder prioritisation.

Regarding the methodology, while the Entropy-TOPSIS approach employed in this study offers an objective and robust ranking technique, this framework should be extended to include hybrid models (such as Entropy-Additive Ratio Assessment (ARAS), AHP-Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS), Best-Worst Method with TOPSIS or Preference Ranking Organisation METHod for Enrichment Evaluation (PROMETHEE) integration) in subsequent research. Consequently, the impacts of various algorithms can be compared during both the weighting and ranking phases. Furthermore, sensitivity analyses of these methods can be conducted to assess the extent to which individual criteria influence decision outcomes. Such analyses are crucial for providing more robust and reliable policy recommendations to decision-makers.

Finally, sustainability performance may vary depending on geographical, cultural, and regulatory contexts. Therefore, conducting regional comparative studies such as those between Europe and China or the Gulf and Europe can facilitate the development of more contextualised and practical roadmaps for regional policymakers. Consequently, it becomes feasible to treat sustainability as a strategic element of management that is not only quantified but also actively guided.

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Appendices

Appendix: 1 Decision Matrix

Criteria	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	SC1	SC2	SC3	SC4	SC5	SC6	SC7	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7
ALT1	127	363	28.00	1.487.233	8.40	-836.00	6734.00	74.960.000.00	28688	13128	46.00	5.00	18.50	25.00	534	34.636	3972203.00	36.501	22.760	9.060.000	71.695	2.900.000
ALT2	74	757	36.40	2.689.000	12.50	-7682.00	15523.00	108.834.000.00	125207	47152	44.80	5.40	24.50	17.20	2.345	78.640	9.500.000	143.905	45.680	11.048.504	26.800	3.507.000
ALT3	134	250	5.83	1.578.829	8.40	-41.000	2152.00	93.385.000.00	36707	13948	36.50	4.00	28.00	23.00	4.653	15.832	2.807.660	377.647	15.769	14.246.972	49.376	3.245.258
ALT4	50	1399	95.00	1.383.000.000	12.60	-8885.00	17337.00	119.567.000.00	102700	40258	39.20	24.00	21.00	43.00	21.716	58.300	1.410.000	1.776.140	81.106	29.000.000	200.000	7.845.300
ALT5	52	942	55.00	11.845.000	15.00	-12385.00	17095.00	134.339.000.00	74000	31080	42.00	2.40	22.50	38.00	1.200	24.243	5.600.000	104.486	443.430	41.969.334	1.300.000	7.329.860
ALT6	107	718	138.00	7.850.250	12.00	-3074.00	9048.00	103.456.000.00	56367	32692	58.00	4.40	29.00	17.00	980	49.799	4.310.000	314.570	127.500	12.591.984	488.910	1.273.000
ALT7	170	614	74.62	177.700.000	7.24	-1715.00	8218.00	152.070.000.000	77005	29454	38.25	2.30	31.00	12.30	4.281	152.380	5.980.000	5.260.000	600.000	13.842.000	2.000.000	4.380.000
ALT8	70	288	11.66	246.310	13.90	-4550.00	6700.00	63.730.000.00	33898	15830	46.70	6.00	31.40	37.70	1.900	129.407	2.590.000	57.033	18.057	7.250.236	35.847	2.271.605
ALT9	157	259	15.80	1.900.000	7.30	-5550.00	8400.00	64.062.000.00	40801	15341	37.60	5.40	38.60	29.00	1.200	36.652	3.120.000	166.100	16.239	11.260.610	51.154	3.494.233
ALT10	35	734	96.85	54.200.000	7.10	-1572.00	13412.00	214.721.97	100431	47744	47.54	5.80	134.36	33.40	4.521	27.873	3.922.780	612.200	11.300	19.318.000	143.390	6.132.700

Appendix: 2 Normalised Decision Matrix for ENTROPY

Criteria	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	SC1	SC2	SC3	SC4	SC5	SC6	SC7	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7
ALT1	0.13	0.06	0.05	0.00	0.08	0.02	0.06	0.00	0.04	0.05	0.11	0.08	0.05	0.09	0.01	0.06	0.09	0.00	0.02	0.05	0.02	0.07
ALT2	0.08	0.12	0.07	0.00	0.12	0.15	0.15	0.00	0.19	0.16	0.10	0.08	0.06	0.06	0.05	0.13	0.22	0.02	0.03	0.07	0.01	0.08
ALT3	0.14	0.04	0.01	0.00	0.08	0.08	0.02	0.00	0.05	0.05	0.08	0.06	0.07	0.08	0.11	0.03	0.06	0.04	0.01	0.08	0.01	0.08
ALT4	0.05	0.22	0.17	0.84	0.12	0.18	0.17	0.00	0.15	0.14	0.09	0.37	0.06	0.16	0.50	0.10	0.03	0.20	0.06	0.17	0.05	0.19
ALT5	0.05	0.15	0.10	0.01	0.14	0.25	0.16	0.00	0.11	0.11	0.10	0.04	0.06	0.14	0.03	0.04	0.13	0.01	0.32	0.25	0.30	0.17
ALT6	0.11	0.11	0.25	0.00	0.11	0.06	0.09	0.00	0.08	0.11	0.13	0.07	0.08	0.06	0.02	0.08	0.10	0.04	0.09	0.07	0.11	0.03
ALT7	0.17	0.10	0.13	0.11	0.07	0.03	0.08	1.00	0.11	0.10	0.09	0.04	0.08	0.04	0.10	0.25	0.14	0.59	0.43	0.08	0.46	0.10
ALT8	0.07	0.05	0.02	0.00	0.13	0.09	0.06	0.00	0.05	0.06	0.11	0.09	0.08	0.14	0.04	0.21	0.06	0.01	0.01	0.04	0.01	0.05
ALT9	0.16	0.04	0.03	0.00	0.07	0.11	0.08	0.00	0.06	0.05	0.09	0.08	0.10	0.11	0.03	0.06	0.07	0.02	0.01	0.07	0.01	0.08
ALT10	0.04	0.12	0.17	0.03	0.07	0.03	0.13	0.00	0.15	0.17	0.11	0.09	0.35	0.12	0.10	0.05	0.09	0.07	0.01	0.11	0.03	0.14

Appendix: 3 Entropy Values for Criteria

Criteria	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	SC1	SC2	SC3	SC4	SC5	SC6	SC7	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7
ALT1	-0.27	-0.16	-0.15	-0.01	-0.20	-0.07	-0.18	0.00	-0.13	-0.14	-0.24	-0.20	-0.15	-0.22	-0.05	-0.16	-0.22	-0.02	-0.07	-0.16	-0.07	-0.18
ALT2	-0.20	-0.25	-0.18	-0.01	-0.25	-0.29	-0.28	-0.01	-0.31	-0.30	-0.23	-0.21	-0.18	-0.17	-0.16	-0.26	-0.33	-0.07	-0.11	-0.18	-0.03	-0.21
ALT3	-0.27	-0.13	-0.05	-0.01	-0.20	-0.20	-0.08	0.00	-0.16	-0.15	-0.21	-0.17	-0.19	-0.21	-0.24	-0.10	-0.18	-0.13	-0.05	-0.21	-0.05	-0.20
ALT4	-0.15	-0.33	-0.30	-0.14	-0.26	-0.31	-0.30	-0.01	-0.29	-0.28	-0.22	-0.37	-0.16	-0.29	-0.35	-0.22	-0.11	-0.32	-0.17	-0.30	-0.14	-0.31
ALT5	-0.16	-0.28	-0.23	-0.04	-0.28	-0.34	-0.30	-0.01	-0.24	-0.24	-0.23	-0.12	-0.17	-0.27	-0.10	-0.13	-0.26	-0.05	-0.36	-0.35	-0.36	-0.30
ALT6	-0.24	-0.25	-0.35	-0.03	-0.25	-0.17	-0.21	0.00	-0.21	-0.25	-0.27	-0.18	-0.20	-0.17	-0.09	-0.20	-0.23	-0.12	-0.22	-0.19	-0.25	-0.11
ALT7	-0.30	-0.23	-0.27	-0.24	-0.19	-0.12	-0.20	0.00	-0.25	-0.23	-0.21	-0.12	-0.20	-0.14	-0.23	-0.35	-0.27	-0.31	-0.36	-0.20	-0.36	-0.23
ALT8	-0.19	-0.14	-0.08	0.00	-0.27	-0.22	-0.18	0.00	-0.15	-0.16	-0.24	-0.22	-0.21	-0.27	-0.14	-0.33	-0.17	-0.03	-0.06	-0.13	-0.04	-0.16
ALT9	-0.29	-0.13	-0.10	-0.01	-0.19	-0.24	-0.20	0.00	-0.17	-0.16	-0.21	-0.21	-0.23	-0.24	-0.10	-0.17	-0.19	-0.07	-0.05	-0.18	-0.05	-0.21
ALT10	-0.12	-0.25	-0.30	-0.11	-0.18	-0.11	-0.26	0.00	-0.28	-0.30	-0.24	-0.22	-0.37	-0.26	-0.24	-0.14	-0.22	-0.18	-0.04	-0.25	-0.11	-0.28

Appendix: 4

Normalised Decision Matrix for TOPSIS

Criteria	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	SC1	SC2	SC3	SC4	SC5	SC6	SC7	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7
Weights	0.011595323	0.015010978	0.030669958	0.177804726	0.003995150	0.024724622	0.012031017	0.234974493	0.011618945	0.010820876	0.000990615	0.030125347	0.025697022	0.006862582	0.064366993	0.02436192	0.012075102	0.102249518	0.084151793	0.015858437	0.087796912	0.012277661
ALT1	0.37586	0.19529	0.12705	0.00107	0.24511	-0.64115	0.18475	0.00040	0.12156	0.13208	0.32984	0.17956	0.11680	0.27020	0.02387	0.04627	0.20999	0.06850	0.02580	0.14485	0.02526	0.13480
ALT2	0.21758	0.32110	0.16516	0.00193	0.36475	-0.39654	0.42589	0.00072	0.52967	0.47441	0.32133	0.19393	0.15480	0.18589	0.10043	0.33176	0.62180	0.02564	0.05982	0.17664	0.01094	0.23521
ALT3	0.39563	0.10970	0.02545	0.00113	0.24511	-0.21215	0.09904	0.00001	0.15529	0.14033	0.26180	0.14165	0.17091	0.24858	0.19927	0.06670	0.18377	0.06728	0.02065	0.22778	0.02015	0.21796
ALT4	0.14608	0.41190	0.41106	0.99104	0.36766	-0.45963	0.47566	0.00079	0.45440	0.40505	0.20117	0.06150	0.13261	0.46474	0.93901	0.24595	0.09729	0.31453	0.10632	0.46364	0.08164	0.52619
ALT5	0.15275	0.41137	0.24956	0.00049	0.43770	-0.63920	0.46902	0.00008	0.31305	0.31270	0.30125	0.08619	0.18448	0.41070	0.05130	0.10227	0.36653	0.01862	0.58973	0.67099	0.53064	0.49161
ALT6	0.31421	0.15927	0.02612	0.00563	0.35016	-0.15686	0.28424	0.00066	0.23845	0.27292	0.41601	0.19001	0.18322	0.18377	0.04197	0.10009	0.28210	0.05605	0.16606	0.20132	0.19957	0.08578
ALT7	0.49910	0.00443	0.34859	0.17734	0.21126	-0.08833	0.25247	1.00000	0.32576	0.29634	0.27535	0.08240	0.19586	0.15294	0.18334	0.64285	0.39140	0.93716	0.78579	0.22130	0.01637	0.70977
ALT8	0.20563	0.12638	0.02591	0.00018	0.40560	-0.23487	0.18382	0.00042	0.16140	0.19227	0.33496	0.21547	0.19839	0.44045	0.08137	0.54503	0.10952	0.01016	0.02165	0.11591	0.01463	0.15236
ALT9	0.46119	0.11165	0.07169	0.00136	0.21301	-0.26649	0.20846	0.00042	0.17200	0.15835	0.20909	0.19193	0.24388	0.31143	0.05139	0.15462	0.29421	0.02959	0.02127	0.18063	0.02088	0.23436
ALT10	0.10281	0.12309	0.41945	0.03884	0.20718	-0.08115	0.36797	0.00000	0.42486	0.48036	0.34099	0.20829	0.84891	0.36098	0.19362	0.11739	0.25675	0.10907	0.01480	0.30885	0.05853	0.41132

Appendix: 5

Weighted Normalised Matrix for TOPSIS

Criteria	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	SC1	SC2	SC3	SC4	SC5	SC6	SC7	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7
Weights	0.011595323	0.015010978	0.030669958	0.177804726	0.003995150	0.024724622	0.012031017	0.234974493	0.011618945	0.010820876	0.000990615	0.030125347	0.025697022	0.006862582	0.064366993	0.02436192	0.012075102	0.102249518	0.084151793	0.015858437	0.087796912	0.012277661
ALT1	0.00433	0.00279	0.00190	0.00019	0.00098	-0.00107	0.00272	0.0001158	0.00141	0.00143	0.00013	0.00541	0.00100	0.00185	0.00147	0.00136	0.00114	0.00066	0.00531	0.00230	0.00277	0.00276
ALT2	0.00252	0.00409	0.00507	0.00034	0.00146	-0.00060	0.00513	0.0001682	0.00015	0.00132	0.00058	0.00198	0.00126	0.00046	0.00088	0.00751	0.00362	0.00003	0.00200	0.00006	0.00789	0.00263
ALT3	0.00456	0.00165	0.00081	0.00020	0.00098	-0.00525	0.00071	0.0001443	0.00152	0.00026	0.00043	0.00455	0.00071	0.00181	0.00163	0.00222	0.00088	0.00074	0.00081	0.00177	0.00023	0.00263
ALT4	0.00176	0.00927	0.01132	0.17621	0.00147	-0.01134	0.00577	0.0001348	0.00050	0.00438	0.00028	0.02597	0.00141	0.00591	0.00509	0.01011	0.01356	0.00894	0.00715	0.00717	0.00648	0.00648
ALT5	0.00177	0.00627	0.00765	0.00151	0.00175	-0.01581	0.00564	0.0002076	0.00054	0.00138	0.00030	0.00020	0.00182	0.00582	0.00030	0.00249	0.00443	0.00190	0.04887	0.01064	0.04659	0.00604
ALT6	0.00364	0.00473	0.01920	0.00140	-0.00392	0.00299	0.0001599	0.00277	0.00156	0.00041	0.00136	0.00471	0.00126	0.00270	0.00512	0.00141	0.00373	0.01405	0.00319	0.01752	0.00105	0.00105
ALT7	0.00579	0.00004	0.01038	0.02264	0.00084	-0.00219	0.00271	0.2349741	0.00179	0.00121	0.00027	0.00149	0.00503	0.00091	0.01179	0.01566	0.00043	0.00582	0.06613	0.00351	0.01748	0.00161
ALT8	0.00238	0.00190	0.00162	0.00003	0.00162	-0.00251	0.00221	0.0000995	0.00167	0.00172	0.00013	0.00649	0.00510	0.00580	0.00573	0.01330	0.00205	0.00104	0.00199	0.00144	0.00128	0.00187
ALT9	0.00535	0.00171	0.00270	0.00024	0.00056	-0.00278	0.00227	0.0000990	0.00261	0.00147	0.00027	0.00584	0.00662	0.00155	0.00030	0.00377	0.00242	0.00003	0.00079	0.00236	0.00183	0.00280
ALT10	0.00119	0.00483	0.01348	0.00609	0.00083	-0.00203	0.00443	0.0000003	0.00494	0.00520	0.00034	0.00627	0.04891	0.00548	0.01245	0.00256	0.00310	0.01115	0.00025	0.00490	0.00514	0.00505

Contextualising Subjective Well-Being Through Happiness and Life Satisfaction: A Microdata Analysis

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Öznel İyi Oluşu Mutluluk ve Yaşam Memnuniyeti Üzerinden Bağlamsallaştırmak: Mikro Veri Analizi

Abstract

The primary aim of this study is to identify the direct and indirect factors influencing the two dimensions of subjective well-being: happiness and life satisfaction. In this context, using pseudo-panel data and path analysis, the study investigates whether happiness and life satisfaction in Türkiye vary across different socioeconomic, demographic, and environmental factors. Furthermore, it examines whether satisfaction with health and future expectations mediate these relationships and whether gender moderates them. Key findings indicate that higher education negatively influences happiness but positively affects life satisfaction, highlighting the complex interaction between educational attainment and well-being. Notably, the study reveals shifting dynamics over time: higher education initially correlates with greater happiness through improved health satisfaction and future expectations, but later correlates with lower happiness due to reduced future expectations. Moreover, age's influence on life satisfaction is mediated by health satisfaction and future expectations, suggesting the importance of addressing health and outlooks to enhance overall well-being. Policy recommendations stemming from these insights include interventions to improve healthcare access, promote healthy lifestyles, mitigate socioeconomic disparities, and enhance educational and environmental conditions.

Keywords : Subjective Well-Being, Happiness, Life Satisfaction, Pseudo-Panel, Path Analysis.

JEL Classification Codes : C15, C23, C38, I31.

Öz

Bu çalışmanın temel amacı, öznel iyi oluşun iki boyutu olan mutluluk ve yaşam memnuniyeti üzerinde doğrudan ve dolaylı etkili olan faktörleri belirlemektir. Bu bağlamda, yapılan pseudo-panel data ve path (yol) analizleri ile Türkiye’de mutluluk ve yaşam memnuniyetinin çeşitli sosyoekonomik, demografik ve çevresel faktörler çerçevesinde farklılaşıp farklılaşmadığı; mutluluk ve yaşam memnuniyetinde sağlıktan memnuniyetin ve gelecek beklentilerinin aracılık etkisinin olup olmadığı ile cinsiyetin düzenleyici bir rolünün var olup olmadığı tespit edilmeye çalışılmıştır. Temel bulgular, yükseköğrenimin mutluluğu olumsuz, yaşam memnuniyetini ise olumlu yönde etkilediğini göstererek, eğitim düzeyi ile iyi oluş arasındaki karmaşık etkileşime dikkat çekmektedir. Sonuçlar, özellikle zaman içinde bu dinamiklerin değişebildiğine işaret etmektedir: Başlangıçta yükseköğrenim, artan sağlık memnuniyeti ve olumlu gelecek beklentileri aracılığıyla daha yüksek mutlulukla ilişkilendirilirken, ilerleyen dönemde azalan gelecek beklentileri nedeniyle mutluluk azalabilmektedir. Ayrıca, yaşam

yaşam memnuniyeti üzerindeki etkisinin sağlık memnuniyeti ve gelecek beklentileri aracılığıyla dolaylı olarak gerçekleştiği saptanmış; bu da genel iyi oluşu artırmak için sağlık ve bireylerin geleceğe dair bakış açılarına yönelik müdahalelerin önemini vurgulamaktadır. Bu bulgulardan hareketle geliştirilen politika önerileri arasında sağlık hizmetlerine erişimin iyileştirilmesi, sağlıklı yaşam biçimlerinin teşvik edilmesi, sosyoekonomik eşitsizliklerin azaltılması ve eğitim ile çevresel koşulların güçlendirilmesi yer almaktadır.

Anahtar Sözcükler : Özel İyi-Oluş, Mutluluk, Yaşam Memnuniyeti, Pseudo-Panel, Path Analizi.

1. Introduction

Health is defined not only as the absence of any disease or disability but as a state of complete physical, mental and social well-being (WHO, 1948). This state of well-being is a product of biological and environmental factors and has increasingly been evaluated holistically, especially in recent years. The consideration of health as a fundamental human right and, conversely, its direct impact on human capital distinguishes the healthcare sector, making it a primary concern of public interest in all societies (Sen, 2002; Wagstaff & Van Doorslaer, 2000). In this context, health is closely related to subjective well-being. The World Health Organisation (WHO) considers subjective well-being a cornerstone of public health and, in this regard, a prominent objective of health policies in developed countries (Barger et al., 2009).

Subjective well-being has long been viewed as a philosophical debate, but recently it has become an important political objective due to its deep connections to health, human capital, and development. Subjective well-being, in general terms, can be defined as an individual's subjective evaluation of their life as desirable, enjoyable, and good (Diener, 1984). Subjective well-being is fundamentally associated with feeling good and functioning well. It involves an interaction of factors such as the individual's ability to cope with normal life stresses, feeling in control of one's life, experiencing positive social relationships, and having a sense of purpose in life (Ruggeri et al., 2020).

Discussions followed, leading to a consensus on terminology within the field. The central proposition was to adopt "well-being" as the predominant term encompassing all related measures. Traditionally, the scientific exploration of well-being has often been equated with the study of "happiness". However, this label lacks precision because it fails to fully capture the diverse range of specific states and broader dimensions of well-being. While the term "happiness" appeals to its marketability and intuitive quality, it is essential to maintain scientific rigour by accurately representing the complex nature of the subject matter. Under the preferred terminology, measures of "happiness" are confined to those that explicitly address happiness, whereas broader aspects of well-being encompass evaluations of life satisfaction and various domains, such as job satisfaction, positive emotions, and the absence of negative emotions. This distinction ensures clarity in research discourse and

aligns with the nuanced understanding that different facets of well-being may operate independently to some extent (Diener et al., 2010).

Based on this discussion in the literature, it is possible to argue that the two dimensions of subjective well-being are life satisfaction and happiness. Life satisfaction is primarily associated with the environment in which individuals position themselves and the comparisons they make. Satisfaction is significantly influenced by an individual's goals and objectives, expectations and hopes in life, reference groups, and internal and external social groups. Apart from the other parameters, life satisfaction is also correlated with emotional well-being (Berlin & Connolly, 2019). Happiness, on the other hand, is an emotional state rather than a cognitive one, distinct from satisfaction, and is influenced by individuals' positive and negative experiences. While there is a certain degree of correlation between life satisfaction and happiness, they are fundamentally distinct (Selim, 2008).

One of the fundamental reasons for investigating subjective well-being is its relationship with health and, consequently, with social/human capital and development. There is a known positive relationship between improvements in individuals' health conditions and economic growth and human capital. Human capital, by definition, encompasses all knowledge, skills, and abilities that make individuals more beneficial and productive (Başar, 2008). Particularly in developed countries, productivity increases are nourished not only by physical capital but also by significant increases in labour productivity. Therefore, human capital is considered a crucial element of both growth and development (Mushkin, 1962).

According to economists such as Mushkin (1962), Becker (1994), and Fuchs (1966), health is considered a component of human capital, while Grossman (1972) argues that health is a capital stock in itself. In this regard, health capital differs significantly from other forms of human capital. This is because an individual's accumulation of knowledge and health affects their productivity both in and out of the market, whereas an individual's health capital determines their preference between time spent in the production process and remaining time (Başar, 2008).

During the 1950s and 1960s, many developing countries achieved high per capita income figures. Despite this increase in income, the standard of living did not change in some countries. This situation is also valid from the perspective of subjective well-being. According to Appleton and Song (2008), the economic growth experienced in wealthy countries over the past 50 years has not had a significant impact on individuals' happiness in those countries. These findings in the related literature are also consistent with the Easterlin (1974) Paradox and may not exhibit the same synchrony between income and happiness across all countries (Caporale et al., 2009).

Subjective well-being is also associated with professional and personal success. It has been found that individuals with higher levels of subjective well-being exhibit greater productivity and creativity in both personal relationships and workplace settings.

Furthermore, panel data studies have demonstrated that subjective well-being is subject to intergenerational transmission mechanisms (Ruggeri et al., 2020). In this regard, the correlation between subjective well-being and performance at both the micro and macro levels, as well as its positive long-term effects on social capital, has been established (Di Tella et al., 2001).

The well-being literature has explored several central questions regarding the measurement and understanding of well-being on an international scale in recent years. These inquiries included determining the most effective methods for measuring well-being to enable comparisons across countries, assessing the variations in well-being measures among individuals and nations over time, and investigating whether the factors influencing well-being differ more within nations or among them. For instance, Inglehart (2004) measured subjective well-being using the World Values Survey and classified the rankings into four main groups (namely, high, medium-high, medium-low, and low). These rankings revealed that income and economic growth were important but not sufficient predictors for subjective well-being. Building upon these questions, the studies delved into two specific focal points. Firstly, they examined the role of certain parameters, such as income, in explaining differences in well-being within countries, across nations, and over time. Secondly, it explored whether international differences in well-being stem from shared reactions to local conditions or from culturally distinct evaluations of life circumstances. These comprehensive investigations aimed to shed light on the complex dynamics underlying global well-being and to provide insights into the factors shaping individual and societal perceptions of happiness and satisfaction. On the other hand, some studies focused mainly on internal factors and sought to analyse direct determinants of happiness and life satisfaction. In addition, some studies focused on mediating effects on happiness and life satisfaction rather than on the parameters that directly affect them. Whether focusing on direct or indirect effects, studies examined many socioeconomic and demographic factors (e.g., Frey & Stutzer, 2002; Dolan et al., 2008) and aimed to understand which factors were effective in shaping individuals' happiness and life satisfaction in that country. While the economics of happiness has been extensively studied in developed countries, empirical research on Türkiye has gained momentum with pioneering studies by Selim (2008), who investigated the socioeconomic determinants of happiness, and Dumludağ et al. (2016), who focused on the roles of income comparison in life satisfaction.

This study differs from the literature in two main points. Firstly, by separating happiness and life satisfaction, this study aims to identify the direct, mediated, and moderated effects on subjective well-being. Secondly, this study aims to investigate the direct and indirect effects on happiness and life satisfaction across a broader range of years, rather than a single year or period. The current study uses a pseudo-panel data approach to analyse direct effects on subjective well-being. Since longitudinal data covering such a broad time span for this aim are not available for Türkiye, relying solely on cross-sectional data would limit the understanding of dynamic changes over time. Therefore, constructing a pseudo-panel from repeated cross-sections would be a proper methodological choice to accurately capture long-term dynamics and overcome the limitations of single-year analyses.

To analyse mediated and moderated effects on subjective well-being, path analysis is conducted, and analyses are repeated for all examined years. Thus, it is observed whether there have been significant changes in the mediators and moderators over the years. Although some studies in the literature have utilised path analysis to demonstrate the mediating role of various variables in the model (e.g., see Lara et al., 2020; Patria, 2022), the existing literature employing the pseudo-panel data method remains relatively limited.

1.1. The Importance of Subjective Health Satisfaction, Hope and Future Expectations on Subjective Well-Being

In addition to examining various socio-economic and demographic determinants of subjective well-being, the current study places particular emphasis on subjective health satisfaction, hope, and future expectations. These factors are considered not only as direct influences on happiness and life satisfaction but also as key elements that may directly affect other variables influencing subjective well-being. In other words, individuals' health satisfaction and future expectations may also mediate the relationship between happiness and life satisfaction. For example, although many studies have shown the opposite, the literature often emphasises a U-shaped relationship between age and life satisfaction. However, when age and life satisfaction are positively synchronised, if the individual is also satisfied with their health, subjective health satisfaction may further boost life satisfaction. A similar pattern can be observed when considering hope and future expectations. The existing literature does not establish a generally accepted correlation between education level and life satisfaction. While some studies suggest that life satisfaction decreases as education level increases due to various factors, others argue the opposite. In this context, individuals' perspectives on their future may play a clarifying role. Specifically, hope and future expectations may mediate or partially mediate the relationship between education level and life satisfaction. Since self-consciousness and life expectations may increase among highly educated individuals, their future expectations and hopes may decrease relative to those of others, thereby negatively affecting their life satisfaction. This pattern may have deepened, especially in developing economies and in countries facing social and financial turbulence. In light of the exemplifications mentioned above, the current study tests both the direct and indirect effects of subjective health and future expectations. Indirect effects, in other words, mediating or partial mediating effects, are sought to be revealed with path analyses. A considerable amount of literature on subjective well-being has emphasised the importance of health and health-related subjects. The evidence reviewed here (see, for example, Okun et al., 1984; Habibov & Afandi, 2016; Ngamaba et al., 2017; and Kushlev et al., 2020) suggests a pertinent role for health satisfaction in both happiness and life satisfaction. On the other hand, numerous studies have attempted to understand the impacts of individuals' hopes and future expectations on happiness and life satisfaction. According to Snyder et al. (2005), hope includes both the will to achieve certain goals and the ways to achieve this effectively. Accordingly, hopes and expectations for the future can affect individuals' happiness and life satisfaction, both directly and indirectly. Many recent studies (e.g., Cotton Bronk et al., 2009; Hoy et al., 2013; Nie et al., 2019) have shown that future expectations mediated happiness and life satisfaction of individuals.

1.2. Moderated Role of Gender: Do the Determinants of Happiness and Life Satisfaction Differ by Gender?

This study investigates the moderating role of gender in the relationship between subjective well-being, future expectations, and subjective health satisfaction. Accordingly, one of the basic hypotheses of this study is that the direct and indirect factors affecting happiness and life satisfaction may differ across gender. While some studies indicate general similarity in the predictors of life satisfaction and happiness across genders (see, for example, Diener et al., 2000; Joshi, 2010; Della Giusta et al., 2011; Joshanloo, 2018; Fugl-Meyer et al., 2002), a significant portion of the relevant literature also highlights the moderating role of gender in the context of subjective well-being (see, for example, Inglehart, 2002; Tiefenbach & Kohlbacher, 2014; Meisenberg & Woodley, 2015; Gagne et al., 2022; Comolli et al., 2024) aligning with the hypotheses of this study.

2. Data & Methodology

2.1. Data & Pseudo-Panel Construction

This study conducts a comprehensive analysis using microdata from the Life Satisfaction Survey (LSS) datasets provided by the Turkish Statistical Institute (TURKSTAT) for the years 2004, 2017 and 2022. However, the use of data in this study is incidental to the broader aim of demonstrating the robustness and applicability of the methodological framework employed. While the dataset offers valuable insights specific to the Turkish context, the study's primary focus is not limited to these country-specific findings. Instead, it illustrates how advanced analytical methods, such as pseudo-panel data construction and path analysis, can be applied to examine subjective well-being across various contexts.

The key point of this research lies in the methodological innovations, which can be generalised to other regions, countries, and datasets. By utilising a large micro dataset, this study demonstrates how to account for both direct and indirect effects on well-being, providing a widely applicable model. The choice of Türkiye as the data source was based on availability and the time span of the LSS, but the underlying relationships among variables such as education, health satisfaction, and future expectations are not unique to Türkiye. These relationships reflect broader social and psychological processes that transcend national boundaries.

Moreover, the methodological approach used to explore mediating and moderating factors, as well as the dynamic nature of subjective well-being over time, can be applied to data from other countries. The tools used in this study are designed to uncover generalizable patterns, making them suitable for comparative analysis. This enables researchers to replicate the approach with similar datasets from different regions and achieve comparable insights.

The paper is structured around two main pillars. First, it examines the direct impact of socio-economic, demographic, and environmental factors on individual happiness and life satisfaction. In this phase, the pseudo-panel data model (PPDM) is employed to convert these cross-sectional datasets into a panel data format, facilitating panel analyses of happiness and life satisfaction trends in Türkiye. Second, the study investigates the relationships between income, age, education, environmental factors, and life satisfaction and happiness, and analyses whether health and future expectations play a mediating role and whether gender has a moderating effect. For these analyses, path analysis is utilised.

However, it is noteworthy that the inclusion of life satisfaction questions in the LSS micro datasets began only in 2017. Consequently, while the cohorts for happiness analysis span the years 2004 to 2022, the analysis specifically focusing on life satisfaction is restricted to the period from 2017 to 2022. An overview of the pseudo-panel method and path analysis is provided subsequently.

Many studies on happiness and life satisfaction rely on cross-sectional data from a single year. The main problem with this approach is that it captures only factors affecting life satisfaction and happiness in that specific year, limiting understanding of changes over time.

In addressing this methodological drawback, Deaton's work (1985) on pseudo-panel data models (PPDMs) offers a pragmatic solution. PPDMs enable comprehensive analyses even in the absence of panel datasets by aggregating cross-sectional data into synthetic panel data. This technique involves segmenting cross-sectional data into distinct clusters or cohorts, thereby emulating the dynamics of panel data across successive time periods.

One of the most important points to consider when using the PPDM is that the clustering process must be applied according to variables that do not change much over time. For instance, when applying clustering, variables such as age and gender should be selected rather than income, which is more likely to change annually (Baltagi, 2008). According to Deaton (1985), PPDM also has advantages over panel data. For example, PPDM is not affected by the attrition problem in standard panel data. The attrition problem is one of the problems encountered in longitudinal panel data. The person may initially decide to join survey and longitudinal studies; however, they may stop participating over time for various reasons (personal preference, death, etc.). Since this situation is cumulative, the loss in each period can add up to a large overall observation loss over time. This may have biased effects on the quality and validity of surveys and the results of the research. In addition, clustering cross-sectional data enables larger micro- and macro-level analyses.

2.2. Econometric Strategy: Pseudo-Panel and Path Analysis Model

To estimate the direct and indirect effects on subjective well-being, a two-stage estimation strategy is employed, combining pseudo-panel fixed effects and path analysis.

2.2.1 Analysis Direct Effects with Pseudo-Panel Data (PPDM) Models

The brief representation of PPDM is as follows:

$$Y_{it} = a + \beta X_{it} + \mu_{it} \quad i = 1, \dots, N; \quad t = 1, \dots, T \quad (1)$$

Here, i indicates the cross-section and t indicates the time dimension. Additionally, a is a scalar, X_{it} is the vector of explanatory variables for the i^{th} observation at time t , and β is the vector of parameters to be estimated. In panel data analysis, the one-way error component model, as described below, is most commonly used.

$$\mu_{it} = \mu_i + v_{it} \quad (2)$$

Here, μ_i represents specific effects that are unobserved and do not change over time, while v_{it} represents unobserved effects that vary both across individuals and over time. When the 1st and 2nd equations are combined, equation (3) is formed.

$$Y_{it} = a + \beta X_{it} + \mu_i + v_{it} \quad i = 1, \dots, N; \quad t = 1, \dots, T \quad (3)$$

In the standard panel data model, specific effects can be estimated by least squares if they are uncorrelated with the explanatory variables. On the other hand, when specific effects are correlated with explanatory variables, the fixed effects model is estimated by taking the difference between each variable and its time average. Since specific, identical units are not included in independent cross-sectional data sets, the aforementioned model cannot be used. For this reason, Deaton (1985) suggested cluster (cohort) modelling and showed that consistent estimators could be obtained in repeated cross-sectional data. Thus, the same unit effect can be achieved with clusters with common features (Kaya-Aydın, 2021). As a result of clustering all observations, equation (4) can be achieved.

$$\bar{Y}_{ct} = \bar{x}_{ct}\beta + \bar{\mu}_{ct} + \bar{v}_{ct} \quad c = 1, \dots, C; \quad t = 1, \dots, T \quad (4)$$

In this equation, c indicates the cluster (cohort) number. $\bar{Y}_{ct}$ represents the average of all individuals belonging to cluster c at time t , according to the Y . Unlike μ_i obtained from standard panel data, Equation 3, $\bar{\mu}_{ct}$ retains the subscript t to indicate that the cluster mean for each period is calculated from new and likely different individuals. This results in a potentially different value for each period. In practice, if the number of individuals in each cell is large, the assumption of ($\bar{\mu}_{ct} = \bar{\mu}_c$) is made for each t and the pseudo-panel equation is written as the fixed cluster effect $\bar{\mu}_c$ and fixed individual effect $\bar{\mu}_i$ as equation (5) (Russell & Fraas, 2005).

$$\bar{Y}_{ct} = \bar{x}_{ct}\beta + \bar{\mu}_c + \bar{v}_{ct} \quad c = 1, \dots, C; \quad t = 1, \dots, T \quad (5)$$

In the context of pseudo-panel data modelling (PPDM), the fixed effects model succeeds owing to the underlying assumption that idiosyncratic effects are orthogonal to the explanatory variables in the random effects framework. Consequently, the need for synthetic clustering, a characteristic feature of random-effects modelling, is avoided. In accordance

with this methodological framework, fixed-effects analyses are systematically conducted for both the happiness and life satisfaction pseudo-panels. This approach ensures robust control for unobserved individual-specific heterogeneity, thereby enhancing the robustness of the analyses. For clustering, age was selected in the (LSS) and the micro data sets were converted into panel format with the PPDM. In this way, the clustering process around continuous and changing data, as Baltagi (2008) noted, was avoided, and panel data were created by clustering the appropriate age variable. To ensure consistency across LSSs, data from individuals aged 18-90 were used in the study. For the clustering process, ages were grouped into three ranges, resulting in 24 cohorts. The choice of a 3-year birth interval was driven by the need to balance cohort homogeneity and sample size sufficiency. Deaton (1985) and Verbeek (2008) emphasise that the number of observations in each cohort must be sufficiently large to minimise the measurement error of cohort means. As demonstrated in Table 2 (and Appendix), this study utilises a very large dataset with sufficiently large cohort sizes. These sizes are well above the recommended thresholds for safely ignoring sampling error bias. Table 1 shows how the variables were obtained from LSS microdata sets.

Table: 1
Explanations of the Variables

Variables Name	Sub-groups	Obtained from which question	Scale of the variables
life_satisfaction	-	When you think as a whole, rate your recent life satisfaction (between 1-11)	1: not at all satisfied 11: very satisfied
happiness	-	When you think of your life as a whole, how happy are you? (between 1-5)	1: not happy to all 5: very happy
income_sat	-	Are you satisfied with your household's monthly income? (between 1-5)	1: not happy to all 5: very happy
health_sat	-	Are you satisfied with your health? (between 1-5)	1: not happy to all 5: very happy
expectations	-	When you think about the next 5-year period, how do you expect your situation to be in general? (between 1-3)	1: will deteriorate 3: will develop
education	-	What is your completed level of education?	1: No school completed or illiterate; 2: primary-secondary school; 3: high school; 4: associate or bachelor's degree 5: postgraduate
environment	houses	Are you satisfied with your residential houses? (between 1-5)	1: not happy to all 5: very happy
	district	Are you satisfied with the district where you live? (between 1-5)	1: not happy to all 5: very happy
	neighbours	Are you satisfied with the relationships with your neighbours? (between 1-5)	1: not happy to all 5: very happy
	public security services	Are you satisfied with the public security service? (between 1-5)	1: not happy to all 5: very happy

As shown in Table 1, all variables analysed were continuous. The variables presented in Table 1 (happiness, life satisfaction, etc.) are measured on Likert-type ordinal scales. Although these variables are categorical, treating them as continuous is common in the literature when the number of categories is sufficiently large (typically 5 or more) (Ferrer-i-Carbonell & Frijters, 2004). Therefore, in this study, these ordinal variables are treated as continuous to facilitate the calculation of means for the pseudo-panel construction and subsequent path analysis. To examine the impact of external environmental factors on happiness and life satisfaction, an environmental variable was constructed by aggregating

and averaging responses to questions regarding housing, district, neighbours, and public order in the datasets. Additionally, individuals' education levels were categorised into five levels.

Table: 2
Descriptive Statistics after Clustering

Variable	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max
		Happiness Analysis					Life Satisfaction Analysis			
education	456	2.144	.481	1	3.228	144	2.326	.489	1.357	3.228
environment	456	3.808	.113	3.125	4.188	144	3.809	.103	3.583	4.048
Expectations	456	2.068	.235	1	2.672	144	1.957	.162	1.659	2.539
Income_sat	456	3.015	.203	1.5	4	144	3.06	.188	2.759	3.63
Health_sat	456	3.466	.317	2.385	4.5	144	3.516	.295	2.692	4.057
happiness	456	3.518	.127	3	4.125					
life satisfaction						144	6.46	.252	5.143	7.19
age group	456	12.5	6.93	1	24	144	12.5	6.946	1	24
Year	456			2004	2022	144			2017	2022

Table 2 presents descriptive statistics for the transformed dependent and independent variables following the pseudo-panel data conversions. As shown in Table 2, individuals aged 18 to 90 were clustered into three age ranges, yielding a total of 24 clusters in both the happiness and life satisfaction analyses. To analyse the determinants of happiness and life satisfaction using PPDM fixed-effects analyses, the variables *happiness* and *life_satisfaction* were set as the dependent variables for the respective analyses, with the others as independent variables in both analyses. Detailed descriptive statistics on sample sizes, gender distributions, and education levels for each of the 24 cohorts are provided in the Appendix. These tables confirm that, despite the natural demographic decline in older age groups, sample sizes remain sufficiently large to neglect the measurement error bias inherent in pseudo-panel estimation (Deaton, 1985; Verbeek, 2008).

2.2.2. Analysing Mediated and Moderated Effects on Happiness and Life Satisfaction with Path Analysis

The PPDM fixed-effects model will reveal which factors have a statistically significant impact on happiness and life satisfaction over time. However, do these variables directly affect happiness and life satisfaction? Alternatively, do some specific factors that were at the forefront in the related literature play a mediating role? In other words, when examining the relationships between socioeconomic, demographic, and environmental factors such as income, age, education, and environment and life satisfaction and happiness, do an individual's health satisfaction and expectations for the future play a mediating role? To test whether such a relationship exists, path analysis was performed in the study.

With path analysis, estimates are produced of the magnitude and importance of hypothetical causal connections among sets of variables, which can be visualised using path diagrams. As is well known, diagrams are used in path analysis, and a brief explanation of the method is provided below.

$$M = i_M + a_1X + e_M \quad (6)$$

$$Y = i_Y + c'_1X + b_1M + e_Y \quad (7)$$

Equations 6 and 7 show the path model of Hayes (2012) with one dependent variable Y , one independent variable X , and one mediating variable M . Here, a_1 and b_1 represent indirect effects, c'_1 represents direct effects, and the total effect is shown as $c_1 = a_1b_1 + c'_1$. The direct and indirect effects of the independent variable are derived from two linear models, one of which predicted the mediating variable from the independent variable (Hayes, 2012).

Here, it also shows that i is the cutoff point, equation (5) shows that M is estimated from X , and equation (6) shows that Y is estimated from both X and M . The direct effect of X on Y is estimated by c'_1 in equation (6). Here it is shown how much a one-unit change in X affects Y , independent of the change in M . On the other hand, the indirect effect of X on Y through M is estimated by a_1b_1 . More clearly, a_1 in equation (6) represents the effect of X on M , and b_1 in equation (7) represents the effects of M , which controls X , on Y . The direct and indirect effects of X on Y are summed to give the total effect of X on Y . This total effect can also be estimated with the following regression (8):

$$Y = i_{Y^*} + c_1X + e_{Y^*} \quad (8)$$

As in this study, it is possible to test multiple mediators rather than a single mediation relationship. In this case, the effects of more than one mediating variable can be analysed using the parallel multiple mediator model. Suppose that X can affect mediators k and k can causal relations with Y . However, mediators k cannot affect each other. In this scenario, equation 9 shows the direct and indirect effects of k number of mediators M from X . As a result, the model containing all k mediators, independent variables X and dependent variable Y might be created as in equation 10.

$$M_i = i_M + a_iX + e_M \quad (9)$$

$$Y = i_Y + c'_1 + \sum_{j=1}^k b_jM + e_Y \quad (10)$$

Here, the direct effect of X is estimated by c'_1 and the specific indirect effect of X on Y through M_j is estimated by a_jb_j . There are k specific indirect effects that add up to the total indirect effect of X on Y through k variables. As in the simple model with a single agent, the total effect of X (like c_1 in equation 7) is the sum of the direct effect of X and the k specific indirect effects of X up to M . So, the total indirect effect is shown in equation (11).

$$c_1 = c'_1 + \sum_{j=1}^k a_jb_j \quad (11)$$

In other words, total indirect effects are the difference between total and direct effects, which is shown in equation (12).

$$\sum_{j=1}^k a_jb_j = c_1 - c'_1 \quad (12)$$

Before the interpretation of the drawn path diagrams, the goodness of fit must also be tested. Related literature recommends checking RMSEA (root mean square error of approximation), CFI (Comparative Fit Index), and TLI (Tucker-Lewis Index) values. Accordingly, for the path diagram to be statistically significant, the RMSEA should be less than 0.08 (Hooper et al., 2008; Kim et al., 2016; UCLA, 2022). TLI and CFI are expected to be greater than 0.90. Furthermore, to statistically test whether the identified indirect effects are significant, the Sobel test was employed (Sobel, 1982). While Path Analysis estimates the magnitude of indirect pathways, the Sobel test determines whether the mediator variable carries the influence of the independent variable to the dependent variable at a statistically significant level. The test statistic (z-value) is calculated from the path coefficients and their standard errors.

As mentioned above, this study has two mediators, namely health satisfaction and future expectations. The mediating effect of these variables on happiness and life satisfaction levels was examined with path analyses. The 2004 and 2022 LSS microdata sets were used to identify happiness mediators, whereas the 2017 and 2022 LSSs were used for life satisfaction analysis. Therefore, it is also possible to observe whether there was a significant change in mediators over the years.

Tables 3 and 4 present descriptive statistics for the datasets used in the path analyses.

Table: 3
Descriptive Statistics of the Path Analysis for Happiness

Variables	2004					2022				
	N	mean	sd	min	max	N	mean	sd	min	max
age	5950	41,23	15,84	18	90	8383	43,97	15,91	18	90
health sat	5950	3,516	0,945	1	5	8383	3,656	0,814	1	5
income sat	5950	2,781	1,051	1	5	8383	2,933	1,053	1	5
happiness	5950	3,511	0,893	1	5	8383	3,387	0,893	1	5
expectations	5950	2,301	0,698	1	3	8383	1,935	0,835	1	3
environment	5950	3,725	0,542	1	5	8383	3,777	0,509	1	5
education	5950	2,155	0,848	1	5	8383	2,658	0,998	1	5

Table: 4
Descriptive Statistics of the Path Analysis for Life Satisfaction

Variables	2017					2022				
	N	mean	sd	min	max	N	mean	sd	min	max
age	8286	43,96	16,21	18	90	8383	43,97	15,91	18	90
life satisfaction	8286	6,497	2,173	1	11	8383	6,532	2,328	1	11
health sat	8286	3,624	0,809	1	5	8383	3,656	0,814	1	5
income sat	8286	3,094	0,990	1	5	8383	2,933	1,053	1	5
expectations	8286	2,188	0,781	1	3	8383	1,935	0,835	1	3
environment	8286	3,762	0,467	1	5	8383	3,777	0,509	1	5
education	8286	2,477	0,984	1	5	8383	2,658	0,998	1	5

Table 3 shows that individuals' average happiness levels and their hopes and expectations for the future decreased in 2022 compared to 2004. On the other hand, average health satisfaction levels, income and environment have increased. When the two reference periods are compared, the average education levels and ages of the individuals included in the study are higher in 2022.

When the average data for individuals in the study for 2017 and 2022 were compared, it was observed that their life satisfaction and satisfaction with health and the environment increased. However, satisfaction with income and expectations for the future decreased in 2022.

3. Results

This section first presents the results of the PPDM analysis, which directly examines factors influencing happiness and life satisfaction, followed by the results of the path analysis, which assesses indirect effects.

3.1. Pseudo-Panel Data Analyses Results

Table: 5
PPDM Fixed Effects Analyses Results

Variables	Happiness	Life Satisfaction
education	-0.143*** (0.0282)	0.479* (0.237)
environment	0.301*** (0.0723)	0.203 (0.493)
income_sat	0.240*** (0.0366)	0.781** (0.267)
health_sat	0.197*** (0.0377)	0.451 (0.276)
expectations	0.296*** (0.0291)	0.0655 (0.217)
Constant	0.658* (0.267)	0.470 (1.925)
Observations	456	144
Number of cohorts (age group)	24	24

*Standard errors in parentheses. * $p < .05$, ** $p < .01$, *** $p < .001$.*

Table 5 presents the outcomes of the fixed-effects analyses conducted within the PPDM framework for both happiness and life satisfaction. Notably, the happiness analysis yielded statistically significant results for all independent variables examined. Specifically, a negative correlation emerged between individuals' education level and happiness, suggesting that happiness decreases with higher educational attainment. Conversely, a positive association was observed between individuals' happiness and their satisfaction with the living environment, household income, satisfaction with health, and positive outlook towards the future. These findings indicate that higher satisfaction with one's living environment, higher household income, greater satisfaction with health, and optimistic expectations for the future are associated with higher levels of happiness.

In contrast, the examination of life satisfaction revealed statistically significant associations solely with education and income levels. The fixed-effects analysis within the PPDM framework shows that as individuals' educational attainment and household incomes increase, life satisfaction increases in parallel.

The PPDM analyses underscored direct determinants influencing both happiness and life satisfaction. However, the mediation hypotheses regarding the indirect effects of

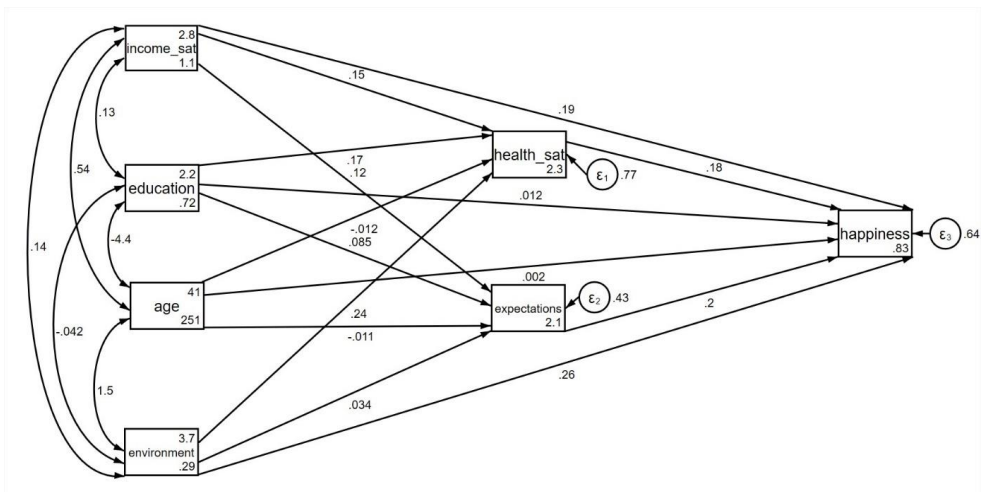
individuals' satisfaction with their health and expectations for the future remained unexplored. To address these mediation dynamics, a subsequent examination employing path analysis was undertaken.

3.2. Path Analyses Results

3.2.1. Happiness Analysis Results

LSS 2004 and 2022 microdata sets were used to determine whether health satisfaction and expectations for the future have a mediating role on individuals' happiness levels. In this way, the aim was to observe whether the mediation effect has changed over the years.

Figure: 1
Happiness Analysis Path Results for 2004



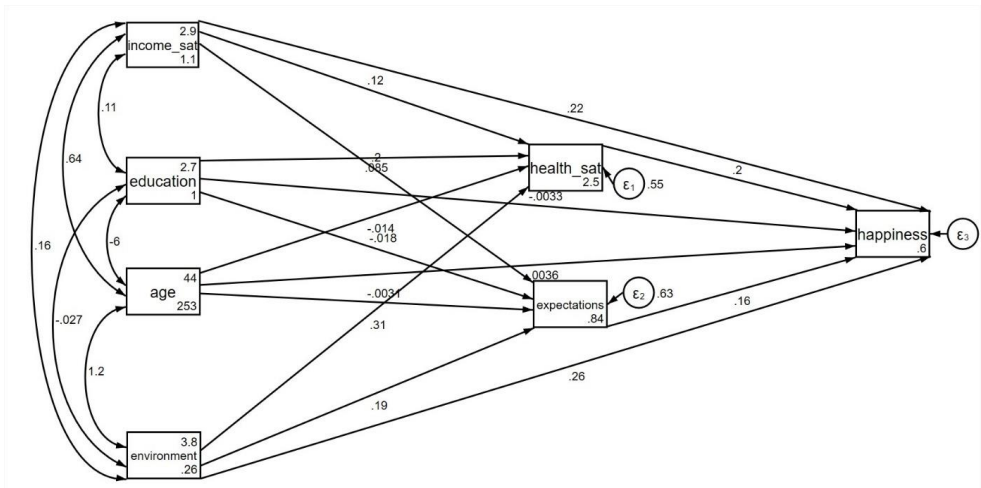
The findings of the path analysis, which examined the mediating effects of health satisfaction and future expectations on the associations between individuals' income, educational attainment, age, satisfaction with their environment, and happiness in 2004 and 2022, are illustrated in Figures 1 and 2, respectively. Notably, the goodness-of-fit indices of the path models were significant (RMSEA: .07, CFI: .99, and TLI: .85 for 2004; RMSEA: .05, CFI: .99, and TLI: .92 for 2022).

The results of the path analyses show that health satisfaction and future expectations served as mediators in the relationship between educational attainment and happiness. A direct correlation between educational level and happiness was not observed in either 2004 or 2022. Instead, the analyses revealed an indirect effect whereby increases in educational attainment were associated with higher levels of health satisfaction and future expectations, thereby elevating individuals' happiness in 2004 due to the positive trend in these mediators.

However, in 2022, the mediation effects of future expectations between education and happiness shifted: increases in educational level were associated with decreases in future expectations, which in turn led to declines in individuals' happiness.

Furthermore, health satisfaction was identified as a partial mediator in the relationships between income, age, satisfaction with the environment, and individuals' happiness levels in 2004, as evidenced by Sobel test statistics of $Z=10.635$, $Z=-16.35$, and $Z=9.07$, respectively. Similarly, future expectations were found to have partial mediating effects on the relationships between income satisfaction, age, environmental satisfaction, and individuals' happiness levels in 2004, with Sobel test values of $Z=9.38$, $Z=-12.50$, and $Z=2.07$, respectively. These findings underscore the interplay among the principal variables, shedding light on the intricate mechanisms that underlie the determinants of happiness.

Figure: 2
Happiness Analysis Path Results for 2022

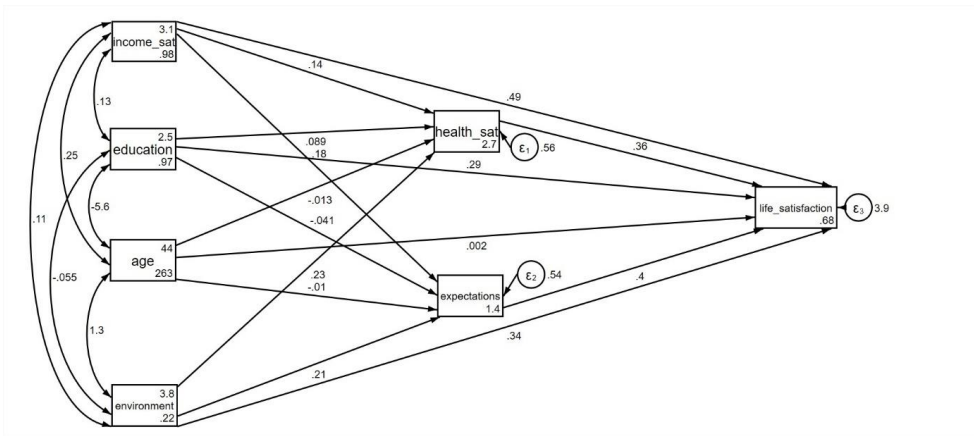


In Figure 2, the depicted findings show the role of health satisfaction as a partial mediator in the relationships between individuals' income satisfaction (Sobel test score: $Z=11.10$), age ($Z=-14.23$), satisfaction with their environment ($Z=12.67$), and happiness levels in the year 2022. Simultaneously, the examination of mediating effects on future expectations revealed a significant partial mediation. Specifically, future expectations emerged as a substantial mediator between income (Sobel test score: $Z=12.52$), age ($Z=-4.95$), satisfaction with the environment ($Z=8.49$), and individuals' happiness levels. These Sobel test scores provide quantitative evidence of the mediating roles of health satisfaction and future expectations.

3.2.2. Life Satisfaction Analysis Results

With the main goal of identifying the potential mediating roles of health satisfaction and future expectations in individuals' life happiness, path analyses were conducted using the Life Satisfaction Survey (LSS) microdata for 2017 and 2022. We decided to use the 2017 LSS dataset because, as we discussed in earlier sections, the explicit question on life satisfaction levels was added to the full LSS administration for the first time in 2017. Through iterative path analyses of the 2017 and 2022 datasets, the study sought to determine whether significant changes in the mediator effects occurred between 2017 and 2022.

Figure: 3
Life Satisfaction Analysis Path Results for 2017



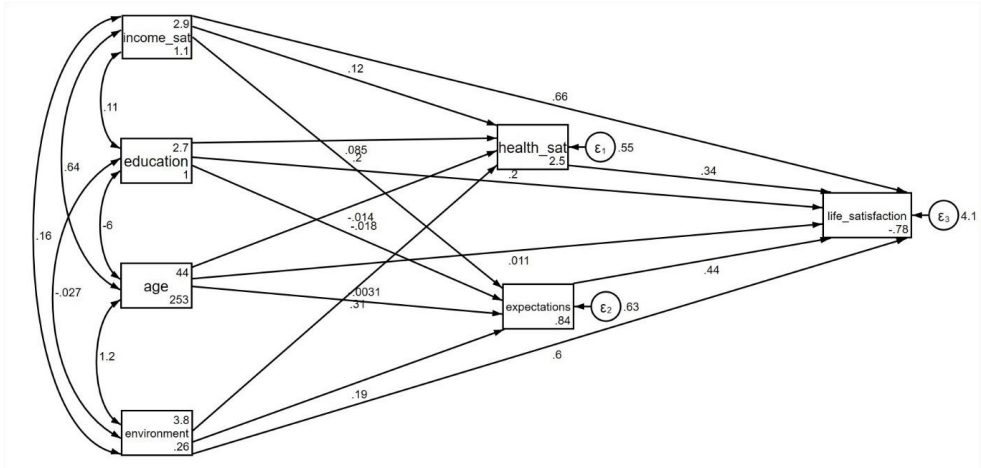
The path analysis's schematic depiction is shown in Figure 3, where the goodness of fit indices yielded statistically significant values (RMSEA: .05, CFI: .99, and TLI: .93). The ensuing analysis unveiled the robust mediating roles of health satisfaction and future expectations in the relationship between age and individuals' life satisfaction.

Interestingly, the findings emphasise the absence of a direct association between age and life satisfaction. However, an important indirect effect was observed: advancing age was correlated with diminished health satisfaction and future expectations, resulting in a decline in individuals' life satisfaction in 2017.

Additionally, a partial mediation analysis was conducted between health satisfaction and financial satisfaction (Sobel test score: $Z=9.96$), education ($Z=7.71$), environmental satisfaction ($Z=8.89$), and people's life satisfaction. In a similar vein, future expectations were found to be a partial mediator between people's levels of life satisfaction and their wealth ($Z=8.98$), education ($Z=7.42$), and environmental satisfaction ($Z=8.61$). These Sobel test results provide quantitative evidence of the mediating roles of health satisfaction and

future expectations in explaining the complex interactions among socioeconomic variables, environmental perceptions, and people's subjective well-being.

Figure: 4
Life Satisfaction Analysis Path Results for 2022



The path diagram for the 2022 life satisfaction analysis is shown in Figure 4. Goodness of fits of the analysis were found significant (RMSEA: .05; CFI: .99, and TLI: .92). In contrast to the findings observed in 2017, as presented in Figure 2, the mediating roles of health satisfaction and future expectations in the relationship between age and life satisfaction transitioned to partial mediation effects in the subsequent analysis. Notably, life satisfaction also partially mediated the effects of income (Sobel test score: $Z=8.98$), education ($Z=7.42$), and satisfaction with the environment ($Z=9.76$) on individuals' overall life satisfaction in 2022.

Similarly, future expectations were identified as partial mediators between income ($Z=12.91$) and satisfaction with the environment ($Z=8.61$) in influencing individuals' life satisfaction levels during the same temporal epoch. However, no discernible mediating effect of future expectations was observed in the relationship between education and life satisfaction in 2022.

These findings highlight the nuanced evolution of mediating dynamics over time, revealing shifts in the relationships among socio-economic factors, environmental perceptions, and individuals' subjective well-being across different temporal contexts.

4. Discussion and Conclusion

The primary objective of this study is to investigate the factors influencing subjective well-being, considering both individual and structural components. Beyond identifying

these factors, the study also aims to explore the mediating and moderating variables involved and to track their evolution over time. A key methodological contribution is the application of the pseudo-panel data method and path analysis, tools commonly utilised in other disciplines but less frequently applied in well-being research. These methods allow for a more detailed analysis of both direct and indirect effects, using a large micro dataset.

By employing these methods, this study uncovers the complicated relationships between education, happiness, and life satisfaction. The main findings indicate that higher levels of education have a negative impact on happiness but a positive effect on life satisfaction. This finding suggests that while higher education might not necessarily increase happiness, it could contribute to greater life satisfaction. This could be due to various factors, such as higher levels of education providing individuals with more opportunities, a sense of accomplishment, or a greater ability to navigate life's challenges. Understanding these nuances can be crucial for policymakers and educators when designing programs aimed at improving well-being. In the existing literature, while some studies may suggest that education has little influence on happiness (e.g., Layard, 2005; Michalos, 2017), others indicate a more nuanced relationship where education can impact life satisfaction positively, even if its effect on happiness is less clear or negative (e.g., see Shields et al., 2009; Veenhoven, 2010). These varying perspectives highlight the complexity of the issue and the need for further research to understand the mechanisms at play. On the other hand, the decrease in happiness associated with increased education can also be considered in light of the theory advanced by Graham and Pettinato (2002). According to this theory, education raises individuals' expectations and aspirations regarding income, social status, and job quality. However, in developing economies or during periods of economic fluctuation, structural constraints such as high unemployment rates among graduates or mismatches between skills and wages can prevent the realisation of these aspirations. Based on this theory, the inverse relationship between education and happiness in Türkiye can be discussed within this framework.

Perhaps most importantly, one key aspect is to explore the mediators underlying the effects observed in studies of factors influencing happiness and life satisfaction. This involves identifying the variables that indirectly influence the relationship in question, as well as their changes over time. In this regard, the path analysis results reveal that educational attainment indirectly influences happiness through health satisfaction and future expectations. In 2004, higher education was linked to greater health satisfaction and future expectations, which in turn increased happiness. However, by 2022, this relationship changed, with higher education now associated with lower future expectations and decreased happiness. Furthermore, the path analysis results for life satisfaction indicate that health satisfaction and future expectations mediate the relationship between age and life satisfaction. While age itself is not directly linked to life satisfaction, older age is associated with lower satisfaction with health and future expectations, leading to reduced life satisfaction. Additionally, health satisfaction and future expectations partially mediate the relationship between income, education, satisfaction with the environment, and life satisfaction. Based on these findings, policy recommendations could include interventions

to improve health satisfaction and foster positive future expectations among the population. This could involve initiatives to enhance healthcare access and quality, promote healthy lifestyles, and support individuals in planning and achieving their future goals. Additionally, policies that address socio-economic disparities and improve educational and environmental conditions may help enhance overall life satisfaction.

These findings have important implications for both methodological and practical applications. Methodologically, the study illustrates how pseudo-panel data and path analysis can be used to capture temporal changes in subjective well-being and its determinants, even when longitudinal data are unavailable. This approach is especially useful in research fields that rely heavily on cross-sectional data, providing a framework for assessing the impact of time without requiring extensive longitudinal datasets.

While the findings in this study stem from a specific dataset, the methods employed are broadly applicable. Researchers can implement similar methodological frameworks across different contexts and countries to analyse subjective well-being and other complex social phenomena. By doing so, they can compare the factors influencing well-being across various regions and identify both universal and context-specific variables. This methodological flexibility makes the study's approach highly valuable for future well-being research.

While the findings are intriguing and provide valuable insights, the study is subject to certain limitations. One of these is the potential for response bias in survey-based studies, particularly in a study with such a subjective and relative subject matter. Respondents may provide inaccurate or biased information, either intentionally or unintentionally. This can occur due to social desirability bias, in which respondents provide answers they believe are socially acceptable, or due to recall bias, in which respondents may not accurately remember past events. Second, specific to this study, because data on happiness and life satisfaction in Türkiye are cross-sectional and lack a longitudinal dimension, a pseudo-panel had to be constructed to account for the effect of time on missing information.

A recommendation for future studies is to compare the findings of this study with those from other countries or regions. Such comparisons could provide valuable insights into the factors influencing happiness and life satisfaction across different contexts. This approach could help identify universal factors.

In conclusion, the main contribution of this study lies in its methodological advancements, particularly the use of pseudo-panel data and path analysis to explore subjective well-being. While the data provide valuable insights, the methodological framework offers a robust tool for analysing complex relationships in the absence of longitudinal data, making it a key asset for researchers in this field. Future studies may benefit from replicating these methods in diverse contexts to uncover further the factors that shape happiness and life satisfaction globally.

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Appendix: Detailed Descriptive Statistics of the Constructed Cohorts

Table: A1
Descriptive Statistics by Cohorts for Happiness Analysis (2004-2022)

age_group	age	age (mean)	women %	education (mean)	N_sample
1	18-20	18,97	57,19	2,51	14942
2	21-23	22,06	57,50	2,72	15682
3	24-26	25,02	56,43	2,80	17334
4	27-29	28,01	57,43	2,72	17909
5	30-32	31,00	55,89	2,68	19352
6	33-35	34,00	55,51	2,61	19730
7	36-38	37,00	55,09	2,53	18685
8	39-41	39,97	53,87	2,42	18895
9	42-44	42,96	53,60	2,37	17535
10	45-47	45,99	53,30	2,29	16414
11	48-50	49,00	53,03	2,22	16650
12	51-53	52,04	51,01	2,19	14542
13	54-56	54,98	51,18	2,13	13167
14	57-59	57,94	49,71	2,08	12582
15	60-62	60,87	50,65	1,98	10534
16	63-65	63,99	50,74	1,87	10092
17	66-68	66,99	51,20	1,82	7389
18	69-71	69,97	51,76	1,73	6142
19	72-74	72,95	50,92	1,66	5114
20	75-77	75,84	52,76	1,55	4318
21	78-80	79,10	50,67	1,50	3276
22	81-83	81,93	47,90	1,47	1933
23	84-86	84,84	53,03	1,42	1137
24	87-90	87,69	54,36	1,43	447

Table: A2
Descriptive Statistics by Cohorts for Life Satisfaction Analysis (2017-2022)

age_group	age	age (mean)	women %	education (mean)	N_sample
1	18-20	18,94	48,16	2,67	2631
2	21-23	22,03	52,47	2,92	2733
3	24-26	25,03	52,17	3,03	2902
4	27-29	28,01	54,17	3,02	3120
5	30-32	31,00	51,73	2,97	3120
6	33-35	34,01	51,14	2,89	3189
7	36-38	37,02	51,66	2,75	3370
8	39-41	39,98	49,93	2,70	3459
9	42-44	42,99	51,97	2,64	3244
10	45-47	45,99	50,15	2,49	3055
11	48-50	48,95	48,76	2,40	2820
12	51-53	52,01	48,60	2,34	2570
13	54-56	55,00	47,79	2,30	2534
14	57-59	57,97	47,59	2,27	2198
15	60-62	60,96	47,50	2,19	1939
16	63-65	64,01	49,07	2,10	1771
17	66-68	66,99	48,98	2,01	1472
18	69-71	69,93	48,47	2,01	1207
19	72-74	72,91	48,78	1,91	941
20	75-77	75,89	51,59	1,83	692
21	78-80	78,88	52,16	1,68	462
22	81-83	81,88	49,83	1,62	291
23	84-86	84,88	50,91	1,56	220
24	87-90	87,73	46,15	1,51	104

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Hysteresis in EU Member States: A Comprehensive Analysis Using the Fourier Approach

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AB Üyesi Ülkelerde Histerezis: Fourier Yaklaşımıyla Kapsamlı Bir Analiz

Abstract

This study examines the persistence of inflation and unemployment in European Union (EU) member states between 1991 and 2023, focusing on hysteresis effects and the applicability of the Non-Accelerating Inflation Rate of Unemployment (NAIRU) framework. The EU represents a unique empirical setting due to the diversity of its national labour markets and fiscal structures within a shared economic space. These asymmetries increase the likelihood of long-term macroeconomic imbalances, making the analysis of hysteresis particularly relevant. The study addresses this issue using nonlinear econometric techniques, specifically the Fourier KPSS test and ECM-based bootstrap cointegration analysis, to detect smooth structural changes and long-run relationships between inflation and unemployment. The empirical results indicate strong evidence of inflation hysteresis across most EU countries and selective unemployment hysteresis in specific cases such as Germany, Hungary, and Ireland. Moreover, a significant long-term cointegration between inflation and unemployment is observed, challenging the conventional assumptions of the Phillips Curve. The study contributes methodologically by integrating advanced testing procedures and empirically by offering a comprehensive, comparative perspective across member states. These findings highlight the need for flexible, country-specific policy strategies to mitigate persistent inflation and labour market rigidities, thereby fostering long-term macroeconomic stability and convergence within the EU.

Keywords : Inflation Persistence, Unemployment Hysteresis, NAIRU, the EU, Panel Data Analysis.

JEL Classification Codes : E24, E31, C22.

Öz

Bu çalışma, 1991-2023 yılları arasında Avrupa Birliği (AB) üye ülkelerinde enflasyon ve işsizliğin kalıcılığını ve histerezis etkilerini incelemektedir. Histerezis, ekonomik şokların uzun vadeli etkilerini vurgulayarak, özellikle para ve maliye politikalarının tasarımıyla geleneksel yaklaşımların ötesine geçilmesi gerektiğini ortaya koymaktadır. Bu bağlamda çalışmada, geleneksel birim kök testlerinin ötesine geçen ve yapısal değişimleri daha esnek bir şekilde yakalayan Fourier KPSS testi ile ECM Bootstrap eşbütünlüşme analizi kullanılmıştır. Elde edilen bulgular, birçok AB ülkesinde enflasyonun kalıcı olduğunu ve Almanya, Macaristan, İrlanda gibi bazı ülkelerde işsizlikte de histerezis etkisinin belirgin olduğunu göstermektedir. Ayrıca, enflasyon ve işsizlik arasında uzun dönemli bir eşbütünlüşme ilişkisinin bulunduğu tespit edilmiştir. Bu durum, geleneksel Phillips Eğrisi yaklaşımını sorgulamakta ve politika yapıcılar açısından ülke bazlı, esnek politika çerçevelerine olan ihtiyacı vurgulamaktadır.

Anahtar Sözcükler : Sürekli Enflasyon, İşsizlik Histerezisi, NAIRU, Avrupa Birliği, Panel Veri Analizi.

1. Introduction

Understanding hysteresis in inflation and labour markets is essential for the EU member states because it challenges the traditional belief that economic shocks have only short-term effects. Instead, hysteresis indicates that disruptions, such as financial crises, pandemics, or structural shifts, can lead to long-lasting changes in unemployment and inflation, making recovery more complicated and uneven across member states. This is particularly important in the EU, where economies vary greatly in labour market flexibility, wage-setting methods, and vulnerability to external shocks. As shown in this study, inflation rates in many EU countries are non-stationary, and unemployment exhibits hysteretic behaviour in several cases, including Germany, Hungary, and Ireland. These results suggest that standard policy tools may be inadequate or inappropriate if they do not consider persistent effects. Therefore, a detailed understanding of hysteresis is vital for creating effective, country-specific monetary and fiscal policies. It also highlights the significance of active labour market policies, structural reforms, and enhanced labour mobility to reduce long-term damage. Ultimately, managing hysteresis is key to maintaining employment stability, price consistency, and fostering deeper economic convergence within the EU.

Focusing on the EU member states is especially relevant in the context of hysteresis because the EU represents a unique economic and institutional environment characterised by a shared monetary policy managed by the European Central Bank (ECB), alongside nationally diverse labour markets and fiscal systems. This structural asymmetry makes the region particularly vulnerable to persistent shocks, as member states lack independent monetary tools to address localised crises. Additionally, the EU has faced multiple major disruptions in recent decades, from the 2008 financial crisis to the sovereign debt crisis and the COVID-19 pandemic, all of which have had uneven and lasting impacts across countries. These events offer valuable opportunities to analyse how inflation and unemployment dynamics change under hysteresis. Furthermore, the EU's focus on convergence and cohesion adds urgency: if hysteresis effects vary greatly across countries, they could threaten broader goals of integration and economic stability. This makes the EU not only a relevant but a crucial case for understanding the long-term impacts of macroeconomic shocks and the limitations of traditional policy responses.

The relationship between inflation and unemployment has long intrigued economists, beginning with Phillips (1958), who identified a non-linear, inverse connection between the two. This concept evolved with contributions from Phelps (1967) and Friedman (1968), who argued that monetary policy could influence unemployment only in the short run, introducing the idea of adaptive expectations and the NAIRU, and who later earned Nobel Prizes. The NAIRU reflects the natural rate of unemployment that does not accelerate inflation, and it is closely linked to hysteresis, in which unemployment or inflation

persistently deviates from its long-run path after a shock (Blanchard & Summers, 1986). In labour markets, this is often driven by structural issues such as reduced bargaining power, high firing costs, or long-term skill erosion among the unemployed. The insider-outsider theory (Blanchard & Summers, 1986; 1987) and wage-setting dynamics (Gottfries & Horn, 1987; Lindbeck & Snower, 2001) explain how insiders maintain job security while outsiders struggle to re-enter the labour market. Critics like Rowthorn (1999) and Haltmaier (2012) argue that demand-side factors also play a role. Meanwhile, prolonged unemployment can reduce employability and suppress deflation, particularly in sluggish economies (Meloni et al., 2022). As Furlanetto et al. (2021) show, employment tends to react more to output declines than productivity shifts, with labour productivity often offsetting demand shocks to maintain stable output per employee.

Fourier analysis is especially effective at identifying hysteresis because it captures smooth, gradual structural changes over time without needing predefined breakpoints, unlike traditional unit root tests. Its flexibility allows it to detect non-linear patterns and ongoing deviations typical of hysteresis. By accurately modelling cyclical and irregular shifts, the Fourier method improves the reliability of stationarity tests, making it particularly useful in complex, evolving economic environments like those of EU member states. What distinguishes this research is its application of the Fourier methodology, addressing a notable gap in the literature by exploring both inflation and unemployment hysteresis within EU member states and their long-run interaction. By incorporating this advanced approach, the study brings a fresh analytical dimension to a topic that has received limited comprehensive treatment. This study employs nonlinear dynamic models to examine the degree of linkage between persistent trends in unemployment and inflation across EU members. The research is organised into three key sections: the first presents an overview of key studies on the EU; the second delves into recent empirical developments; and the third details the research methodology, presents the findings, and explores their policy implications.

2. Empirical Literature

Hysteresis describes a situation where the effects of an economic shock linger even after the initial cause has disappeared. In other words, the system doesn't revert to its previous state but instead settles into a new, altered path. For instance, if a recession causes a sharp increase in unemployment, hysteresis suggests that unemployment could stay high even after economic growth resumes, because long-term joblessness damages workers' skills and discourages participation in the labour market. This concept challenges the traditional view that economies naturally recover to full employment and is especially relevant when examining persistent inflation or unemployment trends in EU member states.

The empirical literature on hysteresis in unemployment across EU member states shows both widespread confirmation and notable differences. Studies such as Jump and Stockhammer (2018) and Caporale et al. (2022) consistently find strong evidence of unemployment persistence using methods such as maximum likelihood estimation and fractional integration, especially after major economic shocks. These results support the

hysteresis hypothesis, which states that unemployment does not automatically return to its natural rate following a shock. However, other research points to significant exceptions.

The presence or absence of hysteresis seems connected to structural features, such as employment protection laws, the strength of collective bargaining, and the effectiveness of activation policies. For example, Mladenovic (2016) and Özdemir (2020) present mixed results for the Eurozone and Central and Eastern European countries, showing that the magnitude and duration of hysteresis effects vary across countries.

Beyond unemployment, recent research highlights hysteresis in inflation dynamics. Reichlin and Zettelmeyer (2024) emphasise that supply-side shocks and structural adjustments, such as those experienced during the COVID-19 pandemic, can entrench inflation expectations if policy responses are delayed or poorly calibrated. These insights reinforce the findings of Meloni et al. (2022), who show that prolonged unemployment reduces employability and can prevent expected deflation from materialising, thus complicating monetary policy responses.

Taken together, these studies underscore that while hysteresis is a widespread phenomenon in the EU, its intensity and persistence are uneven, shaped by country-specific labour market designs, macroeconomic frameworks, and institutional capacities. Understanding these differences is essential for designing effective, tailored policies to counteract long-term economic scarring and support convergence within the EU. Despite this extensive body of literature, several notable gaps persist. First, most studies analyse either inflation or unemployment hysteresis in isolation, often overlooking their potential long-term interdependence. Second, many rely on linear or fractional integration methods, which may fail to capture smooth, gradual structural changes that characterise real-world macroeconomic processes.

In addressing these shortcomings, recent research has increasingly turned to causality and persistence testing frameworks that better account for non-linearities. For example, Jump and Stockhammer (2018) and Caporale et al. (2022) employ panel unit root and long-memory models to test for hysteresis. Similarly, Doganer (2022) utilize unit root tests with structural breaks. However, most of these approaches assume abrupt structural changes or fixed time points of shift. In contrast, the Fourier KPSS test, as implemented in the present study, allows for flexible modelling of smooth structural evolution, thereby capturing gradual transitions and non-linear adjustments without requiring a priori specification of breaks.

Moreover, this study enhances robustness by integrating ECM-based bootstrap cointegration techniques, which are particularly useful in small-sample contexts and account for cross-sectional dependencies typical of interconnected EU economies. Thus, by employing these advanced methods and jointly analysing inflation and unemployment hysteresis in a unified framework, this research offers a more dynamic, realistic, and nuanced understanding of macroeconomic persistence. In doing so, it responds to the critical need for

methodological innovation and comparative depth in the study of hysteresis across heterogeneous EU labour markets.

3. Data & Methodology

The nonlinear Fourier KPSS test and the ECM bootstrap cointegration method are particularly well-suited for analysing hysteresis and asymmetries in macroeconomic time series. The Fourier KPSS test enhances traditional stationarity analysis by allowing for smooth, gradual structural breaks without requiring pre-specified breakpoints. This flexibility makes it especially effective in capturing the slow-moving, non-linear shifts characteristic of hysteresis, which may be driven by institutional reforms, evolving expectations, or gradual policy adjustments. Similarly, the ECM bootstrap cointegration approach offers robust inference in the presence of cross-sectional dependence and small sample biases, enabling a reliable assessment of long-run relationships between inflation and unemployment across heterogeneous EU economies. These methods are critical for uncovering subtle but persistent patterns that conventional linear models may overlook.

The data used in this study were obtained from the World Bank's World Development Indicators database and consist of annual observations on inflation and unemployment for EU member states from 1991 to 2023. Data before 1991 were unavailable or incomplete for many countries, particularly those that underwent major structural transitions or joined the EU later, thereby limiting the temporal scope of the analysis but ensuring consistency and comparability across the panel.

The model is represented as follows:

$$U_t = U_{t-1} + e_t \quad (1)$$

Here, U_t represents the unemployment rate at a given time, and e_t denotes the error term, which captures any external shocks to the unemployment rate.

The equation of expectations is:

$$E_{t-1}(U_{t+\tau}) = U_{t-1} \quad (2)$$

For all ($\tau = 0, 1, \dots$), the expected value based on observations at time ($t-1$) is expressed as (E_{t-1}). Any temporary shock to the unemployment variable is represented by e_t , which leads to a lasting break in the expected unemployment rate. Consequently, $E_{t-1}(U_{t+\tau})$ does not return to its pre-shock level, reflecting the presence of hysteresis and the persistence of unemployment shocks over time.

In contrast, in a non-hysteretic model, U_t follows a stationary process. For large τ values, the expected unemployment rate remains constant and equal to the NAIRU represented by $E_{t-1}(U_{t+\tau}) = U_{t-1}$.

Phillips indicates that the connection between inflation and the unemployment rate is given by (Santomero & Seater, 1978):

$$D_w/w = bU^c \quad (3)$$

The Phillips curve, with “w” denoting the gross wage rate and the unemployment rate always positive, cannot be linear, as unemployment cannot take negative values.

The impact of unit roots in economic time series has been widely studied by Taylor (1989), Lee and Enders (2004), and Becker et al. (2004, 2006), who emphasise that breaks and shocks can cause persistent deviations from long-term trends. To address this, traditional unit root tests evolved to account for these structural changes, first by detecting level or trend breaks, and later by using the Fourier method, which models gradual shifts through frequency selection rather than specific break dates.

Enders and Lee (2012) introduced the Fourier KPSS test for single-frequency analysis, and Karul (2016) expanded it to multiple frequencies, improving the detection of structural changes. The panel test statistic is computed by averaging individual LM statistics across countries. Statistics are established via Monte Carlo simulations, with results showing that the test's asymptotic distribution depends on the frequency parameter (k). The Akaike Information Criterion typically guides frequency selection, with lower k values preferred to capture structural shifts, as highlighted by Becker et al. (2004).

In the Fourier KPSS framework, the null hypothesis (H_0) assumes stationarity, while the alternative hypothesis (H_1) indicates non-stationarity and the presence of a unit root. Therefore, rejection of the null hypothesis provides evidence in favour of hysteresis. The LM statistics are calculated for each cross-sectional unit and evaluated using the critical values reported by Becker et al. (2006). Since hysteresis implies the persistence of shocks over time, rejection of stationarity is interpreted as evidence supporting the hysteresis hypothesis.

Table: 1
Preliminary Test Outcomes

Delta Test (INF and UNP)	T-stats.	p-value
$\hat{\Delta}$ (small sample)	2.791	0.003*
$\hat{\Delta}_{adjusted}$	2.932	0.002*
CDLM Test (UNP)	T-stats.	p-value
(Breusch & Pagan, 1980) LM	43.252	0.003*
(Pesaran-2004)-CDLM1	3.434	0.000*
(Pesaran-2004)-CDLM2	-3.762	0.000*
(Pesaran et al. 2008)Bias-adjCD	-0.877	0.810
CDLM Test (INF)	T-stats.	p-value
(Breusch & Pagan, 1980) LM	57.224	0.000*
(Pesaran-2004)-CDLM1	5.589	0.000*
(Pesaran-2004)-CDLM2	-3.622	0.000*
(Pesaran et al. 2008)Bias-adjCD	2.749	0.000*

* indicates statistical significance at the 5%. Table 1 presents the preliminary test results assessing the stationarity and cross-sectional dependence of inflation (INF) and unemployment (UNP) across EU member states from 1991 to 2023.

The Delta test statistics for both variables are statistically significant at the 1% level ($p < 0.01$). The significant Delta statistics reject the null hypothesis of slope homogeneity and indicate cross-sectional heterogeneity among EU member states. Cross-sectional dependence is also strongly evident. For unemployment, the Breusch-Pagan LM and Pesaran's CDLM1 and CDLM2 tests yield significant results ($p < 0.01$), although the bias-adjusted CD test is not statistically significant. In contrast, all four tests for inflation, including the bias-adjusted CD test, indicate significant cross-sectional dependence ($p < 0.001$). These findings confirm that macroeconomic variables in EU countries are not only persistent over time but also interdependent across borders, justifying the use of second-generation panel methods that account for both non-stationarity and cross-country spillovers in the analysis of hysteresis.

Table: 2
Fourier KPSS Test Result for Inflation (Consumer Prices % Annual)

Countries	intercept (k=1)	int. & trend (k=1)	intercept (k=2)	int. & trend (k=2)	intercept (k=3)	int. & trend (k=3)
Austria	0.1596	0.0371	0.3110	0.0584	0.3915	0.1160
Belgium	0.1530	0.0439	0.1003	0.0852	0.1501	0.1211
Bulgaria	0.0672	0.0602	0.3285	0.1251	0.1888	0.0431
Croatia	0.1468	0.0418	0.0762	0.0877	0.0758	0.1104
Cyprus	0.0670	0.0472	0.1463	0.0576	0.1235	0.0449
Czechia	0.1423	0.0443	0.1490	0.1128	0.1695	0.1289
Denmark	0.0583	0.0529	0.0392	0.0342	0.0549	0.2299
Estonia	0.1314	0.0370	0.0970	0.0802	0.1446	0.1082
France	0.1826*	0.0353	0.1998	0.0698	0.1610	0.0478
Finland	0.1275	0.0279	0.1084	0.0798	0.1698	0.1174
Germany	0.0532	0.0422	0.2506	0.0558	0.1837	0.0821
Greece	0.0805	0.0423	0.0479	0.0486	0.0615	0.1116
Hungary	0.0641	0.0492	0.2262	0.0643	0.0859	0.0910
Ireland	0.2683*	0.0651	0.1920	0.1634	0.2153	0.1441
Italy	0.1074	0.0945	0.1194	0.0966	0.2022	0.1402
Latvia	0.0802	0.0424	0.0477	0.0484	0.0611	0.0672
Lithuania	0.1055	0.0413	0.1199	0.0953	0.2028	0.1115
Luxembourg	0.1296	0.0472	0.0802	0.0847	0.0932	0.1368
Malta	0.2060*	0.0567	0.1717	0.0821	0.1122	0.0287
Netherlands	0.1580	0.0458	0.1190	0.0927	0.1724	0.1466
Poland	0.0723	0.0565	0.2928	0.0749	0.1442	0.0666
Portugal	0.1010	0.0288	0.0991	0.0712	0.1576	0.1341
Romania	0.0660	0.0426	0.2536	0.0345	0.2425	0.1018
Slovenia	0.1232	0.0265	0.1000	0.0753	0.1679	0.1214
Slovak Rep.	0.0922	0.0572	0.1792	0.1555	0.1679	0.0696
Spain	0.2824*	0.0690	0.1506	0.1651	0.1669	0.1313
Switzerland	0.1192	0.0416	0.1750	0.0539	0.1839	0.0441
Sweden	0.1695	0.0304	0.1257	0.1059	0.1726	0.1465
Probability Values	0.0000*	0.0000*	0.3050	0.0000*	0.4558	0.0000*
Panel Stat. F-KPSS	5.8669	6.9734	0.5102	4.3666	0.1110	5.7941

* indicates statistical significance at the 5% level based on critical values from Becker et al. (2006). Panel test statistics are calculated using the Bartlett Kernel and assume normality, according to Becker et al. (2006: 389, Table 1). For the model with an intercept, the critical values at the 5% significance level are 0.1720 for $k=1$, 0.4152 for $k=2$, and 0.4480 for $k=3$. For the model with c and t (trend), the critical values at the 5% significance level are 0.0546 for $k=1$, 0.1321 for $k=2$, and 0.1423 for $k=3$.

Table 2 reports the results of the Fourier KPSS panel stationarity tests for inflation across EU member states under alternative frequency specifications ($k = 1, 2$, and 3) and model forms including intercept and intercept with trend. Since the null hypothesis of the Fourier KPSS test assumes stationarity, statistically significant test statistics imply rejection of stationarity and support the presence of inflation hysteresis.

At the panel level, the Fourier KPSS statistics are statistically significant in most model specifications, particularly for the models with trend components. These findings indicate that inflation does not follow a stationary process across the EU member states and that inflationary shocks tend to have persistent effects over time. Therefore, the results provide strong evidence in favour of inflation hysteresis at the panel level.

The findings suggest that inflation dynamics within the EU are characterised by long-lasting responses to macroeconomic shocks rather than rapid adjustment toward equilibrium. This persistence may reflect structural rigidities, evolving inflation expectations, and country-specific institutional factors. Overall, the results support the view that inflationary disturbances in EU member states are not purely temporary and may generate lasting effects on macroeconomic performance.

Table: 3
Fourier KPSS test results for Unemployment

Countries	Intercept (k=1)	int. & trend (k=1)	intercept (k=2)	int. & trend (k=2)	intercept (k=3)	int. & trend (k=3)
Austria	0.0945	0.0286	0.2995	0.0802	0.3870	0.0792
Belgium	0.1619	0.0365	0.2797	0.0401	0.4325	0.0534
Bulgaria	0.0441	0.0417	0.2356	0.0601	0.2981	0.0545
Croatia	0.0570	0.0514	0.0939	0.0896	0.1133	0.0813
Cyprus	0.1404	0.0301	0.4243*	0.1189	0.4720*	0.1056
Czechia	0.1371	0.0455	0.3660	0.2333	0.3392	0.1847
Denmark	0.0760	0.0615	0.3685	0.1136	0.4459	0.1121
Estonia	0.2391	0.0570	0.3809	0.1188	0.4012	0.1220
France	0.1172	0.0573	0.3043	0.1591	0.3994	0.1578
Finland	0.1667	0.0488	0.2707	0.0787	0.3548	0.1014
Germany	0.2407*	0.0346	0.3303	0.1645	0.3517	0.1613
Greece	0.0449	0.0398	0.4408*	0.1642	0.3279	0.1818
Hungary	0.2028*	0.0277	0.4063	0.1339	0.4911*	0.1468
Ireland	0.2566*	0.0509	0.2096	0.1448	0.2756	0.1567
Italy	0.2032*	0.0528	0.4518*	0.1773	0.4370	0.1740
Latvia	0.1117	0.0483	0.2120	0.0374	0.4133	0.0413
Lithuania	0.2028	0.0403	0.5022	0.1614	0.6120*	0.1722
Luxembourg	0.0947	0.0599	0.4815*	0.1171	0.2251	0.1121
Malta	0.2651*	0.0430	0.5710*	0.1862	0.5444*	0.1863
Netherlands	0.0291	0.0210	0.4203*	0.1988	0.4608*	0.2072
Poland	0.2648*	0.0592	0.2882	0.1410	0.2943	0.1414
Portugal	0.0888	0.0469	0.5461*	0.0486	0.6158*	0.0608
Romania	0.1019	0.0501	0.4196*	0.1299	0.5506*	0.1251
Slovenia	0.1957*	0.0519	0.5250*	0.0857	0.5403*	0.0929
Slovak Rep.	0.3016*	0.0496	0.3092	0.1896	0.3158	0.1781
Spain	0.1093	0.0566	0.2168	0.1338	0.2315	0.1241
Switzerland	0.0361	0.0361	0.1581	0.0418	0.2275	0.0415
Sweden	0.0748	0.0376	0.2831	0.1258	0.3422	0.1412
Probability Values	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
Panel Stat. F-KPSS	7.7776	6.3564	8.3297	9.8076	8.7234	8.3396

Table 3 reports the results of the Fourier KPSS stationarity tests for unemployment across EU member states, using models with an intercept and trend for different frequencies ($k = 1, 2, 3$). The null hypothesis of the KPSS test assumes stationarity; rejection implies non-stationarity, indicating hysteresis. Panel-level probability values for all models (across $k = 1, 2$, and 3 , both intercept-only and trend-included) are all significant at the 1% level ($p < 0.01$), rejecting the stationarity hypothesis and suggesting widespread evidence of non-stationarity and potential hysteresis in unemployment across the EU. However, when

analysing individual country-level results, several exceptions emerge. Countries such as Germany, Hungary, Ireland, Italy, Malta, Slovenia, and Poland consistently show statistically significant KPSS values that exceed critical thresholds (e.g., > 0.172 for the intercept model with $k=1$ at the 5% level), indicating strong evidence of unemployment hysteresis. In contrast, countries like Austria, Belgium, and the Netherlands show lower KPSS statistics, failing to reject the null in some model variants, implying stationary behaviour and supporting the NAIRU hypothesis. The significance of * (at the 5% level) highlights these individual deviations. Overall, the results reveal that while the average panel behaviour points toward hysteresis, the phenomenon is not uniform; it varies significantly by country and model specification, underlining the importance of structural and institutional differences across EU labour markets.

Table: 4
ECM Boot Co-Integration Test Results for the Intercept and Trend Model

For all models	t-statistics	Bootstrap P. Values
g_{τ} Group mean	-10.440	0.019*
g_{α} Group mean	-11.695	0.040*
p_{τ} Panel	-10.140	0.002*
p_{α} Panel	-17.056	0.002*

* indicates statistical significance at the 5%.

The Error Correction Mechanism (ECM) cointegration test (Westerlund, 2007) evaluates whether a stable long-run interaction of variables exists over time and across different cross-sectional entities. According to Westerlund (2007), the null hypothesis posits the absence of cointegration. However, the bootstrap results at the 5% threshold reject this assumption, indicating a lasting connection between inflation and unemployment across EU member states. These outcomes challenge conventional perspectives by confirming an enduring relationship, further reinforced by unit root tests that highlight structural shifts in both variables over time.

4. Conclusion

This study provides strong empirical evidence that inflation in the EU member states demonstrates persistent, non-stationary behaviour, supporting the hysteresis hypothesis across most member states. While unemployment appears stationary in some country-specific specifications, several EU member states, including Germany, Hungary, Ireland, Italy, Malta, Poland, and Slovenia, exhibit significant evidence of unemployment hysteresis, indicating that the effects of macroeconomic shocks may persist in labour markets over the long run. These results contrast with the traditional NAIRU-based expectation of mean reversion and instead align with recent findings by Caporale et al. (2022) and Meloni et al. (2022), who argue that structural changes and long-term scarring increasingly shape macroeconomic variables in Europe. The confirmation of a stable long-run cointegration relationship between inflation and unemployment across the EU member states further challenges the conventional Phillips Curve framework, reinforcing the need to reconsider short-termist models of stabilisation.

A central contribution of this study lies in its methodological innovation. By applying the Fourier KPSS test and ECM bootstrap cointegration analysis, we can capture smooth, nonlinear structural changes that are often missed by traditional unit root and cointegration tests. Unlike earlier works that tend to treat inflation and unemployment separately, this study integrates both dimensions to reveal how their joint persistence complicates macroeconomic management. Furthermore, by disaggregating country-level results, we demonstrate the heterogeneity of hysteresis effects within the EU member states, a nuance often overlooked in studies that focus on aggregate or regional averages. This granular approach allows for more precise interpretation and supports the call for differentiated, context-specific policy responses.

In light of these findings, several key economic policy recommendations emerge for EU member states. First, monetary policy, especially under the European Central Bank's unified framework, should be more responsive to structural inflation dynamics. Inflation targeting must be supplemented with tools that address supply-side constraints and persistent shocks, such as investment in energy resilience, housing supply, and technological infrastructure. Second, countries exhibiting unemployment hysteresis should prioritise active labour market policies, including retraining programs, mobility support, and incentives for the reintegration of the long-term unemployed. Labour market duality, such as the divide between permanent and temporary contracts, should be minimised to avoid locking workers out of recovery. Moreover, the European Commission should consider revising fiscal rules to allow greater counter-cyclical space for member states facing persistent macroeconomic imbalances, especially amid high debt levels and structural unemployment.

Future research should deepen the exploration of institutional and structural factors that drive heterogeneity in hysteresis effects across countries. Specifically, the interaction between monetary policy frameworks, wage-setting institutions, and labour market regulations warrants further examination. There is also scope for studying how digital transformation, automation, and climate transition policies affect inflation-unemployment dynamics in the long run. Expanding the dataset beyond 2023 and integrating quarterly or sectoral data could improve the temporal and thematic granularity of the analysis. Ultimately, as the EU members continue to navigate post-crisis recovery and long-term transformation, understanding the persistent effects of shocks on macroeconomic variables remains critical for designing inclusive and resilient policy responses.

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Financial Determinants of Tax Avoidance: Evidence from Borsa Istanbul Listed Firms

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Vergiden Kaçınmanın Finansal Belirleyicileri: Borsa İstanbul'da İşlem Gören Firmalardan Kanıtlar

Abstract

This study examines the impact of transfer pricing, deferred tax expense, profitability, capital intensity, and leverage on tax avoidance for BIST50 firms in Türkiye from 2014 to 2023. Using panel data and the PMG-ARDL model, the findings reveal that deferred tax expense, capital intensity, and profitability negatively affect the effective tax rate (ETR), while transfer pricing has a positive and significant impact. Leverage shows no significant effect. The results indicate that firms use strategic tools like depreciation and R&D to reduce tax burdens, suggesting that tax avoidance is a complex, firm-level issue requiring policy attention.

Keywords : Tax Avoidance, Effective Tax Rate, Deferred Tax Expenses, Transfer Pricing, Profitability, Capital Intensity, Leverage.

JEL Classification Codes : H25, H26, M40, M48.

Öz

Bu çalışma, 2014-2023 yılları arasında Türkiye'de BIST50 endeksindeki şirketlerin transfer fiyatlandırması, ertelenmiş vergi gideri, kârlılık, sermaye yoğunluğu ve kaldıraç gibi finansal değişkenlerin vergiden kaçınma üzerindeki etkisini incelemektedir. Panel veri ve PMG-ARDL modeli kullanılarak yapılan analiz, ertelenmiş vergi giderinin, sermaye yoğunluğunun ve kârlılığın etkin vergi oranını (ETR) negatif yönde etkilediğini; transfer fiyatlandırmasının ise ETR üzerinde pozitif ve anlamlı bir etkiye sahip olduğunu ortaya koymuştur. Kaldıraç ise anlamlı bir etki göstermemiştir. Bulgular, firmaların vergi yükünü azaltmak amacıyla amortisman ve Ar-Ge gibi stratejik araçları kullandığını işaret ederek, vergiden kaçınmanın çok boyutlu ve firma düzeyinde politika odaklı ele alınması gereken bir konu olduğunu vurgulamaktadır.

Anahtar Sözcükler : Vergiden Kaçınma, Etkin Vergi Oranı, Ertelenmiş Vergi Giderleri, Transfer Fiyatlandırması, Kârlılık, Sermaye Yoğunluğu, Kaldıraç.

1. Introduction

Taxes are compulsory financial obligations that the state collects from citizens and institutions to finance public services (Darsani & Sukartha, 2021: 13). Taxes constitute the most comprehensive and most important source of revenue for the state to meet its expenditures sustainably (Alfina et al., 2018; Bellikli, 2024: 502). Therefore, the accurate and complete collection of tax revenues is essential for the orderly provision of public services such as education, health, infrastructure, and social security (Yıldız & Demir, 2019: 330).

On the other hand, since taxes are an expense that reduces firms' profits, taxpayers develop strategies to minimise their liabilities. This conflict of interest between the state and businesses leads to "tax avoidance" activities within legal limits and "tax evasion" activities through illegal means (Suciarti et al., 2020: 76; Karahan-Gökmen & Adıgüzel, 2019: 54). In both cases, the state's tax revenues decrease, difficulties arise in financing public expenditures, and inequities in income distribution increase (Yıldız & Demir, 2019: 330).

Tax avoidance encompasses all arrangements that firms use within the legal framework to reduce, defer or eliminate their tax liability (Oats & Tuck, 2019: 567; Alexander & Pisa, 2023: 3). In other words, tax avoidance refers to any activity aimed at lowering the tax liability relative to a firm's pre-tax earnings. (Kovermann & Velte, 2019: 2; Nguyen, 2020: 1044). In the broadest sense, tax avoidance is a set of methods and techniques to minimise the tax payable by exploiting gaps in existing regulations without contravening current tax legislation (Suciarti et al., 2020: 76; Pandoyo & Bahari, 2022: 24-25).

Tax avoidance strategies include practices such as transfer pricing, accelerated depreciation, taking advantage of R&D incentives, deducting interest expenses from the tax base through borrowing, and transferring income through tax havens (Saeed, 2023: 2; Weisbach, 2003: 9). Transfer pricing, which is the concentration of profits in a country with a low tax rate by determining the prices of goods and services between subsidiaries, is another practice (Kyj & Romeo, 2015: 36; Güney & Bozkurt, 2011: 150; Karahan-Gökmen & Adıgüzel, 2019: 58). Multinational companies may also resort to aggressive tax planning by taking advantage of the differences between different tax regimes (Ubay, 2024: 129; Pangaribuan et al., 2021: 4998; Wang & Wright, 2024: 688).

Theoretical approaches such as agency theory, corporate income tax theory, and information asymmetry constitute a significant foundation for analysing tax avoidance strategies. For example, agency theory emphasizes that conflicts of interest between managers and shareholders play a crucial role in tax planning, leading managers to attempt to reduce tax liabilities to maximize short-term profits (Jensen & Meckling, 1976: 306; Desai & Dharmapala, 2009: 9). Information asymmetry, on the other hand, enables companies to minimize their tax burden by leveraging informational advantages over tax authorities and engaging in complex tax arrangements (Karabacak, 2013: 16).

Another tax avoidance strategy used by multinational corporations involves exploiting mismatches between different national tax systems to reduce their overall tax liability. This approach, referred to as aggressive tax planning, is often considered an improper managerial practice and a legally questionable activity. Moreover, it is regarded as one of the main reasons why governments may fall short of achieving their tax revenue targets (Ubay, 2024: 129; Pangaribuan et al., 2021: 4998).

Transfer pricing is one of the commonly employed methods of tax avoidance. It refers to the pricing of goods and services between related parties, such as a parent company and its subsidiary or two affiliated subsidiaries (Kyj & Romeo, 2015: 36). In other words, transfer pricing involves setting prices for the transfer of finished or semi-finished goods or components between affiliated entities in a way that shifts profits to low-tax jurisdictions (Güney & Bozkurt, 2011: 150). In such arrangements, one entity becomes the seller and the other the buyer, thereby affecting the seller's revenue and the buyer's cost of goods sold. This manipulation reduces taxable income and facilitates tax avoidance (Karahan-Gökmen & Adıgüzel, 2019: 58). In multinational corporations, the pricing of intra-group transactions involving goods, services, intangibles, and capital flows also falls under transfer pricing and directly influences pre-tax profits and the amount of corporate income tax payable in both jurisdictions (Saeed, 2023: 2).

In this context, transfer pricing aligns with corporate income tax theory by allowing firms to optimise their tax liabilities, while information asymmetry facilitates the effective application of such strategies (Hanlon et al., 2005: 408).

Another mechanism provided by governments is the deductibility of interest expenses on corporate loans. While interest payments are considered expenses for the borrower, if both the lending and borrowing entities are subsidiaries of the same multinational corporation located in different countries, this structure can allow the firm to reduce its tax burden in high-tax jurisdictions. By ensuring that subsidiaries in low-tax countries lend to those in high-tax regions, companies can generate favourable tax deductions on interest payments (Contractor, 2016: 33; Hope et al., 2013).

Investment decisions regarding fixed assets also have significant implications for tax payments. The depreciation of fixed assets constitutes a major component of corporate expenses. Firms with substantial fixed assets may reduce their tax liabilities by leveraging depreciation costs. Managers may seek to minimise tax payments by strategically utilising depreciation. As a result, capital-intensive firms tend to benefit more from depreciation deductions. This is especially relevant when an asset's economic life exceeds its depreciation period. The availability of various depreciation methods allows capital-intensive firms to accelerate or defer depreciation charges, thereby managing their tax obligations more effectively (Ribeiro et al., 2015: 8-9).

Another frequently employed tax avoidance strategy involves managers exploiting the flexibilities and gaps arising from differences between accounting standards and tax

legislation to calculate taxable income. As a result, the reported commercial profit may differ from the taxable income. These discrepancies can be either permanent or temporary. When temporary differences exist between commercial and taxable profits, deferred tax items arise (Özer & Sayar, 2024: 89).

Together with balance sheet management strategies, the management of deferred tax items enables firms to defer their tax burden to future periods, thereby improving short-term cash flows (Hanlon et al., 2005: 409; Fajarwati et al., 2020: 960).

In recent years, tax avoidance has become a significant topic of debate not only in academic and political circles but also among the general public, particularly due to increasing media coverage of global corporations' tax strategies (Kovermann & Velte, 2019: 1; Bilicka et al., 2022: 1). Companies employ various methods with different motivations to minimize their tax burden while simultaneously aiming to optimize financial performance. In this context, the present study aims to examine tax avoidance behaviour from a financial perspective, focusing on companies listed on Borsa Istanbul (BIST) in Türkiye. The research empirically analyses the relationships between key financial variables such as transfer pricing, financial leverage, profitability, capital intensity, and deferred tax expense and tax avoidance. This study makes a significant contribution to the tax avoidance literature on both theoretical and empirical levels. Its originality lies in being the first study to integrate and analyse this specific combination of critical variable transfer pricing, leverage, return on assets, deferred tax expense, and capital intensity within a single model. The literature review has revealed no prior study that investigates these five variables together. Previous research (Desai & Dharmapala, 2009; Armstrong et al., 2015; Alfina et al., 2018; Darsani & Sukartha, 2021; Pangaribuan et al., 2021; Suciarti et al., 2020; Amelia et al., 2022; Widyastuti et al., 2022; Terzi, 2024; Bellikli, 2024) has either examined only a subset of these variables or focused on different combinations. Similarly, studies conducted in Türkiye have either been accounting-oriented (Terzi, 2024; Bellikli, 2024) or have been limited in variable selection. Apart from the relationship between return on assets and tax avoidance (Öztürkçü-Akçay, 2020), there appears to be no research that thoroughly investigates the financial dimensions of tax avoidance. Therefore, this study will serve as a valuable guide for tax regulators on revenue optimisation and for firms on tax planning. It will also provide a fundamental reference for academics analysing the interaction among transfer pricing, leverage, profitability, capital intensity, and deferred tax expense in relation to tax avoidance.

This study consists of five chapters. In the introduction, information on tax avoidance and the strategies used to avoid it is provided. In addition, explanations of how the study's variables relate to tax avoidance are provided. In the second section, a literature review of studies on this subject is presented. The third section provides information on data and methodology. The fourth section presents empirical analysis and findings. In the conclusion section, the findings are discussed, and policy recommendations are given.

2. Literature Review

Tax avoidance has evolved into a multidimensional field of inquiry, gaining momentum both theoretically and empirically. The extant literature explores how various factors, such as corporate governance mechanisms, financial structures, managerial characteristics, and accounting policies, influence firms' tax planning behaviours. However, many studies fall short in analytical depth due to a lack of robust theoretical frameworks or a systematic thematic classification of empirical variables. Addressing these limitations requires integrating well-established theoretical lenses, including agency theory, corporate tax theory, and resource dependence theory, while organising variables thematically across managerial factors, financial indicators, governance structures, and accounting practices.

From the perspective of agency theory, principal-agent conflicts between managers and shareholders are fundamental in shaping firms' tax avoidance strategies. Desai and Dharmapala (2009) demonstrated that agency costs affect tax preferences by analysing discrepancies between income reported to capital markets and tax authorities. Armstrong et al. (2015) revealed that board independence and financial expertise have differential impacts on tax avoidance depending on its intensity, whereas Pandoyo and Bahari (2022) found managerial traits to be statistically insignificant in this context. These mixed findings suggest that the effects of governance-related variables may vary with firm-specific conditions.

In the context of corporate tax theory, firms' efforts to minimise tax burdens are often shaped by their financial and operational structures. Alfina et al. (2018) reported positive associations between leverage and firm size with tax avoidance, though profitability appeared irrelevant. These findings were partially supported by Amelia et al. (2022) and Widyastuti et al. (2022), while Riani et al. (2024) reported no significant effects. Additionally, Darsani and Sukartha (2021) observed a negative effect of corporate ownership and a positive effect of capital intensity, whereas Suciarti et al. (2020) found capital intensity to have a negative effect, with other variables showing no significance. Such inconsistencies indicate that financial determinants of tax avoidance may be highly sensitive to contextual factors such as country-specific tax regulations or firm size and industry.

Resource dependence theory emphasises the role of external pressures, including institutional and regulatory forces, in influencing corporate tax behaviour. Çelikay and Yılcı (2019) paradoxically argued that strong corporate governance practices may, under certain conditions, facilitate more aggressive tax avoidance strategies. Stiglingh et al. (2022) found that tax transparency scores were positively correlated with effective tax rates, while Dyreng et al. (2019) observed that firms with lower cash effective tax rates experienced greater tax uncertainty, especially those with subsidiaries in tax havens. These findings underscore how external environmental pressures can shape firms' tax avoidance decisions, either as constraints or strategic opportunities.

When managerial characteristics are evaluated alongside financial indicators, the results remain inconclusive across empirical studies. Pangaribuan et al. (2021) reported that

leverage, profitability, and sales growth positively influence tax avoidance, whereas Suciarti et al. (2020) suggested that their effects are only jointly significant. In contrast, Pandoyo and Bahari (2022) found no significant joint effect, emphasising once again the role of institutional and contextual factors in shaping empirical outcomes.

Within the realm of accounting policies, recent studies have explored the relationship between tax avoidance and financial reporting practices, including conservatism, prudence, and earnings management. Delgado et al. (2023) found a nonlinear but positive association between earnings management and tax avoidance. Terzi (2024) showed that accounting prudence is positively linked to tax avoidance when supported by higher return on assets. Meanwhile, Bellikli (2024) reported that accounting losses contribute to higher tax avoidance, while conservative accounting practices tend to reduce it. These findings suggest that financial reporting discretion may be strategically employed to facilitate or constrain tax minimisation efforts.

Taken together, the literature illustrates that tax avoidance is a complex and context-sensitive phenomenon that cannot be adequately understood through isolated variables or fragmented approaches. Instead, a comprehensive analytical framework that integrates theoretical perspectives and thematically clusters empirical variables is necessary for meaningful insight. This study contributes to the field by synthesising agency theory, corporate tax theory, and resource dependence theory and by systematically organising key financial, managerial, and accounting variables.

Positioned within the underexplored context of Türkiye's emerging market economy, this study focuses on publicly listed firms in BIST to investigate the financial determinants of corporate tax avoidance. By analysing the roles of transfer pricing, leverage, profitability, capital intensity, and deferred tax expenses, it contributes novel empirical evidence to the international literature. The integration of agency theory, corporate tax theory, and resource dependence theory through a thematically structured model offers both theoretical enrichment and practical insights for policymakers, tax authorities, and corporate stakeholders seeking to better understand and regulate tax avoidance behaviour.

3. Data & Methodology

In this study, data from the financial statements of 30 companies listed on the Borsa Istanbul (BIST), specifically those included in the BIST 50 index and with data suitable for analysis, for the period 2014-2023, were used. The data utilised in the study were obtained from the Public Disclosure Platform (PDP), through which disclosures required to be made public under Turkish Capital Markets and Stock Exchange legislation are published. The study's dependent variable is the Effective Tax Rate (ETR), which reflects tax avoidance, while the independent variables are transfer pricing (TP), leverage (LEV), return on assets (ROA), deferred tax expense (DTE), and capital intensity (CI). Table 1 presents the variables used in the study, along with their symbols and descriptions.

Table: 1
Variables and Descriptions

Variables*	Symbol	Variable Description
Effective Tax Rate	ETR	Total Tax Expense / Pre-tax Income
Transfer Pricing	TP	Receivables from Related Parties / Total Receivables
Leverage	LEV	Total Liabilities / Total Equity
Deferred Tax Expense	DTE	Deferred Tax Expense _t - Deferred Tax Expense _{t-1} / Total Assets _{t-1}
Return on Assets	ROA	Net Profit for the Period / Total Assets
Capital Intensity	CI	Total Tangible Fixed Assets / (Total Assets

* Calculated by the author using data obtained from The Public Disclosure Platform (PDP).

The relationship between ETR (used as a tax-avoidance variable) and the DTE, TP, CI, LEV, and ROA variables was examined using the model shown below.

$$\text{Model: } \text{ETR}_{it} = a_1 + a_2\text{DTE}_{it} + a_3\text{TP}_{it} + a_4\text{CI}_{it} + a_5\text{LEV}_{it} + a_6\text{ROA}_{it} + u_{it} \quad (1)$$

ETR serves as a critical indicator of the extent to which companies fulfil their tax obligations (Hanlon & Heitzman, 2010: 139; Wang & Mao, 2021: 368; Baker et al., 2024: 510). TP reflects the pricing policies applied by companies in transactions involving goods and services with related parties. It demonstrates firms' potential to reduce their taxable income through intragroup arrangements (Pargaribuan et al., 2021: 5002). LEV represents the degree to which a firm finances its assets through debt. As an indicator of financial risk, this variable may influence corporate tax avoidance behaviours (Pandoyo & Bahari, 2022: 27). DTE arises from temporary differences between accounting income and taxable income. It reflects the misalignment between accounting standards and tax regulations (Machdar & Nurdiniah, 2021: 108). ROA ratio indicates a firm's ability to generate profit from its total assets and provides insight into operational efficiency (Prabowo, 2020: 98). CI refers to the level of investment in fixed assets. A higher proportion of fixed assets may contribute to lower tax burdens through depreciation, making CI a potential determinant of tax avoidance (Darsani & Sukarta, 2021: 16). Through these variables, this study examines the structural and financial determinants that may influence firms' tax avoidance behaviours.

4. Empirical Findings

In this study, panel data analysis methods were employed to analyse the data of 30 companies listed on the Borsa Istanbul BIST50 index for the period 2014-2023. Initially, cross-sectional dependence among variables was examined, followed by appropriate unit root tests to assess the stationarity of the series. The homogeneity of slope coefficients across all units in the constructed model was tested, and the model was estimated using the Panel ARDL cointegration analysis. The analyses were conducted using Stata and Eviews software.

Tests used to examine cross-sectional dependence vary with the sizes of the time and cross-sectional dimensions. When the time dimension (T) exceeds the cross-sectional dimension (N), the LM test developed by Breusch and Pagan (1980) is preferred (Göçer et al., 2012: 455). However, when N exceeds T, the original LM test becomes biased. It may lead to significant size distortions (Bailey et al., 2021: 2). If both the time and cross-sectional

dimensions approach infinity, the scaled LM test proposed by Pesaran (2004) can be applied. Nevertheless, even this test may exhibit bias when the cross-sectional dimension is large while the time dimension remains small (Güloğlu & İvrendi, 2010: 384), and in cases where $N > T$, Pesaran (2004) recommends the Cross-Section Dependence (CD) test. Furthermore, to account for potential bias in the scaled LM test, Pesaran et al. (2008) suggest the use of the bias-adjusted LM test (Güzel & Akın, 2021: 17). Since the number of cross-sectional units surpasses the number of time periods in this analysis, the study employs the CD test by Pesaran (2004) in Equation (2) and the bias-corrected LM test proposed by Pesaran et al. (2008) in Equation (3).

$$CD_{PES} = \sqrt{\frac{2T}{n(n-1)}} \left(\sum_{i=1}^{n-1} \sum_{j=i+1}^n \hat{\rho}_{ij} \right) \quad (2)$$

$$LM_{BC} = \sqrt{\frac{2}{n(n-1)}} \left(\sum_{i=1}^{n-1} \sum_{j=i+1}^n T \hat{\rho}_{ij} \left[\frac{(T-k) \hat{\rho}_{ij}^2 - \mu_{Tij}}{\sqrt{v_{Tij}^2}} \right] \right) \quad (3)$$

The outcomes of the cross-sectional dependence tests applied to the variables are reported in Table 2.

Table: 2
Cross-Sectional Dependence Test Results

Variables	LMBP	LM _{PES}	LM _{BCadj}	CD _{PES}
ETR	631,59 [0,000]	6,66 [0,000]	4,99 [0,000]	1,99 [0,045]
DTE	760,25 [0,000]	11,02 [0,000]	9,36 [0,000]	9,47 [0,000]
TP	755,21 [0,000]	10,85 [0,000]	9,18 [0,000]	1,91 [0,055]
CI	927,37 [0,000]	16,69 [0,000]	15,02 [0,000]	6,47 [0,000]
LEV	834,11 [0,000]	13,53 [0,000]	11,86 [0,000]	4,69 [0,094]
ROA	763,76 [0,000]	11,14 [0,000]	9,47 [0,000]	9,93 [0,000]

According to the LM_{BCadj} and CD_{PES} test results presented in Table 2, cross-sectional dependence is present in all variables. Therefore, second-generation unit root tests that account for cross-sectional dependence will be employed to examine the stationarity of the variables.

In the presence of cross-sectional dependence, the Panel CIPS test proposed by Pesaran (2007), as shown in Equation (5), is employed. In this test, the lagged cross-sectional averages of the ADF regression, as specified in Equation (4), are initially calculated. Subsequently, an extended version of these averages is used to estimate the CADF regression. The CIPS statistic is then obtained by averaging the estimated CADF values.

$$\Delta Y_{it} = a_i + b_i Y_{i,t-1} + c_i \bar{Y}_{t-1} + d_i \Delta \bar{Y}_t + \varepsilon_{it} \quad (4)$$

$$CIPS(N, T) = N^{-1} \sum_{i=1}^N CADF_i \quad (5)$$

The outcomes of the unit root tests are shown in Table 3.

Table: 3
Unit Root Test Results

CIPS Unit Root Test				
Variables	Intercept		Intercept and Trend	
	Z st.	Prob.	Z st.	Prob.
ETR	0,34	0,635	-0,97	0,165
DTE	-1,49*	0,068	-0,44	0,328
TP	-2,31***	0,010	-2,16**	0,015
CI	1,19	0,883	0,52	0,701
LEV	2,25	0,988	1,46	0,929
ROA	1,42	0,922	1,83	0,967
DETR	-3,68***	0,000	-1,49*	0,067
DDTE	-6,45***	0,000	-3,40***	0,000
DCI	-6,06***	0,000	-4,52***	0,000
DLEV	-3,61***	0,000	-1,67**	0,047
DROA	-4,12***	0,000	-3,49***	0,000

* 10%, **5%, and ***1% indicate significance at the 10%, 5%, and 1% levels, respectively.

An assessment of the unit root test results in Table 3 reveals that the TP variable is stationary at the level across both the intercept-only and intercept-and-trend specifications, whereas the other variables attain stationarity after first differencing. Whether a change in one cross-section affects the other units at the same level is examined using the slope homogeneity test proposed by Pesaran and Yamagata (2008). The test is presented in Equations (6) and (7) (Pesaran & Yamagata, 2008: 57).

$$\tilde{\Delta} = \sqrt{N} \left(\frac{N^{-1}\tilde{S} - k}{\sqrt{2k}} \right) \quad (6)$$

$$\tilde{\Delta}_{adj} = \sqrt{N} \left(\frac{N^{-1}\tilde{S} - E(Z_{it})}{\sqrt{Var(Z_{it})}} \right) \quad (7)$$

Here, N represents the number of cross-sections, S denotes Swamy's test statistic, and k indicates the number of regressors.

The test results are presented in Table 4.

Table: 4
Homogeneity Test Results

Model	Test Statistic		Prob.
	Delta tilde		
	Delta tilde adj	-0,46	0,642
		-0,84	0,396

The results shown in Table 4 indicate that the slope coefficients are homogeneous. This suggests that the coefficient estimates for the variables do not differ across units.

Considering that the dependent variable is integrated of order one and the explanatory variables are a mix of I(0) and I(1), the long-run relationship among the variables is investigated using the panel ARDL framework developed by Pesaran et al. (1999). The model parameters are estimated via the Pooled Mean Group (PMG) estimator, which is appropriate under mixed integration orders and assumes that the error terms are

independently and identically distributed with zero mean and constant variance across cross-sectional units (Da Silva et al., 2018: 49)

The long-term relationships indicated by the panel ARDL model are shown in equation (8).

$$Y_{it} = \alpha_i + \sum_{j=1}^p \beta_{ij} Y_{it-j} + \sum_{j=0}^q \gamma_{ij} X_{it-j} + \sum_{j=0}^k \delta_{ij} A_{it-j} + \sum_{j=0}^m \theta_{ij} B_{it-j} + \varepsilon_{it} \quad (8)$$

Here, $i = 1, \dots, N$ represents the number of cross-sectional units, $t = 1, \dots, T$ represents the time dimension, and ε denotes the error term (Nazhoğlu, 2011: 74). The optimal lag lengths for each variable and unit are represented by p , q , k , and m . By including the lag length for both endogenous and exogenous variables, issues arising from endogeneity are corrected, and the estimates become consistent and efficient (Attiaoui et al., 2017: 13039). Then, equation (8) is formulated as an error-correction model to estimate both short- and long-term parameters. The error-correction forms of the panel ARDL models are defined as in equation (9).

$$\Delta Y_{it} = \alpha_i + \lambda_i Y_{it-1} + \gamma'_i X_{it} + \delta'_i A_{it} + \theta'_i B_{it} + \sum_{j=1}^{p-1} \beta_{ij} \Delta Y_{it-j} + \sum_{j=0}^{q-1} \gamma''_{ij} \Delta X_{it-j} + \sum_{j=0}^{k-1} \delta''_{ij} \Delta A_{it-j} + \sum_{j=0}^{m-1} \theta''_{ij} \Delta B_{it-j} + \varepsilon_{it} \quad (9)$$

In the equation specified in Equation (9), the term λ_i represents the error correction coefficient, which is expected to be negative, and is expressed as: $\lambda_i = -(1 - \sum_{j=1}^p \beta_{ij})$, $\gamma'_i = \sum_{j=0}^q \gamma_{ij}$, $\delta'_i = \sum_{j=0}^k \delta_{ij}$, $\theta'_i = \sum_{j=0}^m \theta_{ij}$. Here, Δ represents the first difference operator. γ' , δ' , θ' represent the long-term coefficients, while β'' , γ'' , δ'' , θ'' represent the short-term coefficients (Özgür, 2018: 105).

The optimal lag length is determined using the VAR methodology, with the results provided in Table 5.

Table: 5
Results of Optimal Lag Length

Lag	LogL	AIC	SC	HQ
0	17,58	-0,38	-0,17	-0,30
1	160,44	-3,94	-2,48*	-3,37
2	204,47	-4,21	-1,49	-3,15
3	253,33	-4,64	-0,66	-3,08
4	359,38	-5,21	0,01	-3,17

The results presented in Table 6 show that the optimal lag length is the first lag according to the Schwarz Information Criterion (SC). Using the optimal lag length, the PMG estimator proposed by Pesaran et al. (1999) was used to estimate Equation (9), and the results are displayed in Table 6:

Table: 6
PMG Estimation Results

Model ARDL(1,1,1,1,1)		Coeff.	Test Stat.	Prob.
Long-term	DTE	-0,65	-10,83	0,000
	TP	0,10	22,01	0,000
	CI	-0,03	-9,79	0,000
	LEV	3,56e-05	0,09	0,923
	ROA	-0,78	-34,99	0,000
Short-term	ECM	-0,74	-4,40	0,000
	Δ DTE	-1,18	-0,91	0,362
	Δ TP	-6,50	-1,06	0,287
	Δ CI	1,41	1,69	0,093
	Δ LEV	0,26	1,93	0,055
	Δ ROA	2,01	2,10	0,037

According to the results presented in Table 6, the error correction parameter (ECM) is negative (-0.74), less than 1, and statistically significant at the 1% level. This indicates cointegration among the variables. According to the PMG estimation results, the variables DTE, CI and ROA have a negative and meaningful effect on ETR in the long run. On the other hand, TP has a positive and significant effect on ETR. The LEV variable has no significant effect. In the short run, the variables CI, LEV and ROA have a positive and significant effect on ETR. The value of the error correction parameter (-0.74) indicates the speed at which short-term deviations in the series return to equilibrium in the next period. About 74% of the imbalances in one period are corrected in the next period, and the series returns to its long-run equilibrium after about one period.

The tests for multicollinearity, heteroskedasticity, and normality related to the model analysing tax avoidance are presented in Table 7.

Table: 7
Results of Multicollinearity, Heteroskedasticity, and Normality Tests

Var	VIF	1/VIF
DTE	1,00	1,00
TP	1,09	0,91
CI	1,10	0,90
LEV	1,01	0,99
ROA	1,15	0,86
Cameron & Trivedi's decomposition of the IM-test	Chi2	Prob.
White	19,70	0,476
Skewness	3,57	0,613
Kurtosis	2,86	0,091

The VIF values presented in Table 7 indicate no multicollinearity among the variables. According to the results of the heteroskedasticity, skewness, and kurtosis tests from the information matrix test proposed by Cameron and Trivedi (1990), there are no issues with heteroskedasticity or normality in the model.

To examine the generalizability and stability of the model coefficients, the analysed firms were divided into two groups: the service sector and the manufacturing sector, and the analysis was repeated. The results are presented in Table 8.

Table: 8
Service/Manufacturing Sector PMG Estimation Results [ARDL (1,1,1,1,1)]

	Var.	Service Sector			Manufacturing Sector		
		Coeff.	Test Stat.	Prob.	Coeff.	Test Stat.	Prob.
Long-term	DTE	-1,56	-6,19	0,000	-1,97	-36,87	0,000
	TP	1,27	6,69	0,000	0,06	7,65	0,000
	CI	-0,07	-9,61	0,000	-0,22	-28,76	0,000
	LEV	0,0001	0,38	0,701	0,01	5,07	0,000
	ROA	-1,48	-10,97	0,000	0,10	3,55	0,000
Short-term	ECM	-0,46	-2,20	0,032	-0,60	-3,01	0,003
	ΔDTE	-1,86	-0,78	0,435	-0,31	-0,17	0,864
	ΔTP	-17,07	-1,15	0,253	0,93	0,63	0,525
	ΔCI	3,74	1,47	0,147	0,31	0,63	0,528
	ΔLEV	0,51	1,57	0,123	0,16	1,14	0,255
	ΔROA	0,94	1,07	0,290	1,87	1,15	0,252

According to the results presented in Table 8, the ARDL analysis for the service and manufacturing sectors indicates that DTE and CI significantly reduce the effective tax rate (ETR) in the long term across both sectors, thereby increasing tax avoidance. While TP positively affects ETR in both sectors, the effect is considerably stronger in the service sector. The ROA variable shows a sectorally divergent impact: in the service sector, increased profitability leads to higher tax avoidance, whereas in the manufacturing sector, it leads to greater tax compliance. Additionally, LEV is statistically significant and positively associated with ETR only in the manufacturing sector, suggesting that manufacturing firms more effectively utilise the interest-deduction benefits of debt financing. The short-term effects are statistically insignificant in both sectors, implying that tax planning strategies are shaped primarily by long-term decisions.

Table 9 Panel Granger Causality results examines the causal relationships between ETR as a proxy for tax avoidance and the independent variables in the model (DTE, TP, CI, LEV, and ROA), within the framework of the Granger causality test.

Table: 9
Panel Granger Causality Results

Coeff.	Test Stat.	Prob.
ETR does not Granger-Cause DTE	3,22	0,041
DTE does not Granger-Cause ETR	1,71	0,182
ETR does not Granger-Cause TP	0,64	0,526
TP does not Granger-Cause ETR	0,13	0,876
ETR does not Granger-Cause CI	0,25	0,774
CI does not Granger-Cause ETR	1,25	0,286
ETR does not Granger-Cause LEV	0,33	0,719
LEV does not Granger-Cause ETR	2,20	0,112
ETR does not Granger-Cause ROA	0,47	0,623
ROA does not Granger-Cause ETR	2,85	0,060

According to Table 9, there is a statistically significant causal relationship from ETR to DTE ($p = 0.041$), which is valid at the 5% significance level. This result indicates that changes in the effective tax rate affect deferred tax expenses, suggesting that past values of ETR have predictive power over DTE. However, the reverse relationship, namely, from DTE to ETR, is not statistically significant ($p = 0.182$), implying that changes in deferred tax expenses do not have a determining effect on ETR.

For the other variables, no significant unidirectional or bidirectional causal relationships are observed. The Granger causality tests between ETR and the variables TP, CI, and LEV are statistically insignificant ($p > 0.10$). Although ROA does not have a statistically significant causal effect on ETR, the causality from ROA to ETR is marginally significant ($p = 0.060$), which, while offering only weak evidence at the 10% level, may still suggest that firm profitability could influence the effective tax rate.

This overall picture indicates that most relationships in the model remain correlational and require further testing and analysis to confirm causal linkages. In particular, the significant causality from ETR to DTE suggests that historical tax-burden levels may shape deferred-tax planning strategies.

5. Conclusion

This study analyses the interrelationships among key financial indicators that affect tax avoidance behaviours, utilising financial data from firms listed in the BIST50 index in Türkiye for the period 2014-2023. In the study, ETR is adopted as the dependent variable representing tax avoidance, while the independent variables include TP, DTE, CI, LEV, and ROA. The long- and short-term relationships between the variables were examined using the Panel ARDL method, and directional causality relationships were analysed with Granger causality tests. Tests for multicollinearity, heteroskedasticity, and normality supported the model's statistical validity and the reliability of the findings.

As expected, the analysis results revealed that DTE, CI, and ROA had significant and negative effects on ETR in the long run. These findings indicate that firms, within the framework of agency theory and corporate income tax theory, engage in long-term financial planning to reduce their tax burden through depreciation practices and deferred tax strategies. In particular, the triggering effect of increased profitability on tax avoidance efforts signals a strong connection between financial performance and tax avoidance, driven by managerial motivation to maximise shareholder wealth. These results also suggest that firms' accounting policy choices are closely intertwined with their financial decision-making processes regarding tax obligations.

On the other hand, the positive effect of TP on ETR, consistent with some findings in the international literature, suggests that in the Turkish context, TP practices may enhance tax compliance and reduce avoidance due to strict regulatory oversight and legislative constraints imposed by tax authorities. While LEV was not significant in the general model, it was positively and significantly associated with ETR only in the manufacturing sector, indicating that the tax advantages stemming from interest expenses vary across sectors.

In the short-term analysis, ROA's positive and significant effect on ETR contrasts with the long-term findings, revealing that short-term profitability may increase tax burdens. Granger causality results showed that deferred tax strategies are shaped as proactive responses to past tax liabilities and that profitability is a key factor in tax planning. The

observed differences across the service and manufacturing sectors underline the critical role of sector-specific characteristics (cost structures, regulatory frameworks, managerial motivations) in shaping tax avoidance behaviour.

The most significant contribution of this study lies in its integration of a comprehensive set of financial indicators (TP, DTE, CI, LEV, ROA) to examine their impact on tax avoidance in Türkiye, as well as its sector-based comparative analysis. While these variables have typically been addressed in isolation or in limited combinations in the literature, this study's holistic and comparative approach reveals the financial dynamics and sectoral heterogeneity of tax avoidance behaviours in Türkiye. Additionally, the use of the Panel ARDL methodology and robustness checks enhances the reliability and generalizability of the findings. In this respect, the study contributes to closing an important gap in both theoretical and empirical literature.

This study also offers important implications for policymakers and tax authorities. First, increasing transparency regarding deferred tax assets and liabilities and implementing sector-based benchmarks can help identify potential tax-planning risks more effectively. To prevent profit shifting, it is necessary to enhance disclosure of related-party transactions and pricing methods in transfer pricing practices, and to develop risk-based audit mechanisms, particularly in the service sector. Firms with high capital intensity and profitability should be prioritised within risk-based audit frameworks due to their potential for aggressive tax planning. Moreover, the establishment of regular monitoring systems to assess the interaction between financial incentives and tax behaviour is recommended to evaluate the effectiveness of tax incentives. Lastly, promoting voluntary disclosure of corporate tax strategies in firms' annual reports can enhance corporate transparency and reinforce investor confidence.

Nevertheless, the study has certain limitations. The analysis is limited to large-scale firms within the BIST50 index, which restricts the generalizability of the findings to small and medium-sized enterprises (SMEs) and other non-financial sectors. The inherently complex nature of variables such as transfer pricing and deferred tax expense may limit the study's capacity for in-depth analysis. Furthermore, as the dataset is based on official financial reports, the potential influence of reporting errors and intra-industry differences in accounting practices cannot be entirely ruled out. Finally, the model does not incorporate governance-related variables (e.g., board structure, independent directors), corporate governance mechanisms, or audit quality, which constrains a comprehensive understanding of the multidimensional nature of tax avoidance. Future studies are encouraged to integrate these factors for more holistic analyses.

In conclusion, this study demonstrates that financial-based variables can meaningfully explain tax avoidance behaviours in Türkiye and highlights the necessity of accounting for sectoral differences in these behaviours. The findings not only contribute to the academic literature but also offer guidance for policymakers and practitioners on developing strategies to ensure tax justice and improve tax collection efficiency. In

particular, close monitoring and regulation of the tax-planning strategies of highly profitable, capital-intensive firms are critical to achieving tax equity and supporting sustainable economic growth.

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The Effects of Geopolitical Risk on Investor Attention towards Renewable Energy: Evidence from Türkiye

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Jeopolitik Risklerin Yenilenebilir Enerjiye Yönelik Yatırımcı Dikkati Üzerindeki Etkileri: Türkiye Örneği

Abstract

This study is the first to explore how geopolitical risks affect investor attention to renewable energy, with a specific focus on Türkiye. We construct an investor attention index using Google Search Volume Index (GSVI) data for the keyword “renewable energy.” By incorporating the Geopolitical Risk Index (GPR) and World Uncertainty Index (WUI), we examine the impact of major events such as the COVID-19 pandemic, the Russia-Ukraine war, and the war after October 7, 2023, on investor attention since 2008. Given Türkiye’s heavy reliance on foreign energy and its strategic role as an energy bridge between Europe and the Middle East, it offers a critical case for understanding how geopolitical uncertainties shape renewable energy investment behaviour.

Keywords : Geopolitical Risk, Uncertainty, Investor Attention, Türkiye.

JEL Classification Codes : Q42, Q43, D81.

Öz

Bu çalışma, jeopolitik risklerin yatırımcıların yenilenebilir enerjiye olan dikkatini nasıl etkilediğini Türkiye’ye odaklanarak inceleyen ilk çalışmadır. “Renewable energy” anahtar kelimesi için Google Arama Hacmi Endeksi (GSVI) verileri kullanılarak bir yatırımcı dikkati endeksi oluşturulmuştur. Jeopolitik Risk Endeksi (GPR) ve Dünya Belirsizlik Endeksi (WUI) verileri kullanılarak, COVID-19 pandemisi, Rusya-Ukrayna savaşı ve 7 Ekim 2023’ten sonra yaşanan savaş gibi önemli olayların 2008’den bu yana yatırımcıların dikkati üzerindeki etkisi incelenmiştir. Türkiye’nin yabancı enerjiye olan yoğun bağımlılığı ve Avrupa ile Orta Doğu arasında bir enerji köprüsü olarak stratejik rolü, jeopolitik belirsizliklerin yenilenebilir enerji yatırım davranışlarını nasıl şekillendirdiğini anlamak için kritik bir örnek teşkil etmektedir.

Anahtar Sözcükler : Jeopolitik Risk, Belirsizlik, Yatırımcı Dikkati, Türkiye.

1. Introduction

Global energy markets have seen substantial changes in the last ten years due to major geopolitical events, including the COVID-19 pandemic (March 2020), the Russia-Ukraine war (February 2022), and the Israeli-Palestinian war (October 2023), among others. Particularly during the Russia-Ukraine war, these occurrences fueled rising oil prices and increased worries about energy security (Zhao et al., 2024a: 1). As a result, there is now more discussion about renewable energy sources as potential alternatives to fossil fuels (Chen et al., 2019; Michaelides, 2020; Raza & Lin, 2022). Climate concerns, sustainability, and energy security have fueled global interest in renewable energy, and investment in this sector increased significantly between 2022 and 2023 (IEA, 2023: 27). More specifically, investment rose by approximately 7.6%, from 1617 billion USD to 1740 billion USD¹. This raises the question of whether investor attention to renewable energy, at both the global and Turkish levels, has been affected by current geopolitical tensions and economic uncertainties.

In this paper, we contribute to answering this question by investigating the impact of global geopolitical risks and economic uncertainties since 2008 on investor attention to renewable energy at the global and Turkish levels. The reasons for the particular interest in Türkiye are primarily threefold. The first is based on Türkiye's geopolitical positions. The Eurasian and African continents make up the "World Island", according to Mackinder, which is the richest continental combination in all respects. Türkiye is in the middle of this area (Şimşek, 2014: 4). Türkiye is a strategic bridge between Europe and Asia. Given that the last two geopolitical risks (the Russia-Ukraine war and the Israeli-Palestinian war) are in Türkiye's bordering countries, it is particularly vulnerable to these conflicts. Second is based on Türkiye's role in global energy trade. Türkiye is one of the most important routes for the transportation of energy resources. For instance, Europe's fourth natural gas artery, the Southern Gas Corridor, was established through the Trans Adriatic Pipeline (TAP). The Trans Anatolian Natural Gas Pipeline (TANAP), which traverses Türkiye, serves as the backbone of the Southern Gas Corridor. Additionally, the TurkStream Natural Gas Project, which consists of two pipelines with a capacity of 15.75 billion cubic meters each and was built beneath the Black Sea, transports natural gas to Türkiye first, then to European countries (Republic of Türkiye Ministry of Foreign Affairs, 2022). Since the first phase of gas flow in 2020 (Botaş, 2025), Türkiye has received a total of 44.3 billion cubic meters of gas, while European countries have received 59.8 billion cubic meters between 2020 and 2024 (Kılıç, 2025). Energy crises, such as the Russia-Ukraine war, threaten Türkiye's energy security and affect the formation of its energy policy. Third is based on the fact that Türkiye has economic relations with many countries. The COVID-19 pandemic has caused an economic recession worldwide (World Bank, 2022: 50). As Türkiye has trade relations with

¹ In 2015, investments in fossil fuels surpassed those in renewable energy; however, since that year, investment in renewable energy has exceeded that in fossil fuels. In 2023, there was the biggest disparity in the amounts invested. Specifically, in 2023, the global investment in renewable energy reached 1.74 trillion USD, whereas investment in fossil fuels was 1.05 trillion USD (IEA, 2023).

many countries, geopolitical risks directly affect Türkiye's economy. Besides, the US and EU countries experienced higher inflation following the COVID-19 pandemic. There was also a rise in inflation in Türkiye. To fight inflation, the US and EU countries raised interest rates, while Türkiye kept rates low. Subsequently, the USD/TR exchange rate increased (from 6.61 at the beginning of the pandemic to 34.18 in September 2024 (Investing, 2024)). Besides, inflation reached significant levels, increasing from 11.84% in 2019:12 to 64.77% in 2023:12 (TurkStat, 2024). In an economy that is 74% dependent on foreign energy imports (Republic of Türkiye Ministry of Foreign Affairs, 2022), and whose main goal is economic growth, and which needs to increase its production in this direction, it is very sensitive to increases in the price of a basic fuel such as oil. Therefore, one of the most important steps is the transition to renewable energy. Given this, it's critical to ascertain whether geopolitical risks affect investors' attention to renewable energy in Türkiye. Due to its around 70% reliance on imported energy, particularly natural gas, which accounts for 39.5% of its imports from Russia and only 0.7% of its domestic production, Türkiye is a significant case. Thus, the goal is to ascertain whether investors are affected by the current geopolitical uncertainty in Türkiye, particularly the growing utilisation of renewable energy sources in line with the 2017 National Energy Policy. A study in this area will contribute to the body of literature, as few studies have examined how geopolitical risks affect Türkiye (see Mansour-Ichrahieh & Zeaiter, 2019; Tan et al., 2022; Kasal, 2024, among others).

Geopolitical risks and economic uncertainties exert both direct and indirect effects on investor attention. Investors view the rise in geopolitical events and economic uncertainties as external risks, prompting a more cautious approach, particularly amid heightened geopolitical threats. This is a direct consequence of uncertainty-aversion behaviour. The indirect effects can be explained through three channels: The real economic activity channel, which outlines how heightened geopolitical risks precipitate a contraction in economic activity and growth rates; the firm investment channel, which elucidates how uncertainty compels companies postpone or diminish their investment decisions; and third channel is related to the influence of geopolitical risks on financial markets, resulting in a decrease in stock prices and an escalation in volatility, thereby impacting investor behavior and expectations (He, 2023: 2). In the study, four different models are constructed both at the global level and for Türkiye. Our findings indicate that the model examining the interaction among global GPR, Türkiye-specific GPR, and investor attention in both the global and Türkiye-specific cases has greater connectedness than the other models. In contrast, Model 4, which uses the WUI, exhibits lower connectedness because it focuses more on economic uncertainty than on geopolitical risks. In our sample period, there are three main shocks (March 11, 2020: COVID-19 declared as a pandemic, February 24, 2022: Russia-Ukraine War, October 7, 2023: the Israeli-Palestinian war), and except for COVID-19, the other two shocks are more related to increased geopolitical risk rather than economic uncertainty. Besides, globally, connectedness among investor attention, GPR, and WUI increases during the three shocks, whereas in Türkiye, the highest connectedness occurs post-2016, as the country is more responsive to local geopolitical risks, such as the 2016 military coup, than to global ones. While the global GSVI is a net shock receiver across all

models, the Türkiye-specific GSVI is a net shock transmitter (except in Model 2). Last but not least, global investor attention is significantly affected by both economic and geopolitical uncertainties in the short and long term, whereas shocks within its own system more directly influence Türkiye-specific investor attention than uncertainties do.

The remaining sections of this paper are organised as follows. In Section 2, related literature is given. The datasets are described in Section 3. Section 4 presents the empirical methodology, and Section 5 gives the empirical results. Conclusions and policy implications are included in Section 6.

2. Literature Review

We summarise the diverse applications of the Geopolitical Risk Index (GPR) in recent empirical research across macroeconomic, financial, commodity, and environmental domains in Table 1. For instance, Sweidan (2023) examines the impact of GPR on key U.S. macroeconomic indicators, including real income per capita growth, unemployment, and oil prices, while Asomaning et al. (2024) focus on Ghana, analysing how GPR influences foreign exchange reserves, FDI, and inflation. In financial markets, Elsayed & Helmi (2021) investigate how geopolitical risks affect stock returns in MENA countries, and Singh & Roca (2022) study the influence of GPR on China's market index across various valuation ratios. In the context of commodities, Gong & Xu (2022) assess how GPR affects returns across energy, metals, and agriculture, using the S&P Goldman Sachs Commodity Index, while Banerjee (2024) incorporates GPR and global carbon risk to study commodity market responses. Climate-related studies, such as Cengiz & Manda (2022), explore how GPR interacts with CO₂ emissions and renewable energy consumption in Latin America and Asia, and Acheampong et al. (2023) expand this to a 42-country analysis linking GPR to trade openness, emissions, and FDI. These studies collectively underscore the broad relevance of geopolitical risk in shaping global economic and environmental dynamics.

Table: 1
Literature on the Effects of Geopolitical Risks

Scope	Researchers	Variables	Region
The relationship between GPR and macroeconomic indicators	Sweidan, 2023	GPR, growth rate of real income per capita, the unemployment rate, WTI crude oil prices and the trade-weighted US dollar index	US
	Asomaning et al., 2024	GPR, foreign exchange reserves, FDI, external debt, treasury bill rate, CPI, export and import as a percentage of GDP	Ghana
	Jha et al., 2024	Real GDP per capita, investment as a percentage of GDP, human capital, population growth, trade openness, GPR, inflation rate, government expenditure, index of economic freedom, democracy index	41 countries (including Türkiye)
	Hou et al., 2024	GPR, EPU, WUI, WTU, geographical distance, total trade costs, trade costs of agricultural goods, trade costs of manufactured goods, and common language, land border, colonial relationship, and regional trade agreement	43 countries (including Türkiye)
The relationship between GPR and financial markets	Elsayed & Helmi, 2021	GPR, stock returns of each MENA country	MENA Countries
	Singh & Roca, 2022	GPR for China, market index, US stock market index, book-to-market ratio, cash earnings to price ratio, earnings to price ratio, dividend yield ratio	China, Canada
	Zheng et al., 2023	GPR and global stock markets, foreign exchange markets, bond markets, WTI and gold markets	Global

The relationship between GPR and commodity markets	Gong & Xu, 2022	The S&P Goldman Sachs Commodity Index, total return of energy, precious metal, industrial metal, agriculture, and livestock market, GPR	Global
	Cheng et al., 2023	GPR, excess return of a long position in all available commodities futures contracts, commodity carry factor, commodity momentum factor, total return of energy, metal, agriculture, and livestock markets	Global
	Banerjee, 2024	GPR, a commodity index comprising energy, agriculture, and Industrial metals, precious metals and livestock, global carbon as a Proxy for climate and geopolitical risk	Global
The relationship between GPR and climate change	Cengiz & Manda, 2022	GPR, CO ₂ emissions, GDP per capita, total population, fossil energy consumption and renewable energy consumption	12 Latin American and Asian countries
	Dhifaoui et al., 2023	GPR, total precipitation, relative humidity, temperature, wind direction, wind speed	Saudi Arabia
	Acheampong et al., 2023	GPR, real GDP per capita, population, trade openness, emission variables, renewable energy consumption, FDI	42 countries (including Türkiye)
	Lorente et al., 2023	Climate change index, green financial assets, renewable energy markets, GPR	Global

The literature reveals a growing interest in understanding how geopolitical risks influence various aspects of renewable energy (see Table 2). Several studies examine the link between GPR and renewable energy consumption (e.g., Su et al., 2021; Sweidan, 2021; Cai & Wu, 2021), with some incorporating financial development into their analyses (Alsagr & von Hemmen, 2021; Abdallah et al., 2024). Others focus on renewable energy production, such as Hille (2023) for fossil fuel-importing countries and Lee & Lee (2024) for China. Broader environmental studies like those by Chu et al. (2023) and Jlatong et al. (2023) analyse the joint effects of GPR and environmental policies or economic uncertainty on RE, while Acheampong et al. (2023) and Kızılkaya et al. (2024) incorporate emissions and economic growth in cross-country and Türkiye-specific studies, respectively. Additionally, GPR’s impact on renewable energy stock returns has been addressed by Yang et al. (2021), Dutta & Dutta (2022), and others, while research on renewable energy investments under geopolitical tensions includes contributions from Flouros et al. (2022) and Zhao et al. (2024b). Collectively, these studies underline the multifaceted influence of geopolitical risk on renewable energy dynamics across different contexts. Despite the growing interest in renewable energy, relatively few studies have specifically examined investor attention in this context. Song et al. (2019: 4) use the Google Search Volume Index (GSVI) with the keyword “renewable energy” to construct an investor attention variable, analysing its relationship with fossil energy prices and renewable energy stock prices.

Table: 2
Studies on the Relationship between Geopolitical Risk and Renewable Energy

The relationship between GPR and renewable energy consumption	• Su et al. (2021), Sweidan (2021), Cai & Wu (2021), Cheikh & Zaid (2024), Ren et al. (2024) • Alsagr & von Hemmen (2021), Abdallah et al. (2024) focus on the relationship between GPR and RE by including financial development.
The relationship between GPR and renewable energy production	• Hille (2023) focuses on fossil fuel-importing countries, including Türkiye. • Lee & Lee (2024) focus on China.
Studies addressing climate change	• Jlatong et al. (2023) examined the effects of GPR and EPU on RE production, including environmental pollution. • Chu et al. (2023) focus on high- and middle-income countries (including Türkiye) and investigate the impact of the informal economy, environmental policies and geopolitical risks on renewable energy production. • Acheampong et al. (2023) investigated the impact of geopolitical risks on renewable energy consumption by including emission variables and focusing on 42 countries, including Türkiye. • Kızılkaya et al. (2024) examined the relationship between CO₂ emissions and GPR, economic growth, renewable energy consumption and population size for Türkiye.
The relationship between GPR and RE stock returns	• Yang et al. (2021); Dutta and Dutta (2022); Lorente et al. (2023); Zhao et al. (2024a); Ha (2024)
Relationship between GPR and RE investments	• Flouros et al. (2022); Abbas et al. (2023); Dong et al. (2023); Pata et al. (2023); Zhao et al. (2024b); Zheng et al. (2024)

In Türkiye, several studies have investigated the impact of geopolitical risk across various sectors. For instance, Demir et al. (2020), Akadiri et al. (2020), Bayraktaroğlu et al. (2021), Polat et al. (2021) and Tütüncü (2024) analyse the effects of GPR on the tourism industry. Broader economic impacts are examined by Mansour-Ichraikieh & Zeaiter (2019) and Kasal (2024), while Yıldırım et al. (2025) focus on financial markets, and Tan et al. (2022) investigate corporate investment. However, none of these studies has addressed the issue from the joint perspective of geopolitical risk and investor attention².

3. Data & Methodology

3.1. Data

In this study, investor attention is measured using the Google Search Volume Index (GSVI)³, which is frequently utilised in behavioural finance literature. In accordance with Song et al. (2019: 4), a monthly investor attention variable is generated using Google Trends and the keyword "renewable energy"⁴. For a keyword with an indexed value between 0 and 100, GSVI determines the relative search volume. The lowest relative search interest for a given keyword is zero, and the highest relative search interest is one hundred. To generate an index of investor attention to renewable energy, we add 1 to the GSVI index, which has a minimum value of 0 before the logarithmic transformation, in accordance with Pham & Cepni (2022: 200).

This study employs the Geopolitical Risk Index (GPR)⁵ developed by Caldara & Iacoviello (2022), which is constructed from newspaper articles across 10 major publications covering geopolitical tensions. The index offers a quantitative measure of adverse geopolitical events and their associated risks. In addition to a global GPR index, country-specific indices have also been developed for 44 individual countries. In addition to the geopolitical risk index, the world uncertainty index, which tracks global uncertainty, is also included in the model. The world uncertainty index (WUI) is a measure that tracks global

² Nazlıoğlu & Aydoğdu (2025) have developed a model examining the interaction among policy uncertainty, GPR, investor sentiment, and risk aversion. They employed the investor sentiment metric established by Baker and Wurgler (2006) instead of the GSVI to assess investor sentiment and did not focus on Türkiye.

³ Before the work of Da et al. (2011), investor attention was not directly observable, and early studies often relied on indirect measures such as excess returns, trading volume, and turnover variables that primarily reflected trading activity in financial markets. The introduction of more direct proxies for investor attention, such as the Search Volume Index (SVI), social media content (including Twitter, blogs, forums, and Wikipedia), and news data, marked a significant shift in the literature (Yang et al., 2017: 1). Da et al. (2011) were the first to utilize Google Search Volume Index (GSVI) to capture investor attention systematically.

⁴ An investor attention index was also created for Türkiye with the keyword "yenilenebilir enerji", but the results were meaningless, so the model was constructed with the keyword "renewable energy" to ensure consistency with the index created at the global level.

⁵ The index takes values between 0 and 100.

uncertainty by text-mining⁶ the Economist Intelligence Unit (EIU)'s country reports⁷. Put differently, the WUI serves as a metric for assessing both immediate and long-term uncertainties associated with global economic and political events. WUI indicates the frequency of the word "uncertainty" in EIU country reports. For instance, the continuous hostilities between North and South Korea represent long-term uncertainty, whereas the uncertainty that would result from a UK referendum in favour of Brexit is short-term (Ahir et al., 2018: 3). Since both the world uncertainty index and the geopolitical risk index provide monthly data at the country level, the dataset for Türkiye was compiled every month. To facilitate precise comparison, the dataset has been generated monthly at a global scale. Additionally, since the world uncertainty index is constructed beginning from 2008:01, this time frame spans from 2008:01 to 2024:05.

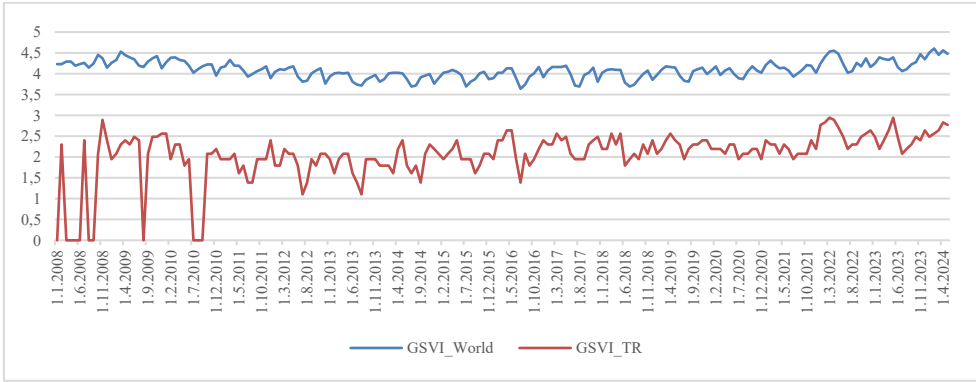
In this study, four different models are constructed at both the global and Türkiye-specific levels; therefore, the relevant variables are determined at both levels. It is found that the variables are stationary at first order. Following Flouros et al. (2022), the relevant variables are included in the model in logarithmic terms. Figures 1, 2 and 3 present the changes in the logarithmic versions of the variables over time⁸. Figure 1 shows the change in investor attention over time and shows that following the February 2022 Russia-Ukraine war, investor attention in renewable energy increased both in Türkiye and globally. The reason for this is that energy security has taken an important place on the agenda of countries with the war, and, accordingly, investors have prioritised the energy transition towards renewable energy to minimise the effects of the war. When the war was first declared, countries, especially in the EU, began seeking alternatives to Russian gas and prioritising energy security; as a result, coal-fired power plants were prioritised during this period, followed by an accelerated transition to clean energy (Tollefson, 2022).

⁶ It involves finding the proportion of words (or their equivalents) with the meaning "uncertain" in the text compiled from world and country reports.

⁷ It involves finding the proportion of words (or their equivalents) with the meaning "uncertain" in the text compiled from world and country reports.

⁸ Series are transformed into natural logarithm as $\ln(P_t / P_{t-1})$.

Figure: 1
Change in Investor Attention Index Over Time

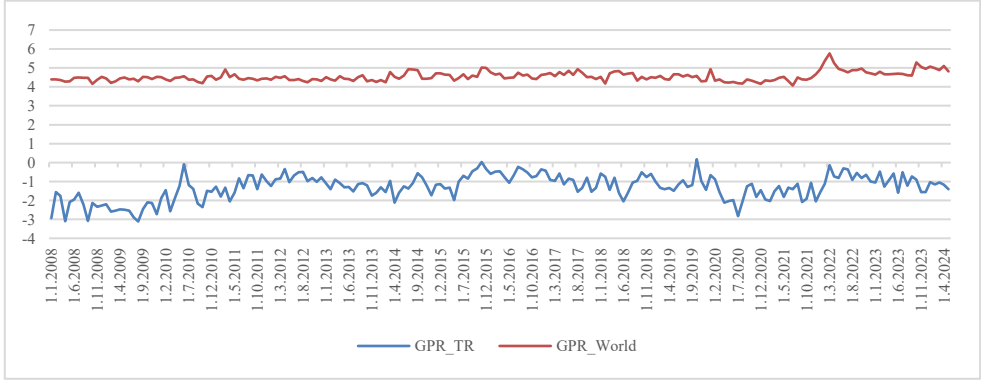


Source: Google Trends (2024).

Note: GSVI_World and GSVI_TR represent global and Türkiye-specific investor attention, respectively.

Figure 2 shows the change in the geopolitical risk index over time and shows that the Türkiye-specific geopolitical risk index has a lower value than the global geopolitical risk index. The reason is that the Türkiye-specific geopolitical risk index accounts for Türkiye's geopolitical situation, domestic and foreign policies, economic conditions, and regional conflicts, whereas the global geopolitical risk index evaluates risks across many countries collectively, and high risks in some countries may raise the global average. The largest response of the Türkiye-specific geopolitical risk index is observed at the end of 2019, when COVID-19 first emerged. After the Russia-Ukraine war, it has started to rise again. The global geopolitical risk index, on the other hand, reaches its highest value following the Russia-Ukraine war. This finding aligns with Hodula et al. (2024: 1), who observe that GPR periodically amplifies economic and financial concerns, particularly during significant geopolitical events. Authors clarify this via two mechanisms: The financial channel, where uncertainty and heightened risk aversion prompt changes in investment portfolios and capital flows, and the real economy channel, which influences global trade, supply chains, and commodities.

Figure: 2
Change in the Geopolitical Risk Index Over Time



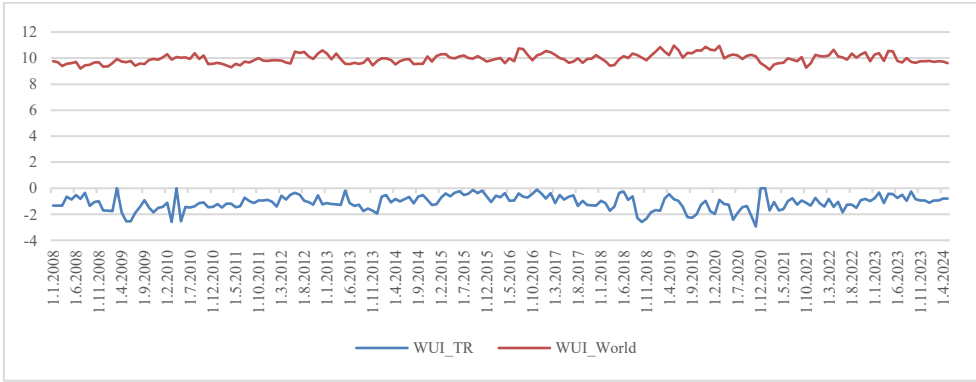
Source: Caldara & Iacoviello, 2022.

Note: GPR_World and GPR_TR represent the global and Türkiye-specific geopolitical risk index, respectively.

Figure 3 shows the change in the world uncertainty index over time and indicates that it has higher values than the Türkiye-specific uncertainty index due to large-scale risks and uncertainties, such as international trade wars, major economic crises, pandemics, and financial volatility. The world uncertainty index reaches its highest level with the declaration of COVID-19 as a pandemic. The Türkiye-specific uncertainty index, on the other hand, reaches its highest value approximately nine months after COVID-19 is declared a pandemic.

All things considered, Figures 1-3 demonstrate that all variables exhibit non-linear patterns over time, with significant shifts aligned with key global events such as the COVID-19 pandemic and the Russia-Ukraine war. These findings align with the literature, which highlights that during times of increased global tensions, variables associated with geopolitical risk, uncertainty, and investor attention are especially vulnerable to abrupt regime changes (He, 2023; Hodula et al., 2024: 1).

Figure: 3
Change in the World Uncertainty Index Over Time



Source: World Uncertainty Index, 2024.

Note: WUI_World and WUI_TR stand for the global and Türkiye-specific world uncertainty index, respectively.

3.2. Methodology

The interaction between the Geopolitical Risk Index and investor attention is analysed using the connectedness framework proposed by Diebold & Yılmaz (2012). This methodology enables the assessment of both the individual influence of a specific variable and the overall dynamics within the system. The analysis is based on a covariance-stationary N-variable VAR(p) model, which is formulated as follows:

$$x_t = \sum_{i=1}^p Q_i x_{t-i} + \varepsilon_t \quad (1)$$

Where x_t is a vector of n endogenous variables, including investor attention, geopolitical risk index and other control variables, the time index, t , ranges from 1 to T . p denotes the number of lags. Q_i is the $N \times N$ parameter matrix with $i=1, \dots, p$ and, is the normally distributed error term matrix. The moving average form, $x_t = \sum_{i=1}^{\infty} A_i \varepsilon_{t-i}$, is used to obtain the dynamic structure in the VAR system. The $N \times N$ coefficient matrix A_i is consistent with the recursion $A_i = \sum Q_j A_{i-j}$, $j=1, 2, \dots, p$ where A_0 is an $N \times N$ identity matrix and $A_i = 0$ for $i < 0$. Moving-average coefficients represent the dynamic process required to determine the study's diffusion indices.

In the VAR model, x_t is a vector of n endogenous variables, including investor attention, the geopolitical risk index, and control variables, observed over $t=1, \dots, T$. The model includes p lags, with Q_i denoting the $N \times N$ parameter matrices and ε_t representing normally distributed error terms. The moving average form, $x_t = \sum_{i=1}^{\infty} A_i \varepsilon_{t-i}$ captures the system's dynamics, where A_i matrices follow the recursion $A_i = \sum Q_j A_{i-j}$ with A_0 as the identity matrix and $A_i = 0$ for $i < 0$. These coefficients define the dynamic structure used to compute connectedness measures.

To evaluate how much each variable contributes to the forecast error variance of the others, we employ the H-step Generalised Forecast Error Variance Decomposition (GFEVD), an order-invariant approach introduced by Diebold & Yılmaz (2012: 58-59).

$$q_{ij}^g(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_j)} \quad (2)$$

Here, σ_{jj} is the standard deviation of the i 'th error term, Σ is the error variance-covariance matrix, and e_i is a selection vector with 1 in the i -th position. The term $q_{ij}^g(H)$ quantifies the contribution of variable j to the forecast error variance of variable i , capturing the directional impact from j to i . These contributions are normalised in each estimation to ensure comparability.

$$\tilde{\theta}_{ij}^g(H) = \frac{\theta_{ij}^g(H)}{\sum_{j=1}^N \theta_{ij}^g(H)} \quad (3)$$

The analysis begins by estimating the VAR model with an optimal lag length. Based on this model, the forecast error variance decomposition is computed, forming the foundation for the connectedness measures. From this, total, directional, and net connectedness indices are derived. Identifying whether a variable acts as a net transmitter or receiver of shocks provides insight into the system's dynamics and supports the development of relevant policy implications.

4. Empirical Findings

In this study, Diebold & Yılmaz's (2012) connectedness approach is used to assess connectedness between variables. This approach provides a framework for examining the impact of a single variable and of the entire network. In the study, four models are constructed at both the global and Türkiye levels. First, the impact of global geopolitical risks on the global investor attention is analysed (Hereafter referred to as Model 1). Second, the impact of Türkiye-specific geopolitical risk and uncertainty index on investor attention to renewable energy is examined (hereafter referred to as Model 2). Third, the impact of GPR on investor attention in Türkiye and globally is analysed (hereafter, Model 3). Finally, the impact of WUI on investor attention in Türkiye and globally is analysed (hereafter, Model 4).

4.1. Empirical Results for the Long-Run Dynamics between Variables

We begin by presenting the results of the static model, which captures long-term relations over the full sample period, followed by the dynamic model results, which highlight short-term interactions among the variables. The "TO" row reflects the total influence each variable exerts on the others, whereas the "FROM" column captures the total impact received by each variable from all others. The Total Spillover Index (TSI) represents the average proportion of the variance of forecast errors across all variables that arises from cross-variable spillovers over the entire sample period. Accordingly, the TSI is 14.18% in

Model 1. This implies that 14.18% of the variation in the variances of the geopolitical risk index, uncertainty index, and investor attention globally can be explained by spillover effects. However, the long-run connectedness is 5.48% in Model 2. This rate in the Türkiye-specific model is lower than in the global model. Comparing Model 1 and Model 2, global GPR affects global GSVI by 23.11%, while Türkiye-specific GPR affects Türkiye-specific GSVI by only 2.02%. Besides, in the long run, while the global GSVI is highly affected by global WUI and global GPR at 27.32%, the rate of Türkiye-specific GSVI affected by Türkiye-specific GPR and Türkiye-specific WUI is very low at 2.08%. In Model 2, Türkiye-specific GPR affects other variables the most (7.48%) and is affected by them the most (8.40%). However, global GPR affects the other variables the most (27.19%), and global GSVI is affected by the others the most (27.32%).

Table: 3
Static Connectedness for Model 1 and Model 2

Model 1: Static Model for GPR, WUI, GSVI (on A Global Scale)				
	GSVI World	WUI World	GPR World	FROM
GSVI World	72.68	4.21	23.11	27.32
WUI World	1.39	94.52	4.08	5.48
GPR World	6.43	3.32	90.25	9.75
TO	7.82	7.53	27.19	42.54
Inc. own	80.51	102.05	117.44	TSI: 14.18%
NET	-19.49	2.05	17.44	
Model 2: Static Model for GPR, WUI, GSVI (Türkiye-Specific)				
	GSVI	GPR	WUI	FROM
GSVI	97.62	2.02	0.05	2.08
GPR	4.48	91.60	3.92	8.40
WUI	0.51	5.46	94.03	5.97
TO	4.99	7.48	3.98	16.44
Inc. Own	102.91	99.08	98.01	TSI: 5.48%
NET	2.91	-0.92	-1.99	

Note: GSVI, GSVI World, WUI, WUI World, GPR, GPR World stand for Türkiye-specific investor attention, global investor attention, Türkiye-specific uncertainty index, global uncertainty index, Türkiye-specific geopolitical risk index and global geopolitical risk index, respectively.

The highest connectedness among the variables is observed in Model 3 (compared to the other models), where we use GPR and GSVI for both global and Türkiye-specific cases, at 29%. According to Model 3, Türkiye-specific GSVI is most affected by global GSVI (13.78%); globally, global GPR is the most influential factor on global GSVI (14.63%). Based on both Model 3 and Model 4, the global GSVI is the most significantly influenced by other variables. In particular, in Models 3 and 4, the global GSVI is predominantly influenced by Türkiye-specific GSVI, Türkiye-specific GPR, and global GPR (42.33% in Model 3), as well as Türkiye-specific GSVI, Türkiye-specific WUI, and global WUI (33.33% in Model 4). In the Model 3, global GPR has the greatest impact on the network, at 42.75%. Both the Türkiye-specific WUI and the global WUI have less influence on the network than GSVI, both globally and in Türkiye. Another important point is that the Türkiye-specific GPR has a bigger effect on the Türkiye-specific GSVI than on the global GPR. Moreover, the Türkiye-specific GSVI is affected by other variables by 30.30%, whereas the global GSVI is affected by other variables by 42.33%. The model with WUI (Model 4) has a lower TSI (19.49%) compared to the model with GPR (Model 3).

Table: 4
Static Connectedness for Model 3 and Model 4

Model 3: Static Model for GPR, GSVI for both Global and Türkiye-Specific					
	GSVI	GSVI World	GPR	GPR World	FROM
GSVI	69.70	13.78	9.33	7.20	30.30
GSVI World	6.17	57.67	4.50	14.63	42.33
GPR	2.12	2.39	74.56	20.92	25.44
GPR World	6.17	3.64	8.14	82.06	17.94
TO	31.48	19.80	21.97	42.75	116.01
Inc. own	101.18	77.48	96.53	124.81	TSI: 29%
NET	1.18	-22.52	-3.47	24.81	
Model 4: Static Model for WUI, GSVI for both Global and Türkiye-Specific					
	GSVI	GSVI World	WUI	WUI World	FROM
GSVI	77.53	15.91	4.14	2.41	22.47
GSVI World	26.35	66.67	2.52	4.46	33.33
WUI	4.14	2.32	90.34	3.20	9.66
WUI World	7.66	2.58	2.25	87.51	12.49
TO	38.16	20.81	8.91	10.08	77.95
Inc. Own	115.69	87.47	99.25	97.58	TSI: 19.49%
NET	15.69	-12.53	-0.75	-2.42	

4.2. Empirical Results for the Short-Run Dynamics between Variables

The global model indicates that TSI increases from 14.18% to 26.50% over the short term. Simply put, the rate at which variables influence one another is greater in the short term. Even though the Türkiye-specific model has shown an increase in TSI, TSI remains at relatively low levels. This suggests that the mutual influence of variables in the Türkiye-specific model is significantly lower than in the global model. In both the long and short runs of Model 2, the Türkiye-specific GPR is the variable that most strongly affects and is affected by other factors. Similarly, the global GSVI is the variable most influenced by global WUI and global GPR in both the long and short term in the global model, while global GPR has the greatest impact on global GSVI and global WUI. It is possible to derive the following: Global investor attention is influenced by global geopolitical risks, whereas Türkiye-specific investor attention is more influenced by the shocks within its own system than by geopolitical risks (according to Table 5). One of the differences between the short-run and the long-run is that the impact of the WUI, both globally and for Türkiye, increases in the short-run (almost approaching that of the GPR). Another difference is that while the global GSVI is a net shock receiver in both the short-run and the long-run, the Türkiye-specific GSVI shifts from a net shock transmitter in the long-run to a net shock receiver in the short-run. In other words, in the short term, investor attention to Türkiye serves as a shock receiver responsive to global uncertainty; in the long term, it becomes a shock transmitter influenced by internal dynamics. The stability and multi-sourced nature of global investor attention accounts for this conclusion, as it does not experience a similar shift. This occurs because, globally, investors concurrently incorporate a wide array of news from various countries and sectors into their decisions, indicating that the long-term trends of an individual country are not pivotal for this variable (Mengoli et al., 2025: 752). This framework constrains the influence of country-specific changes on global investor attention, while leading to pronounced and uneven repercussions in other economies, such as Türkiye, amid significant global uncertainty. Consequently, the global attention indicator functions as a receiver of shocks rather than a transmitter of information. Conversely, Türkiye's

investor attention in renewable energy serves as a net shock receiver, responsive to global swings in the short term. In the long term, the sector's structural growth dynamics, policy direction, and the consolidation of local expectations render it a net shock transmitter, generating information flow towards the global attention indicator.

Table: 5
Dynamic Connectedness for Model 1 and Model 2

Model 1: Dynamic Model for GPR, WUI, GSVI (on A Global Scale)				
	GSVI World	WUI World	GPR World	FROM
GSVI World	61.50	18.59	19.91	38.50
WUI World	6.38	77.67	15.95	22.33
GPR World	6.49	12.19	81.32	18.68
TO	12.87	30.78	35.86	79.50
Inc. own	74.37	108.45	117.18	TSI: 26.50%
NET	-25.63	8.45	17.18	
Model 2: Dynamic Model for GPR, WUI, GSVI (Türkiye-Specific)				
	GSVI	GPR	WUI	FROM
GSVI	94.46	3.59	1.96	5.54
GPR	2.80	91.13	6.06	8.87
WUI	1.37	7.00	91.62	8.38
TO	4.18	10.59	8.02	22.79
Inc. Own	98.63	101.73	99.64	TSI: 7.60%
NET	-1.37	1.73	-0.36	

Connectedness increased in both the WUI model (Model 4) and the GPR model (Model 3). The model with WUI has low connectedness in the long run, while it is almost the same connectedness (with a TSI of 42.72%) as the model with GPR in the short run. In the long term, the global GSVI has the most significant impact on Türkiye-specific GSVI, whereas the global GPR has the most significant impact on it in the short term. In contrast, the global GPR has the greatest impact on the global GSVI over the long term, whereas the Türkiye-specific GSVI has the greatest impact over the short term. However, in the model with WUI, both in the short and long run, Türkiye-specific GSVI is most affected by global GSVI, whereas global GSVI is most affected by Türkiye-specific GSVI. The findings show that shock transmission in the renewable energy market occurs through the mutual interaction of investor attention rather than economic uncertainty indicators. The structure in which Türkiye-specific and global investor attention mutually reinforce each other may arise from factors that respond quickly to internal market information flows. Nevertheless, when geopolitical threats arise, investors in Türkiye exhibit heightened sensitivity to global risk indicators, while global investor attention remains influenced by local dynamics. In the long run, the Türkiye-specific GPR has a greater impact on the Türkiye-specific GSVI than the global GPR does. However, in the short run, the global GPR has a greater impact than the Türkiye-specific GPR. Based on Models 3 and 4, Türkiye-specific GSVI is a net shock transmitter, while global GSVI is a net shock receiver.

Table: 6
Dynamic Connectedness for Model 3 and Model 4

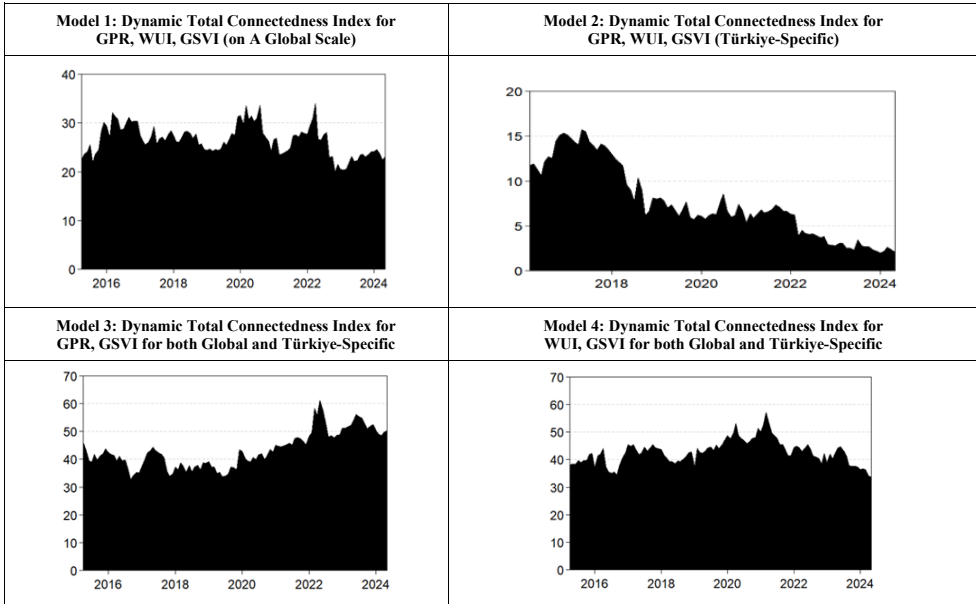
Model 3: Dynamic Model for GPR, GSVI for both Global and Türkiye-Specific					
	GSVI	GSVI World	GPR	GPR World	FROM
GSVI	55.03	15.63	11.06	18.39	44.97
GSVI World	21.38	53.15	10.39	15.08	46.85
GPR	13.15	8.66	62.64	15.55	37.36
GPR World	15.14	53.15	20.74	56.32	43.68
TO	49.66	31.99	42.19	49.02	172.86
Inc. own	104.69	85.14	104.84	105.34	TSI: 43.22%
NET	4.69	-14.86	4.84	5.34	
Model 4: Dynamic Model for WUI, GSVI for both Global and Türkiye-Specific					
	GSVI	GSVI World	WUI	WUI World	FROM
GSVI	56.37	18.49	13.63	11.51	43.63
GSVI World	22.57	50.02	11.11	16.30	49.98
WUI	15.37	7.94	65.92	10.77	34.08
WUI World	16.58	10.29	16.32	56.80	43.20
TO	54.52	36.72	41.07	38.58	170.88
Inc. own	110.88	86.74	106.99	95.38	TSI: 42.72%
NET	10.88	-13.26	6.99	-4.62	

4.3. Dynamic Total Connectedness Index Over Time

In Model 1, during periods of global geopolitical risk (March 2020: COVID-19 declared a pandemic; February 2022: Russia-Ukraine war; October 2023: the Israeli-Palestinian war), connectedness increases. In Model 2, the highest connectedness is observed after 2016. This may be attributed to the 2016 coup attempt in Türkiye. The coup attempt was followed by political uncertainty and regional instability, which had a negative impact on the economy as foreign direct investment (FDI) inflows fell by 30.5% in 2016 (European Commission, 2018: 54). Besides, the declaration of COVID-19 as a pandemic, the Russia-Ukraine war in 2022, and the Israeli-Palestinian war in 2023 show that the connectedness between the variables increases at first, but in general, the connectedness decreases after 2018. In the Model 3, the interaction between the global GPR, global GSVI, Türkiye-specific GPR, and Türkiye-specific GSVI is about 32% after COVID-19, rising to 60% during the Russia-Ukraine war and 55% during the Israeli-Palestinian war in 2023. In Model 4, the responses are similar to those in the GPR model (Model 3). The most significant difference is that, in the Model 3 with GPR, the largest response occurs during the Russia-Ukraine war (around 60%), whereas in the model with WUI, the largest response occurs after COVID-19. This is because the WUI measures uncertainty related to economic policy, market conditions, and global economic trends rather than specifically to geopolitical issues, and the COVID-19 pandemic has caused a worldwide economic recession (World Bank, 2022: 50).

In general, the strongest reaction occurs during the Russia-Ukraine war, with the only exception being Model 2's reaction. Türkiye reacts more to local geopolitical risks, such as the 2016 military coup, than to global risks.

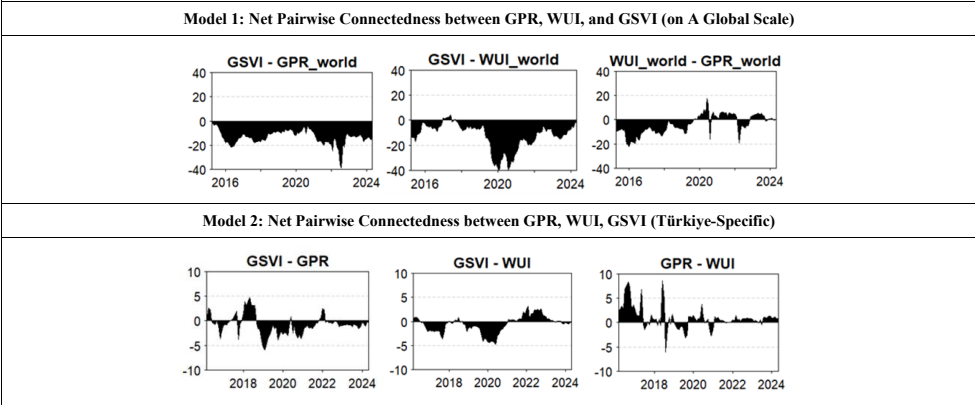
Figure: 4
Dynamic Total Connectedness Index Over Time



4.4. Net Pairwise Directional Connectedness

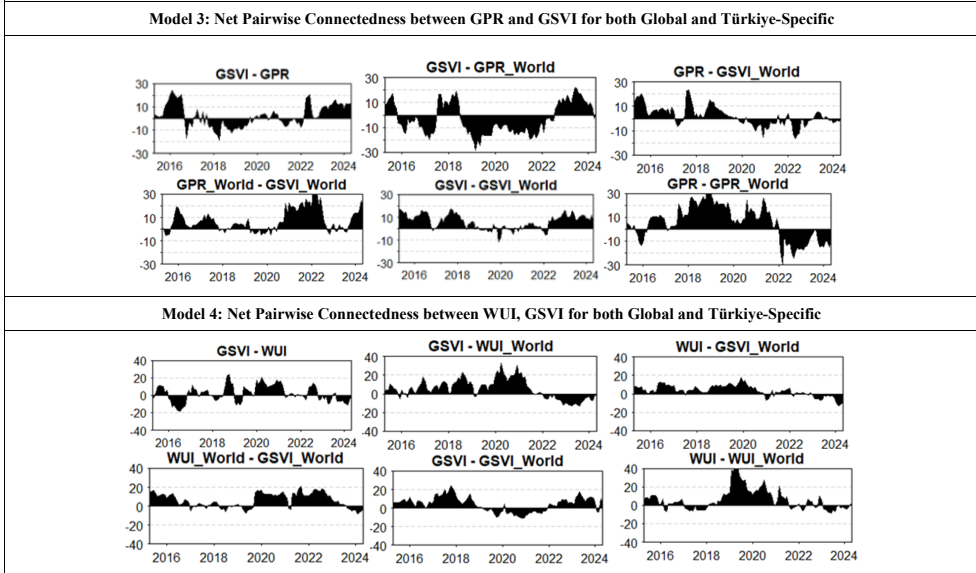
In Model 1, both global geopolitical risk and the world uncertainty index affect global investor attention. On the other hand, in Model 2, geopolitical risk affects investor attention more than investor attention affects geopolitical risk. While the uncertainty index affects investor attention more during the Russia-Ukraine war, investor attention, in turn, affects the uncertainty index during the war. This may be due to the war between Russia and Ukraine destabilising global energy markets, making Türkiye, as an energy importer, susceptible to fluctuations in natural gas and oil prices. Renewable energy has evolved as a strategic hedge against uncertainties and geopolitical threats (Zhao et al., 2024a: 10). Investor attention to renewable energy in Türkiye during wartime may influence the WUI. This is because the energy market has been disrupted, making investors more interested in renewable energy and more aware of energy prices and policy changes. These effects can be seen in the WUI. Consequently, investor attention has emerged as a channel for transmitting external geopolitical shocks to domestic economic instability. Afterwards, its effect gradually decreases (as illustrated in Figure 5).

Figure: 5
Net Pairwise Directional Connectedness for Model 1 and Model 2



Looking at the GSVI-GPR and GSVI-GPR_World graphs (top 2 graphs in the Model 3), the investor attention for Türkiye is more affected by the global GPR (compared to the Türkiye-specific GPR). While Türkiye-specific GSVI do not affect global GPR during the COVID-19 period, they start to affect global GPR more after the Russia-Ukraine war. This may be due to the increased uncertainty caused by the war, which led investors (especially amid the Russia-Ukraine war) to turn to renewable energy, potentially helping ensure Türkiye’s energy security and exerting downward pressure on geopolitical risk. The recent decline in renewable energy costs in Türkiye has also contributed to increased investment. In addition, according to the GSVI-GSVI_World graph, the Türkiye-specific GSVI has a larger impact on the global GSVI. According to Model 4, global WUI has a greater influence on Türkiye-specific WUI. In addition, Türkiye-specific GSVI has a greater effect on the global GSVI, except during the period between the COVID-19 pandemic and the Russia-Ukraine war. Türkiye-specific GSVI affects the WUI (both Türkiye-specific and global) more generally.

Figure: 6
Net Pairwise Directional Connectedness for Model 3 and Model 4



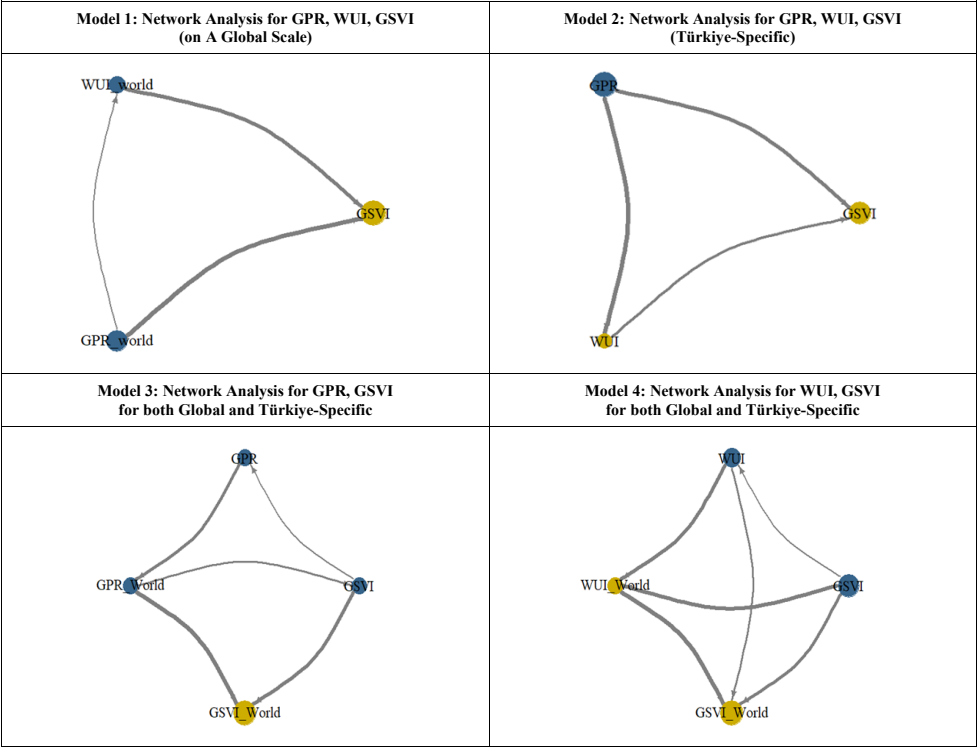
4.5. Network Analysis

Global geopolitical risk and the world uncertainty index are net shock transmitters and affect global investor attention (as shown in Model 1). In the Model 2, both Türkiye-specific GPR and Türkiye-specific WUI affect Türkiye-specific GSVI. Investor attention to renewable energy in Türkiye is more affected by the Türkiye-specific geopolitical risk index than the uncertainty index. While Türkiye-specific GPR is the only shock transmitter in the system, Türkiye-specific GSVI and Türkiye-specific WUI are shock receivers.

Based on the Model 3, global GSVI is a net shock receiver, affected by Türkiye-specific investor attention and global GPR. Global GPR affects Türkiye-specific GSVI, and Türkiye-specific GSVI affects Türkiye-specific GPR, but their connectedness is weak. The strongest connectedness is between global GPR and global GSVI. The results of Model 4 are almost identical to those of Model 3. The two most important differences are that, while Türkiye-specific GPR does not affect global GSVI in Model 3, Türkiye-specific WUI does in Model 4, and that the strongest connectedness is established between global WUI and Türkiye-specific GSVI.

The Global GSVI is a net shock receiver across all models. On the other hand, Türkiye-specific GSVI is a net shock transmitter (except for model 2). The GPR is a net shock transmitter both globally and in the Türkiye-specific case.

Figure: 7
Network Analysis



5. Conclusion

Using Diebold-Yılmaz’s (2012) connectedness approach, we investigate the effects of geopolitical risks and economic uncertainties on the investor attention towards renewable energy at both the global and Turkish levels. To the best of our knowledge, this is the first study to examine the interaction between geopolitical risks and investor attention toward renewable energy.

Our main findings are as follows. First, in both the short and long run, Model 3 has the highest connectedness between variables. In other words, the model that examines the interaction between global GPR, Türkiye-specific GPR, and investor attention for both the global and Türkiye-specific cases shows greater connectedness than the other models. The main reason is the strong interaction between Türkiye-specific GPR and global GPR, as global GPR covers geopolitical risks across all countries. The lower connectedness in the model with WUI (Model 4) is due to WUI focusing more on economic uncertainty, whereas GPR specifically measures risks arising from geopolitical events such as conflicts, wars,

political instability, and diplomatic tensions. In our sample period, there are three main shocks (March 11, 2020: COVID-19 declared as a pandemic, February 24, 2022: Russia-Ukraine War, October 7, 2023: the Israeli-Palestinian war), and except for COVID-19, the other two shocks are more related to increased geopolitical risk rather than economic uncertainty. This is also supported by the fact that the dynamic connectedness index obtained from the model with WUI (Model 4) is the highest in the COVID-19 period. Second, on a global scale, the connectedness between investor attention, the GPR and WUI increases at the time of the three shocks. On the Turkish level, the highest connectedness is observed after 2016. This is because Türkiye reacts more to local geopolitical risks, such as the 2016 military coup, than to global risks. Third, the global GSVI is a net shock receiver in all models. Türkiye-specific GSVI, on the other hand, is a net shock to the transmitter. The only exception is Model 2, which includes Türkiye-specific GPR, WUI, and GSVI. In Model 2, the Türkiye-specific GSVI is a net receiver of shocks. Besides that, GPR is a net shock transmitter on a global and a Turkish scale. Fourth, we have discovered that the global WUI, which assesses uncertainty associated with economic policy, market conditions, and global economic trends, has a greater influence on global investor attention during the COVID-19 pandemic. This is corroborated by Zhao et al. (2024a: 10), who observe that economic uncertainty has a beneficial effect on renewable energy during the initial and subsequent phases of the COVID-19 pandemic. Finally, global investor attention is significantly affected by uncertainties (both economic and geopolitical) in the short and long term. However, Türkiye-specific investor attention is more directly influenced by the shocks within its own system than by uncertainties.

These findings carry several important policy implications. Given that GPR amplifies awareness of catastrophic outcomes, diminishes the appeal of investments in risky projects, and undermines consumer confidence, with 75% of investors expressing concern about GPR (Caldara & Iacoviello, 2022), it is crucial to investigate the connection between investor attention and GPR. Consequently, authorities must regulate excessive market responses by transparently and consistently controlling information dissemination during periods of uncertainty, while incorporating the GPR-attention relationship into financial stability evaluations. Given Türkiye's heavy dependence on energy imports and its vulnerability to geopolitical disruptions, there is a pressing need to strengthen domestic energy security. Policymakers should continue to support renewable energy investments in line with the 2017 National Energy Policy to reduce exposure to external risks. Second, since Türkiye-specific investor attention is more responsive to domestic than global risks, national policies should be adapted to address local concerns and maintain investor trust during periods of internal political or economic instability. Finally, measures like GSVI can serve as real-time indicators of investor attention. Integrating such data into energy policy planning and market monitoring could enhance responsiveness to emerging risks and opportunities. Future studies may investigate shock reactions more comprehensively by employing models that accommodate time-varying dynamics, such as TVP-VAR, given the constraints of the monthly data set utilised in this study, which inadequately represents high-frequency shocks. Moreover, constructing a composite index utilising Natural Language Processing (NLP)

methods with keywords segmented into categories such as wind, solar, and geothermal, rather than the broad term "renewable energy", could yield a more nuanced understanding of investor behaviour in relation to GPR.

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Do Sustainability Index Inclusions Impact Audit Fees? Insights from the Turkish Capital Market

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Sürdürülebilirlik Endeksine Dahil Olmak Denetim Ücretlerini Etkiler Mi? Türk Sermaye Piyasasından Bulgular

Abstract

Sustainability influences corporate strategy and finance, with indices like the BIST Sustainability Index encouraging responsible investment. This study investigates whether inclusion in the BIST 50 Index affects audit fees for firms from 2020 to 2024, using panel data analysis. The results show that the inclusion of the sustainability index does not significantly affect audit fees. However, firm age, total assets, and group affiliation positively affect audit fees, while financial leverage has a negative effect. These findings offer insights into how sustainability performance relates to audit fees in an emerging market context, contributing to the broader literature on corporate sustainability and financial outcomes.

Keywords : Stock Market, Financial Ratios, Sustainability Index, Audit Fees, Non-Bank Financial Institutions.

JEL Classification Codes : G10, G23, G32, M40.

Öz

Sürdürülebilirlik, kurumsal stratejiyi ve finansal kararları etkilemekte; BIST Sürdürülebilirlik Endeksi gibi endeksler ise sorumlu yatırımları teşvik etmektedir. Çalışma, 2020-2024 yılları arasında BIST 50 Endeksi'nde yer alan şirketler için sürdürülebilirlik endeksine dahil olmanın denetim ücretlerini etkileyip etkilemediğini panel veri analiziyle incelemektedir. Sonuçlar, sürdürülebilirlik endeksine dahil olmanın denetim ücretleri üzerinde anlamlı bir etkisi olmadığını göstermektedir. Ancak firma yaşı, toplam varlıklar ve grup bağlantısı denetim ücretlerini olumlu yönde etkilerken, finansal kaldıraç olumsuz etki yaratmaktadır. Bulgular, sürdürülebilirlik performansının denetim ücretleriyle nasıl ilişkilendirildiğine dair gelişmekte olan bir piyasa bağlamında önemli içgörüler sunmakta ve kurumsal sürdürülebilirlik ile finansal sonuçlara ilişkin literatüre katkı sağlamaktadır.

Anahtar Sözcükler : Hisse Senedi Piyasası, Finansal Oranlar, Sürdürülebilirlik Endeksi, Denetim Ücretleri, Banka Dışı Finansal Kurumlar.

1. Introduction

Sustainability is generally regarded as a concept encompassing social equity, environmental protection, and economic development, aiming to ensure responsible resource consumption for future generations, promote environmentally and socially conscious living conditions, and establish a more efficient economic system. From a corporate perspective, sustainability involves aligning financial, environmental, social, and ethical considerations with corporate culture, ensuring that a long-term sustainable mindset becomes an integral part of the organisational structure. As the growing significance and urgency of sustainability issues have compelled firms to take appropriate action, a series of studies has begun to examine the relationship between sustainability and audit fees. For instance, studies (Rabarison et al., 2024; Wu et al., 2023; Xin et al., 2022; Aprianti et al., 2021; Kim & Jung, 2020; Kim et al., 2019) found that sustainability matters like corporate social responsibility (CSR), sustainability disclosure, environmental administrative penalties and green innovations significantly influence audit fees.

Al-Shaer (2020) studied the relationship between sustainability reporting and audit fees. Hou et al. (2022) showed the impact of environmental, social, and governance (ESG) performance on audit fees. Cahyaningati et al. (2022) investigated the relationship between CSR and audit costs.

Undoubtedly, the evolution of sustainability practices has a direct impact on financial markets. At this stage, stock exchanges feel compelled to introduce innovations to meet investors' needs. Among the most notable of these innovations are sustainability indices, introduced by various stock markets worldwide. These indices encourage responsible investment and serve as a platform connecting companies that prioritise sustainability with investors seeking such opportunities.

Borsa Istanbul A.Ş. (BIST) holds a significant position among global stock exchanges as a securities market that offers its investors a sustainability index (SI) service. Due to the limited availability of ESG data in Türkiye, this study uses the SI as a proxy for firms' sustainability performance. The index serves as a market-recognised benchmark, helping investors identify sustainable firms. Given the limited empirical research on ESG and audit fees in emerging markets, this paper investigates the impact of sustainability performance on audit fees of BIST 50 non-financial firms in Türkiye between 2020 and 2024 through panel data analysis. The necessary data were obtained through an extensive literature review and by analysing changes in audit fees of the firms included in the index.

As discussed above in the related literature, prior research (Wu et al., 2023; Cahyaningati et al., 2022) has primarily focused on the influence of sustainability and environmental factors, such as green policy implementation, sustainability products, environmental regulations, and climate-related risks, on audit practices. This study broadens the scope by investigating whether a company's listing on the sustainability index affects its audit fees. According to Al Ani et al. (2024: 658), sustainability practices may present new

opportunities for companies to pursue sustainable growth, as many seek to achieve their sustainability objectives by addressing sustainability issues that may directly influence their operations and financial standing. Moreover, the financial impact of such a thing affects the scope of audit services provided and, consequently, the fees paid to auditors. In this context, this study centres on BIST 50 non-financial firms in Türkiye from 2020 to 2024, exploring the impact of sustainability performance on their audit fees through panel data analysis. The study aims to fill the following gaps in the literature and offer the contributions outlined below:

- While prior studies (Xue & O'Sullivan, 2023; Al-Shaer, 2020) have extensively examined the relationship between sustainability practices and audit fees in developed markets, there is limited research (Cengiz & Öksüz, 2023) focusing on emerging economies such as Türkiye. The Turkish capital market, characterised by its emerging-market status, lower investor protection, and evolving corporate governance structures, offers a distinct environment in which the implications of sustainability-related disclosures and index inclusion may differ from those observed in more mature economies. By focusing on this underexplored context, our study contributes new insights to the growing body of literature on sustainability and assurance services.
- The impact of recent regulatory changes, such as the implementation of Türkiye Sustainability Reporting Standards (TSRS) in 2024, on audit fees remains underexplored. The relatively recent introduction of the TSRS represents a significant regulatory shift aimed at aligning corporate sustainability practices with international standards. This regulatory evolution creates a timely and relevant setting for investigating how market participants, including auditors, respond to sustainability-driven corporate changes. This study examines whether these regulations have altered audit cost structures for sustainability-focused firms.
- Previous research presents mixed findings regarding the impact of sustainability practices on audit fees; some studies find positive effects, like Sun et al. (2020) and Lobo et al. (2018), while others report negative effects, such as Al Ani et al. (2024) and Wu et al. (2023) or insignificant (Cahyaningati et al., 2022) impacts. This study provides empirical evidence that the inclusion of sustainability indices does not increase audit fees, offering a new perspective on the ongoing debate.
- Although factors such as firm age, total assets, and group affiliation have been studied in various contexts, their role in the sustainability-audit fee nexus is not well understood. This study explores these determinants within the framework of sustainability performance.
- While prior research (Xue & O'Sullivan, 2023; Ahmed & Goyal, 2005) suggests that Big Four auditors may charge higher fees due to additional sustainability-related risks, this study finds no significant relationship between Big Four audit firms and audit fees in the context of the SI.

2. Literature Review and Hypothesis Development

2.1. Determinants of Audit Fees

There are numerous studies in the literature that examine the determinants of audit fees by focusing on a single country or market (Saleh & Ragab, 2023; Ardianingsih & Setiawan, 2022; Cunha Silva et al., 2020; ElGammal & Gharzeddine, 2020; Gah, 2020; Owusu & Amoah Bekoe, 2019; Rewczuk & Modzelewski, 2019; Musah, 2017; Afesha, 2016; De Lima Castro et al., 2015; Kikhia, 2014; Amba & Al-Hajeri, 2013; Thinggaard & Kiertzner, 2008; Leventis et al., 2005; Ho & Ng, 1996; Low et al., 1990). However, studies specifically focusing on Türkiye and Borsa Istanbul are relatively scarce (Cengiz & Öksüz, 2023). This is primarily because audit fees were not disclosed in the financial statement footnotes until 2021. Since no official data on audit fees in Türkiye were available in previous years, academic studies on this subject were not feasible.

Audit fee refers to the remuneration earned by auditors for providing professional services (Ye, 2020: 250). Auditors and their teams are entitled to this fee as compensation for their efforts during the contract period. The primary basis for determining the fee is the estimated workload and the time required to complete the audit. However, assessing this workload is not straightforward. Numerous studies have been conducted since the 1980s to establish methods for determining audit fees. A summary of these studies is presented in Table 1.

Table: 1
Summary of Studies Regarding Audit Fees

Author	Sample	Explanatory Variables	Findings
Simunic (1990)	367 U.S. companies (1977 data)	Firm size (total assets), number of subsidiaries, number of industries operated in, receivables-inventory ratio, profit/loss status, auditor tenure, and whether the auditor is a Big Eight firm.	Audit fees are positively correlated with firm size, complexity, the magnitude of receivables and inventories, and whether the auditor is a Big Eight firm, and negatively correlated with auditor tenure.
Low et al. (1990)	291 publicly listed companies on the Singapore Stock Exchange (1986 data)	Company size, accounts receivable to total assets ratio, inventory to total assets ratio, losses in the last three years, presence of contingent liabilities, long-term debt to total funds ratio, current ratio, and qualified opinion in the auditor's report.	The most significant determinant of audit fees is company size. The number of industries (complexity) and inventory ratios are meaningful in specific sectors. Accounts receivable ratio, loss history, and contingent liabilities are significant in certain industries. The impact of contingent opinions in the auditor's report is generally weak. In industry-based analyses, the model's explanatory power has increased, and the importance of variables varies across sectors.
Ho and Ng (1996)	Companies listed on the Hong Kong Stock Exchange: 313 companies (1992) and 396 companies (1993)	Total assets, revenue, debt ratio, liquidity ratio, profitability, number of subsidiaries, auditor size, auditor change, fiscal year-end period, and audit delay.	Audit fees were most influenced by company size (total assets and revenue), operational complexity (number of subsidiaries), and audit timing (fiscal year-end and audit delay). A positive and significant relationship was found between auditor size and audit fees. Debt ratio and liquidity variables were significant in specific periods. Auditor change showed a negative relationship, supporting lower fees in the first year.

Ahmed and Goyal (2005)	566 companies: 118 from Bangladesh, 219 from India, and 229 from Pakistan (1998 data)	Company size, multinational company affiliation, financial condition, operational complexity, and auditor size.	Audit fees were most influenced by company size, multinational company affiliation, and auditor size. Big 4 auditors demand higher fees. The financial condition variable was significant only for Pakistan. The operational complexity variable was not found to be significant. Companies in India paid higher audit fees compared to those in Bangladesh and Pakistan.
Naser and Hassan (2013)	22 non-financial companies, Dubai Financial Market (2011 data)	Company size, profitability, financial risk, company complexity, industry type, auditor size, audit report delay, and audit committee independence.	Audit fees showed a positive and significant relationship with company size and audit committee independence. A significant negative relationship was found between company complexity (COMP) and audit fees. Financial risk, profitability, industry type, auditor status, and audit report delay variables were not found to be significant.
Xue and O'Sullivan (2023)	453 companies, UK Alternative Investment Market (2016 data)	Accounts receivable to total assets ratio, inventory to total assets ratio, subsidiary presence in the US, return on assets ratio, leverage ratio, liquidity ratio, listing duration, and non-revenue generating status. Independent board members ratio, audit committee disclosure, audit committee size, presence of executive members in audit committee, financial expertise of audit committee members, auditor size, previous year's audit fee, company size, number of subsidiaries, non-audit services provided by the auditor, auditor's London-based location, intensive audit period, and auditor change.	Audit fees are negatively and significantly related to the company's liquidity ratio and listing duration. The proportion of independent board members increases audit fees. Audit committee disclosures are associated with higher audit fees. Big 4 auditors demand a 4.6% premium on audit fees. Company size and the presence of non-audit services positively and significantly influence audit fees. Among the control variables, the previous year's audit fee is identified as one of the strongest determinants.
Cengiz and Öksüz (2023)	98 manufacturing sector companies in BIST-100 (2020-2022 period)	Auditor size, type of audit opinion, duration of the relationship between the auditing firm and the audited company, return on assets, asset size, and financial leverage ratio.	A positive and significant relationship was found between the size of the auditing firm and audit fees. A negative and significant relationship was identified between the duration of the relationship between the auditing firm and the company and audit fees. No significant relationship was found between the type of audit opinion and audit fees. The return on assets and asset size positively and significantly influence audit fees, while the financial leverage ratio shows a negative and significant relationship.
Hidayat et al. (2024)	Manufacturing companies listed on the Indonesia Stock Exchange (2018-2021 period)	Company complexity, company size, independent commission, and audit quality.	According to the partial test results, with audit costs as the dependent variable, audit complexity has a positive effect on audit quality, whereas company size and independent commission members do not affect it. Furthermore, company complexity and audit quality positively affect audit fees. Company size and independent commission members did not influence audit fees. Company complexity affected audit costs using audit quality as a mediating variable, indicating that the type of mediation is complementary.

2.2. Sustainability and Audit Fees

Sustainability has become increasingly prominent on firms' agendas and is also affecting stakeholders. As this interaction intensifies, a series of studies have begun to examine the impact of sustainability and social and environmental performance on audit fees. Drawing on previous studies on voluntary assurance and sustainability reports, as well as audit fees, both domestically and internationally, Zhao (2017) selected a set of alternative data reflecting the current state of voluntary assurance for sustainability reports among Australian-listed companies. Based on the data, a comprehensive review was conducted to examine whether the voluntary assurance of sustainability reports affects auditors' audit fees. Finally, the author found that voluntary assurance of sustainability reporting affects audit fees.

Al-Shaer (2020) explores the relationship between high-quality sustainability reporting and earnings management, investigating whether firms with better sustainability reports engage in less earnings manipulation, thereby producing more transparent and reliable financial information. The study also examines whether the impact of sustainability reporting quality on post-audit financial reporting depends on audit effort. Using data from FTSE 350 companies between 2007 and 2018, the study finds a significant negative relationship between high-quality sustainability reports and earnings management. Importantly, this relationship is influenced by audit effort, as measured by audit fees, suggesting that auditors consider the quality of sustainability reporting in their risk assessments. The results remain consistent after sensitivity tests. The study concludes that firms investing in high-quality sustainability reports demonstrate a broader commitment to quality, reducing auditors' concerns about opportunistic behaviour and, consequently, lowering audit effort.

Cahyaningati et al. (2022) investigated the impact of CSR and good corporate governance (GCG) on audit costs and firm value, focusing on whether audit costs mediate the relationship between CSR and firm value. Data was collected from Indonesian companies listed on the Corporate Governance Perception Index between 2016 and 2018. The findings show that CSR does not affect audit costs or firm value, while GCG increases audit fees but negatively impacts firm value. Audit fees do not mediate the relationship between CSR, GCG, and firm value. Xin et al. (2022) investigated the impact of environmental administrative penalties on audit fees, focusing on heterogeneity effects and underlying mechanisms. Using data from heavily polluting listed firms in China, they found that environmental administrative penalties lead to higher audit fees. In another study, the relationship between ESG performance and audit fees for A-share listed companies in Shanghai and Shenzhen from 2011 to 2020 is examined (Hou et al., 2022). Using a two-way fixed-effects model, the paper finds a strong negative association between better ESG performance and lower audit fees. The negative effect is more significant for non-state-owned firms and those audited by Big Four accounting firms. The findings enrich the understanding of ESG performance's impact on firms and expand research on the factors influencing audit fees.

Wu et al. (2023) explore the impact of diversity in green innovation on audit fees, using a sample of 4,901 listed Chinese firms from 2010 to 2021. The findings indicate that greater diversity in green innovation is associated with lower external audit fees. This relationship is driven by enhanced information transparency and improved corporate environmental performance. A heterogeneity analysis reveals that the effect of green innovation on audit fees is stronger in smaller firms, those receiving higher government subsidies, and firms in greener industries. Yang et al. (2023) investigated the impact of firms' climate-related risks on audit fees. Using indicators of physical and transition climate risks, the findings reveal that climate-related risks significantly increase audit fees.

Kammoun and Khoufi (2023) investigate how engagement in sustainable practices moderates the relationship between conditional conservatism and audit fees. Using a sample

of 3,767 firm-year observations from 14 EU countries (2006-2019), the authors conduct a panel data analysis using ordinary least squares to examine the effect of conditional conservatism on audit fees and the moderating role of ESG scores. The findings show that conditional conservatism reduces audit fees, meaning auditors charge lower fees to more conservative clients. However, firms that engage in ESG actions, either individually or in combination, pay higher audit fees. The negative relationship between conditional conservatism and audit fees is weakened only when ESG performance is included, suggesting that firms less committed to ESG sustainability practices may pay lower audit fees when adopting more conservative reporting. In their study, Suryandari and Saripah (2023) aim to provide empirical evidence on how audit committees, firm complexity, and profitability influence audit fees, with firm size moderating these effects. The study population comprises manufacturing companies listed on the Indonesia Stock Exchange between 2019 and 2021. The results show that audit committees have a significant negative effect on audit fees, whereas company complexity and profitability do not affect them. Additionally, firm size weakens the influence of audit committees on audit fees but does not moderate the effect of company complexity and profitability on audit fees. Al Ani et al. (2024) investigate whether firms with high sustainability products pay higher audit fees. Using data from 261 European firms (2010-2019), the study finds that high sustainability products are positively associated with audit fees. The presence of a sustainability committee moderates this relationship, such that environmental and eco-design products are negatively associated with audit fees.

It is thought that investing in sustainable practices may offer companies new opportunities to achieve better results. The financial and non-financial effects of such results may expand the scope of audit services and audit fees. Therefore, H1 was developed as follows:

Hypothesis 1 (H1): Listing in the sustainability index will lead to an increase in audit fees.

3. Data & Methodology

3.1. Data and Sample

This paper focuses on publicly listed companies in the BIST 50 index between fiscal years 2020 and 2024. The BIST 50 Index is selected because the firms included in this index provide more consistent and accessible data regarding sustainability practices and publicly disclosed audit fees. BIST 50 companies generally exhibit stronger corporate governance structures and sustainability strategies and attract greater attention from the public and investors. Moreover, because disclosure of audit fees in Türkiye became mandatory only in 2021, focusing on the BIST 50 ensures greater data reliability and enhances the study's statistical validity by avoiding potential data gaps that would arise with a broader sample. Among these 50 firms, we selected only non-financial firms listed in the SI. We excluded 9 firms due to missing data, outliers, and their operations in the finance industry. After

excluding 9 firms, our sample comprises 41 firms (82% of the initial sample) and 115 firm-year observations. Table 2 provides an overview of the sample utilised in this study.

We collected financial data from the Public Disclosure Platform (PDP) database. PDP is an electronic platform that facilitates the public disclosure of electronically signed statements mandated by capital market regulations and Borsa Istanbul rules. We also utilised the firms' own websites for their financials. Additionally, we used Stata 14.0 to estimate a panel data model in the study.

Table: 2
Sample by Firms and Industry

Industry	Number	%
Holding and Investment Companies	8	19,51
Chemicals, Petroleum, Rubber and Plastic Products	5	12,20
Transportation And Storage	2	4,88
Electricity, Gas, and Water	3	7,32
Wholesale and Retail Trade	4	9,76
Telecommunication	2	4,88
Food, Beverage and Tobacco	3	7,32
Basic Metal	3	7,32
Fabricated Metal Products, Machinery, Electrical Equipment, and Transportation Vehicles	5	12,20
Other	6	14,63
Total	41	100

3.2. Variables

3.2.1. Dependent Variable

To examine the impact of being listed in a sustainability index on audit fees, the study refers to the existing literature to select AF (Al Ani et al., 2024; Wu et al., 2023; Cahyaningati et al., 2022; Hou et al., 2022; Al-Shaer, 2020) as the dependent variable. The fees consist of three components: audit and assurance fees, tax consulting fees, and other assurance services fees, received from independent audit firms by year. The fees have been included in the fees of all subsidiaries and joint ventures. The dependent variable was measured by the natural logarithm of the total amount of audit fees paid by the firms in the current year.

3.2.2. Independent Variable

The sustainability performance of firms was measured by their listing in the SI during the research period. Given that sustainability practices are linked to sustainability performance and play a significant role in firms' sustainability outcomes, this article denotes listing in the sustainability index as "SUST" in the research model.

3.2.3. Control Variables

The paper controlled five firm-specific variables in accordance with previous studies (Al Ani et al., 2024; Kammoun & Khoufi, 2023; Xin et al., 2022). Since prior literature suggests that firm size, measured as the natural logarithm of total assets, influences audit fees (Januarti & Wiryaningrum, 2018; Huguet & Gandia, 2016), we included the variable

TA in the research model. Additionally, we controlled for the materiality of the audit firm (Wu et al., 2023; Cabal-García et al., 2019), represented by the BIG4. To reflect financial stability, we introduced financial leverage (LEV), defined as the ratio of total liabilities to total assets (Rabarison et al., 2024; Kim et al., 2012), and firm age (AGE), measured as the natural logarithm of the number of years since the firm's establishment. The complexity of firms was represented by GROUP, measured as the natural logarithm of the number of subsidiaries owned by the firm (Musa et al., 2021; Silva et al., 2020). Table 3 provides detailed definitions of all variables used in the study.

Table: 3
Definition of Variables

Variable	Code	Description
Audit Fees	AF	Natural logarithm of the total amount of audit fees
Sustainability Performance	SUST	Dummy score of "1" if a firm is listed in the sustainability index, "0" if otherwise
Firm Size	TA	Natural logarithm of total assets
Age of the firm	AGE	Natural logarithm of the number of years since establishment
Complexity	GROUP	Natural logarithm of the number of subsidiaries
Financial Leverage	LEV	Total liabilities/assets
Materiality of the Auditor	BIG4	Dummy score of "1" if the auditor is BIG-4 and "0" if otherwise

3.3. Model Specification

This study employs SUST as the independent variable and AF as the dependent variable to examine the relationship between sustainability performance and audit fees using a panel data model. Given that the analysis includes time series (T) data for a large set of firms, panel data analysis was selected as the appropriate econometric method, as it integrates both cross-sectional (N) and time-series dimensions. Typically, in such analyses, the number of cross-sectional units exceeds the number of time periods, resulting in a structure where $N > T$ (Tatoğlu, 2016: 4).

In panel data models, omitted variables may be correlated with the independent variables, resulting in biased and inconsistent parameter estimates. This issue is known as the problem of endogeneity. Panel data techniques help mitigate this issue by controlling for unobserved heterogeneity, particularly time-invariant omitted variables, thereby reducing estimation bias. Accurately identifying the source of endogeneity is crucial for obtaining consistent estimators. To address potential endogeneity concerns, this study adopts a panel data approach, following the recommendations of Al Ani et al. (2024) and Wu et al. (2023). Specifically, to investigate the impact of sustainability performance on external audit fees, the following regression specification is employed:

$$AF_{it} = \alpha_0 + \alpha_1 SUST_{it} + \alpha_2 Control_{it} + u_i + \vartheta_i + \varepsilon_{it} \tag{1}$$

In Eq. (1), AF_{it} represents external audit fees of firm i in year t . $SUST_{it}$ denotes listing in the sustainability index for firm i in year t . The variable $Control_{it}$ accounts for firm-specific characteristics of firm i in year t . To mitigate the risk of omitting non-time-varying unobservable factors and to prevent bias caused by time trends, the study incorporates firm fixed effects (u_i) and year fixed effects (ϑ_i). The error term is denoted by ε_{it} . Furthermore,

to address autocorrelation, heteroskedasticity and cross-sectional dependence, the study applies firm-level clustered robust standard errors to ensure reliable statistical inference. The firm-level clustering (clustered standard errors at the firm level) method effectively addresses autocorrelation and heteroskedasticity within observations of the same firm over time, and minimises the effects of cross-sectional dependence between firms. This approach was found to be more appropriate given the structure of the panel dataset and the study's objectives. Additionally, using robust standard errors clustered at the firm level enhances the consistency and reliability of the model's parameter estimates, thereby strengthening the interpretation of the results.

At the beginning of the analysis, the study employs the F-test and the Hausman test to determine the appropriate model among the classical, fixed-effects, and random-effects specifications. Subsequently, various specification tests are performed to detect potential issues commonly encountered in panel regression models, such as heteroskedasticity, autocorrelation, and cross-sectional dependency. To assess heteroskedasticity, the study applies the Levene (1960) and Brown and Forsythe (1974) tests. For autocorrelation detection, it utilises the Durbin-Watson (DW) test (Bhargava et al., 1982), the Locally Best Invariant (LBI) test (Baltagi & Wu, 1999), and the Lagrange Multiplier (LM) test (Breusch & Pagan, 1980). To determine cross-sectional dependency, the paper applies the Frees (1995) test. The findings from the heteroskedasticity, autocorrelation and cross-sectional dependency tests are summarised in Table 5.

4. Results

4.1. Descriptive Statistics

Table 4 presents the number of observations (Obs.), mean, standard deviation (Std. Dev.), minimum and maximum values for all variables used in the analysis. AF refers to the log-transformed annual audit fees. SUST is a dummy variable indicating whether a firm is listed in the sustainability index. For variable definitions, see Table 3.

Table: 4
Descriptive Statistics of Key Variables

Variable	Obs.	Mean	Std. Dev.	Min	Max
AF	115	8.99	2.25	5.28	17.33
SUST	115	0.79	0.41	0	1
TA	115	18.43	1.46	15.20	22.14
AGE	115	3.76	0.54	2.19	4.51
GROUP	115	2.60	1.36	0	5.56
LEV	115	0.61	0.17	0.19	1
BIG4	115	0.95	0.22	0	1

The mean value of SUST is 0.79, with a standard deviation of 0.41, indicating that the overall level of sustainability performance among BIST 50 firms is relatively high, but it varies significantly across firms. Regarding AF, the minimum and maximum values are 5.28 and 17.33, respectively, with a standard deviation of 2.25, indicating considerable variation in audit fees across firms.

4.2. Testing of Fundamental Assumptions

Assessing the validity of the classical model specifically, determining whether unit and/or time effects are present, can be accomplished using the F-test in panel data models. This test primarily examines whether there is significant variation in the data across different units. If no substantial differences are detected among units, the classical model is considered appropriate. In the F-test, the null hypothesis ($H_0: \mu_i = 0$) assumes that all unit effects are equal to zero, meaning that individual-specific effects do not significantly influence the model. Therefore, in this study, the F-test was initially performed to decide whether the classical model or an alternative specification, such as the fixed-effects or random-effects model, would be more suitable. Following this, the Hausman test was applied to distinguish between the fixed-effects and random-effects models. We tested our main hypothesis using the empirical model. Table 5 reports the results of key specification tests for model selection, including the F-test, Breusch-Pagan LM test, and Hausman test. It also includes diagnostic tests for heteroskedasticity (Levene, Brown-Forsythe), autocorrelation (Durbin-Watson, Baltagi-Wu, LM), and cross-sectional dependence (Frees test). The results are presented using a 5% level of statistical significance.

Table: 5
Test Results for Panel Data Assumptions

		Model AF
F-test	Prob > F	0.0000
Breusch and Pagan LM test	Prob>chi2	0.0000
Hausman test	Prob>chi2	0.0802
Levene, Brown and Forsythe test for Heteroskedasticity	W0	0.0260
	W50	0.0367
	W10	0.0260
	Durbin-Watson	1.6007
Autocorrelation tests	Baltagi-Wu LBI	2.0565
	ALM	0.0055
	LM	0.0000
Cross-sectional independence	Frees' test	1.074
	Critical value from Frees'	0.6860

Based on the results presented in Table 5, the null hypothesis (H_0) that all unit effects are equal to zero is rejected for the research model, suggesting the presence of significant unit-specific effects. This implies that the classical model should not be used, as it does not account for these variations. The F-test value is calculated as 0.0000.

Breusch and Pagan developed the LM test, which is based on the residuals of the classical model, to assess whether the classical model is appropriate compared to the random-effects model (Tatoğlu, 2016: 178). This test evaluates the null hypothesis ($H_0: \sigma_\mu^2 = 0$), which states that the variance of the random unit effects is zero. If the null hypothesis is rejected, it indicates that the classical model is unsuitable because significant unit-specific effects are present. According to the results, the null hypothesis is rejected, indicating that the variance of unit effects is significantly nonzero. This confirms the presence of unit effects, leading to the conclusion that the classical estimator is not

appropriate for the research model. Consequently, the baseline regression is estimated using the random-effects model.

As a result of the tests conducted, if unit and/or time effects are detected, it becomes necessary to determine whether they are fixed or random. In this study, the Hausman test was applied to distinguish between these two estimators. The Hausman test evaluates the null hypothesis that the random-effects model is appropriate against the alternative that the fixed-effects model is preferable. Based on the test results, the Hausman statistic for the research model was 0.0802 at the 5% confidence level. Since the null hypothesis could not be rejected, the random-effects estimator is appropriate. Therefore, the research model was estimated using the random-effects estimator.

To test for heteroskedasticity, this study applied the Levene (1960) and Brown and Forsythe (1974) tests. The null hypothesis (H_0), which states "the variances of the units are equal", is rejected for the research model, indicating that there is heteroskedasticity in the model. When the autocorrelation results are examined, the basic hypothesis of "there is no autocorrelation" is rejected, and it is concluded that autocorrelation exists. One of the fundamental assumptions in panel data models is that the error terms are independent across units. However, errors often exhibit contemporaneous correlation across cross-sectional units. This phenomenon prevents the correlation matrix from being a unit matrix. Therefore, the assumption of no cross-sectional correlation should be tested. In this study, the Frees (1995) test was used to assess cross-sectional dependence. Since Frees' test statistic is greater than the critical value ($1.074 > 0.6860$), the null hypothesis (H_0) is rejected, indicating the presence of cross-sectional dependence among units.

Multicollinearity refers to the situation in which two or more predictor variables exhibit a high degree of linear relationship with one another. Even if no pair of variables has an exceptionally high correlation, it is still possible for a linear relationship to exist among three or more variables. This phenomenon is called multicollinearity. It occurs when the explanatory variables influence not only the dependent variable but also each other. The magnitude of this effect can reduce the explanatory variables' predictive power in the model. A better way to assess multicollinearity is by calculating the variance inflation factor (VIF). In practice, there is typically a small degree of linearity among the predictors. As a general rule, while a VIF value above 5 suggests problematic multicollinearity, a value above 10 suggests highly problematic multicollinearity (James et al., 2013). To test for multicollinearity in the paper, VIF scores are calculated and presented in Table 6. In addition, the correlation matrix of the study variables is examined to assess multicollinearity in the model (Table 7).

Table: 6
VIF for Explanatory Variables

Variable	VIF	1/VIF
TA	1.42	0.704453
SUST	1.23	0.812523
AGE	1.21	0.828601
GROUP	1.17	0.852030
LEV	1.16	0.865510
BIG4	1.05	0.954203

Table 6 displays the VIF and reciprocal VIF (1/VIF) values for each independent variable in the regression model. A VIF above 5 typically indicates potential multicollinearity concerns. All variables in this study fall within the acceptable range.

Table: 7
Correlation Matrix Between the Variables

	SUST	AGE	LEV	TA	BIG4	GROUP
SUST	1					
AGE	0.1722	1				
LEV	-0.1354	0.2590	1			
TA	-0.3175	-0.3042	-0.1618	1		
BIG4	0.1571	-0.0391	-0.1341	-0.0874	1	
GROUP	-0.0718	-0.0355	0.0982	-0.3123	0.0392	1

Overall, the correlation coefficients are mostly low to moderate, as shown in Table 7, indicating no strong linear relationships between the variables. Specifically, the correlations between the SUST variable and other variables remain low to moderate, suggesting that listing in the sustainability index is negatively associated with TA and LEV. Furthermore, when assessed alongside the VIF scores in Table 6, the correlation matrix confirms that all VIF values fall within the acceptable range, indicating that multicollinearity is not a concern in the research model. Therefore, the explanatory variables do not exhibit strong linear relationships with each other.

4.3. Robustness Tests

The analysis detected autocorrelation, heteroskedasticity, and cross-sectional dependence in the research model. To mitigate these issues and obtain more reliable standard errors, the research model specified in Equation (1) was re-estimated using the robust estimators proposed by Huber (1967), Eicker (1967) and White (1980). The revised estimation results are reported in Table 8.

Table: 8
Estimated Robustness Results of the Regression Model with AF as the Dependent Variable

Variable	Coefficient	z	P> z
SUST	-.213	-0.88	0.376
AGE	.798*	1.86	0.063
LEV	-.818*	-1.68	0.093
TA	1.023***	20.27	0.000
BIG4	.090	0.17	0.863
GROUP	.353**	2.04	0.041
Constant	-13.201***	-7.86	0.000
Observations = 115			
R-squared = 0.5367			
Wald chi2(6) = 588.52			
Prob > chi2 = 0.0000			

Note: Coefficients are based on firm-level clustered robust standard errors. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

According to Table 8, the estimated AF model is statistically significant (Wald test for the AF model, $P=0.0000<0.05$). As shown in Column (2) of Table 4, the coefficients of the AGE, TA and GROUP estimated by robust estimators were significantly positive, indicating the presence of autocorrelation, heteroskedasticity and cross-sectional dependence in the model, which needed to be re-estimated. Column (2) of Table 8 also shows that LEV has a negative and statistically significant effect on audit fees. However, the effects of the listed sustainability index and auditor size on audit fees were not statistically significant.

5. Discussion

Sustainability represents a collective mindset that embraces the future. In this sense, it has increasingly become one of the most compelling topics. As a developing country, Türkiye has been undertaking various initiatives to enhance awareness of sustainability. From the perspective of Türkiye's capital markets, the SI stands out as one of the most significant of these initiatives. Thanks to the index, publicly listed firms with high corporate sustainability performance are included, providing responsible investors with the opportunity to invest in such companies. Therefore, although it is expected that the inclusion of companies in the index would enhance their public recognition and reputation, the findings do not support this assumption and suggest that it has no impact on audit fees. According to these results, H1 is not supported.

There are several possible reasons why being listed in the sustainability index does not have a significant impact on audit fees in this paper. First, audit fees are typically influenced by other factors such as operational complexity, firm size, industry characteristics, and audit risk. Being listed in the sustainability index may not significantly alter auditors' risk assessments, as firms in the index often already comply with certain ESG criteria. If these firms have already established well-structured corporate governance and sustainability practices, auditors may not perceive a substantial increase in their workload, which prevents a significant rise in audit fees.

Firms included in the sustainability index generally have strong corporate governance and effective internal controls, which enhance financial transparency and reduce auditors' workload, limiting the need for extra audit procedures. The mandatory implementation of TSRS since January 1, 2024, standardises sustainability reporting and may reduce audit effort, although its recent introduction means its impact on audit fees is not yet evident. Consequently, high transparency and regulatory compliance help prevent increases in audit fees for these firms.

Additionally, inclusion in the sustainability index may not require significant changes in firms' financial reporting or internal controls, as many likely already comply with sustainability regulations. Consequently, this does not add to the audit process, which helps explain why audit fees remain stable. Moreover, as one of Türkiye's top 50 firms, they likely have strong governance that supports compliance.

Lastly, the widespread adoption of sustainability reporting, supported by regulators and market expectations, has likely made these practices more cost-effective for firms. Additionally, audit firms may have standardised sustainability audit procedures, enabling them to integrate these procedures efficiently without significantly increasing their workload, which helps explain the lack of a noticeable impact on audit fees for firms listed in the sustainability index.

Although firm stakeholders have not felt sustainability activities in Türkiye, there are some studies in the literature showing the positive (Sun et al., 2020; Lobo et al., 2018) and negative (Al Ani et al., 2024; Wu et al., 2023; Xin et al., 2022) relationship between sustainability performance and audit fees. Research findings support the conclusions of Cahyaningati et al. (2022, 2021), indicating that sustainability practices have no impact on audit fees.

On the other hand, the results show that the coefficients of AGE, TA, and GROUP are positive and significant at the 10%, 1%, and 5% levels, respectively, indicating that all of these variables had a significant positive effect on audit fees. AGE may positively impact audit fees due to increased complexity, regulatory scrutiny, and risk over time. As firms grow, their financial transactions become more complex, requiring more extensive audits. Older firms also face stricter compliance requirements and have larger financial histories, increasing auditors' workload. Additionally, the risk of misstatements or fraud may rise, prompting more thorough assessments. While strong corporate governance enhances transparency, it also demands detailed evaluations. Higher stakeholder expectations and the need for customised audit approaches further increase audit costs. These factors collectively explain why older firms incur higher audit fees. The positive effect of TA on audit fees can be attributed to several factors. Larger firms generally have more complex financial structures, with more assets, transactions, and detailed reporting requirements, thereby increasing auditors' workload. This leads to more time-consuming and complicated audit processes. Additionally, larger firms are often subject to greater regulatory oversight, which requires auditors to devote more effort to compliance and risk assessments. The size of the

firm also raises expectations for accuracy and transparency in financial reporting, further driving up audit fees. The positive effect of GROUP on audit fees is related to the increased complexity of financial structures and operations. Subsidiaries introduce additional audit requirements such as intercompany transactions, consolidation, and compliance with different regulatory frameworks. Each subsidiary must prepare its own financial reports, which need to be accurately consolidated at the group level. This process requires auditors to review more transactions and documents, making the audit process more time-consuming and complex. Furthermore, analysing and reporting on the relationships between the activities and financial positions of group companies requires greater expertise and resources, ultimately increasing audit fees. The coefficient on LEV is negative and significant at the 10% level, indicating a significant negative effect on audit fees. The negative effect of financial leverage on audit fees is generally related to how a firm's debt level can reduce audit complexity. While high financial leverage increases a firm's debt exposure, such debt is often associated with fixed financial obligations, which may limit the number of transactions and documents auditors need to review. As a result, simpler financial structures and fewer complex transactions can lead to a more straightforward and less time-consuming audit process. Additionally, when financial leverage is high, the firm's risk profile may be lower because the debt payments are typically fixed and predictable. This reduces variability and risk during the audit, ultimately resulting in lower audit fees. Finally, no statistically significant relationship was found between BIG4 and audit fees.

Although the current study accounts for various conditions, the paper has several limitations that present opportunities for future research. First, the study examines the relationship between the sustainable performance of firms selected from Türkiye and audit fees. While Türkiye is an emerging market, it differs from developed countries such as the USA in its economic system and market characteristics. Thus, samples from other countries may generate different results. Second, the firms examined were not included in the sustainability index during the same periods. Third, because audit fee disclosure to the public began in Türkiye in 2021, this limits the study period. If data acquisition spans a broader time period, the sample size could be increased.

6. Conclusions

In this paper, we investigated how a sustainable performance profile impacts audit fees. The findings of this paper offer policy recommendations for a wide range of stakeholders, including policymakers, managers, and auditors. Based on these findings, it appears that being listed on the sustainability index does not significantly affect audit fees. This is an important finding, particularly regarding how sustainability practices and policies are reflected in firms' cost structures.

Policymakers can encourage sustainability by offering tax cuts or incentives that drive companies towards environmentally friendly practices. Additionally, it can standardise and make certain audit processes more transparent for firms listed on the sustainability index. This could help make participation in the sustainability index a strategy that delivers

long-term benefits rather than a financial burden for them. Furthermore, regulations could be developed to ensure audit fees are determined more equitably and transparently. This could help firms better manage the costs related to sustainability reporting.

Audit firms can employ more sustainability specialists to audit companies listed on the sustainability index. While the study has shown that these expertise requirements do not significantly affect audit fees, developing specialised audit processes for sustainability could still be beneficial. Additionally, audit firms can offer more affordable packages for companies engaged in sustainability reporting, thereby helping them achieve sustainability goals at a lower cost.

Firms should view sustainability practices as a strategic investment and recognise that they do not significantly affect short-term costs, such as audit fees. Instead, sustainability practices can increase brand value and enhance the company's reputation in the long run. Firms should not overlook that participating in the sustainability index not only helps fulfil environmental and social responsibilities but also offers long-term financial benefits. Therefore, sustainability practices should be integrated into the company's overall strategy.

The findings of this study also have important implications for audit practices in other emerging markets with similar regulatory environments, suggesting that standardising sustainability audit procedures can improve efficiency and reduce costs, thus encouraging broader adoption of sustainability practices. Policymakers in these markets should develop clear and consistent frameworks for sustainability reporting and assurance, drawing on best practices such as the TSRS, while enhancing sustainability indices by incorporating dynamic, multidimensional metrics and third-party certifications to boost credibility. Collaboration among regulators, audit firms, and firms is essential to improve reporting standards and auditor expertise continuously, and is supported by targeted training programs. Finally, promoting longitudinal and cross-country research will help refine policies and audit methodologies, supporting sustainable development in emerging economies.

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Assessing the Effects of Political Risks on Türkiye's Trade between 1923 and 1950

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Politik Risklerin Türkiye'nin Ticareti Üzerindeki Etkilerinin Değerlendirilmesi: 1923-1950

Abstract

This paper aims to investigate the political determinants of Türkiye's exports and imports during the early years of the Republican era. Using an augmented gravity model, we analyse how political risk factors influenced Türkiye's trade. To achieve this, we utilise annual trade data for 14 of Türkiye's trading partners from 1923 to 1950. The findings reveal that, unlike tensions in Türkiye's bilateral relations with its trading partners, the geopolitical risks have a significantly negative impact on Türkiye's exports and imports. This suggests that heightened political risk stemming from global events had a detrimental effect on Türkiye's trade during this period, whereas the tensions in its bilateral relations did not affect foreign trade, thanks to the country's focus on security and economic development.

Keywords : Conflict, International Trade, Geopolitical Risk, GPR Index, Gravity Equation.

JEL Classification Codes : F10, F14, N14, N44.

Öz

Bu çalışmanın amacı, Cumhuriyet döneminin ilk yıllarında Türkiye'nin ihracat ve ithalatının politik belirleyicilerini incelemektir. Genişletilmiş çekim modeli kullanılarak, politik risk ile ilişkili siyasi faktörlerin Türkiye'nin ticaretini nasıl etkilediği analiz edilmiştir. Bunun için Türkiye'nin 14 ticaret ortağının 1923'ten 1950'ye kadar olan yıllık ticaret verileri kullanılmıştır. Elde edilen bulgular, Türkiye'nin ticaret ortaklarıyla ikili ilişkilerindeki gerilimlerin aksine, jeopolitik risklerin Türkiye'nin ihracatı ve ithalatı üzerinde önemli ölçüde olumsuz bir etkiye sahip olduğunu ortaya koymaktadır. Bu durum, küresel olaylardan kaynaklanan artan politik riskin bu dönemde Türkiye'nin ticareti üzerinde negatif bir etkiye sahip olduğunu göstermektedir. Bununla birlikte, Türkiye'nin bu dönemde güvenlik ve ekonomik kalkınmaya odaklanan politikalar izleyerek gerginliklerden kaçınmasıyla ikili ilişkilerdeki gerginliklerin dış ticaret üzerinde etkili olmadığı söylenebilir.

Anahtar Sözcükler : Çatışma, Uluslararası Ticaret, Jeopolitik Risk, Jeopolitik Risk İndeksi, Çekim Modeli.

1. Introduction

Although economic considerations predominantly influence trade between countries, political risks also significantly affect trade, particularly when it is crucial to a country's economy. Political factors encompass a wide range of aspects, including diplomatic relations and conflicts. Several empirical studies have investigated how political factors affect bilateral trade, using a wide range of variables, including similarities in political systems and foreign policy, political relations, shared democracy, regime type, alliances between countries, intra- and inter-state conflicts (armed or unarmed), and wars. Among these factors, the effects of conflicts and wars have been examined in many studies. However, there are mixed findings about their effects on international trade. For example, Long (2008) and Hegre et al. (2010) proved that military conflicts had adverse effects on bilateral trade, whereas Reuveny and Kang (1998), Anderton and Carter (2001) and Du et al. (2017) showed that the direction and size of the effects depend on the commodity traded, the economic size of the trading partners and the duration of the conflict.

Recently, the geopolitical risk index (GPR) developed by Caldara and Iacoviello (2022) has also been utilised in research, alongside the aforementioned political factors that pose risks to bilateral trade. The index considers a wide range of political events, from wars and terrorist attacks to nuclear threats. It offers a more complete perspective because it accounts for changes in the definition of political risks and the globalisation of risks. There is a growing body of research that has utilised the GPR index as a proxy for political risk to examine its influence on various economic variables, such as stock and oil prices (Apergis et al., 2018; Zhang et al., 2022). Caldara and Iacoviello (2022), Gupta et al. (2019), Singh et al. (2024), and Pyo (2021) used it to analyse its impact on international trade. The first three studies confirmed negative effects, whereas the latter found that the GPR had no significant impact on trade.

Several studies have investigated the determinants of Türkiye's exports and imports. These studies primarily focus on economic factors, examining the impact of economic integrations such as the Customs Union and/or European Union membership (Antonucci & Manzocchi, 2006; Bilici et al., 2011; Frede & Yetkiner, 2017; Karacan & Korkmaz, 2022)¹. Nevertheless, there is a lack of studies examining the effects of political factors. Specifically, the determinants of the country's trade during its early years remain largely unexplored. Since the establishment of Türkiye as a republic coincided with two major global events, World War II (WWII) and the Great Depression, its foreign policy, as well as its internal economic and political environment, has been significantly influenced by these events.

¹ Antonucci and Manzocchi (2006) and Bilici et al. (2011) analyse the impacts of the Customs Union and/or EU membership on Türkiye's exports and imports, while Frede and Yetkiner (2017) explore a range of regional trade agreements. In addition to studying the effects of the Customs Union and/or EU membership, Karacan and Korkmaz (2022) investigate the impact of the 2001 financial crisis. All these studies suggest that the gravity model provides a good fit for Türkiye's trade patterns, although they present mixed results regarding the effects of trade agreements.

To this end, this paper investigates the economic and political determinants of Türkiye's exports and imports in the early years of its existence as a Republic. We examine the determinants of Türkiye's exports and imports by augmenting the gravity equation with two variables that represent political risk, using annual trade data for 14 trading partners from 1923 to 1950. The first one is the GPR index proposed by Caldara and Iacoviello (2022), while the second is a dummy variable that proxies bilateral tensions between Türkiye and its trading partners. We identify these bilateral tensions during the period in question mainly drawing on the works of Oran (2018) and Sönmezoglu (2015). The findings show that Türkiye's trade in its early years was primarily influenced by GPR, rather than by tensions in its bilateral relations. This suggests that while the rise in political risk from global events negatively impacted Türkiye's exports and imports at the time, tensions in Türkiye's bilateral relations did not affect its foreign trade, owing to the country's focus on security and economic development.

This study makes several notable contributions. First, while the influence of GPR on global trade is well established, research on individual countries remains limited. This study aims to address this gap by providing evidence on the effects of GPR on Türkiye's trade flows. To the best of our knowledge, it is the first to apply the GPR index in this context. Second, although some studies have examined the effect of political risks on Türkiye's trade, none have focused on the early years of the Republic, a period largely shaped by global events. The aftermath of these events heightened the vulnerability of the newly established country and influenced its responses to potential tensions with trading partners. Finally, while numerous studies have analysed the impact of conflicts and wars, they mostly focus on multilateral trade or trade between major powers. In contrast, our study examines the bilateral trade of a neutral, non-major power, offering potential contributions to the existing literature, which presents mixed findings on the effects of political factors on the trade of neutral countries.

The remainder of this paper is organised as follows. A review of the empirical literature that focuses on the effects of political factors on international trade is presented in Section 2. Section 3 outlines Türkiye's trade policy in the context of global developments during the period 1923-1950. Examples of bilateral tensions with trade partners and economic and trade policies adopted in response to different situations are provided in Section 4. Section 5 details the data and model used, whilst Section 6 presents the estimation results and evaluations. Finally, Section 7 offers concluding remarks.

2. Political Risks and Trade Linkage: A Literature Review

International trade has traditionally been analysed from the perspective of economic determinants, with a significant body of literature focusing on factors such as comparative advantage, resource endowments, and market dynamics. While these *de facto* economic elements remain critical, there is a growing recognition of the role political factors play in shaping trade flows. Various variables have been used to examine the influence of political and security factors on bilateral trade, including diplomatic relations, conflicts, similarities

in political systems, foreign policy alignment, political relations, joint democracy, regime types, alliances, and adversaries². Recent global developments, such as sanctions, Brexit, and the United States (US)-China trade war, have further spurred studies on the impact of these events as indicators of political risk in international trade³.

Many studies have used conflicts, both internal and international, armed and unarmed, as well as cooperation, to examine the role of political factors in shaping bilateral trade. One of the leading works by Pollins (1989a) uses the import demand function to investigate the impact of bilateral diplomatic relations on the imports of 6 countries from 24 trading partners. He runs individual regressions for each country and constructs the diplomatic cooperation indicator based on diplomatic events. The results show that imports between dyads increase as the diplomatic cooperation indicator rises. Pollins (1989b) supports this finding using the gravity framework.

Using a measure of conflict and cooperation based on daily events, Reuveny and Kang (1998) investigate the Granger causality between political conflict and trade. They focus on 16 dyads and 10 commodity groups from the 1960s to the 1990s. They find strong relations between conflict and bilateral trade. However, the direction and strength of this relationship between dyads and commodity groups are unclear. Particularly in strategic commodity groups such as iron and steel, fuels, minerals and basic manufacturers, the direction of causality goes from conflict to trade. However, the relationship between conflict and trade is independent of whether or not two countries are political rivals.

As an intense and violent form of armed conflict, war is another political factor that plays a determining role in international trade. Barbieri and Levy (1999) focus on trade

² Other political factors, as sources of political risk, have been employed as determinants of international trade: political system and foreign policy similarity (Dixon & Moon, 1993), joint democracy (Morrow et al., 1998), alliances (Mansfield & Gowa, 1994; Gowa & Mansfield, 1993; Mansfield et al., 2000; Bliss & Russett, 1998; Long, 2003), and trade blocs (Gowa & Hicks, 2013; Jacks & Novy, 2020). The findings on the effects of these variables differ depending on the chosen method, time period, and variable definitions. Within the framework of this study, we focus on the literature that considers conflict and/or cooperation as proxies for political risk.

³ With the emergence of recent developments, a new strand of literature has investigated the effects of political events such as Brexit, the US-China trade war, and the sanctions following Russia's invasion of Ukraine. Felbermayr et al. (2022) and De Lucio et al. (2024) examine the effects of Brexit on UK trade and Spanish firms, respectively. The former finds that EU membership enhances trade for both the UK and the EU, while the latter identifies negative impacts of Brexit on Spanish exports and imports. Benguria and Saffie (2019) and Fajgelbaum et al. (2020) demonstrate the trade-reducing impact of the US-China trade war, while Tu et al. (2020) model the declines in both US imports from China and Chinese imports from the US due to the trade war. Jiao et al. (2024) find that exports from Chinese firms to the US declined substantially, whereas their exports to the EU increased moderately (See Fajgelbaum & Khandelwal, 2022, for a detailed discussion of the US-China trade war). In addition to these, several studies have also explored the impact of political interventions, such as CIA covert actions and international sanctions, on trade. Felbermayr et al. (2020) identify the negative effects of sanctions imposed on Iran, while Nguyen and Do (2021) examine the impact of Western sanctions on Russia's exports and Russia's counter-sanctions on its imports, finding declines in both export and import values. Afesorgbor (2019) examines the impact of threatened versus imposed sanctions on international trade, finding that while imposed sanctions reduce trade flow, threatened sanctions increase it. Finally, Berger et al. (2013) show that US exports to the intervening countries increased following the CIA interventions.

among seven dyads that also experienced wars during the period under consideration (1870-1992). They find that wars lead to a temporary decline in dyadic trade. However, in most instances, war has no permanent long-term effect on trade. Anderton and Carter (2001) assess this result and provide strong evidence that war is associated with a decline in trade between major-power dyads. Although the effect is weaker, this outcome is valid for non-major power dyads as well. Using an annual dataset covering many countries over the period 1870-1997, Glick and Taylor (2010) estimate the effects of both the First World War (WWI) and WWII on trade. They find that the trade disruptions caused by the wars affected not only the belligerents but also the neutrals. Gholz and Press (2001) is among the earliest studies to highlight that war can have positive effects on trade, particularly through trade diversion benefiting neutral countries, while Levy and Barbieri (2004) argue that substantial evidence shows trade between adversaries often continues despite wars. Using high-dimensional fixed-effects models, Gowa and Hicks (2015) show that WWI promoted trade among allies, hindered trade between adversaries, and enhanced trade with neutrals. Hedberg and Karlsson (2015) is another study that examines the effects of wars such as the Crimean War, the Franco-Prussian War, WWI, and WWII on a neutral country. By analysing Swedish trade data from 1838 to 1960, they suggest that neutral countries with access to open trade channels were able to sustain or even grow their trade, despite the decline in global trade during wartime. Using recent developments in the empirical gravity literature and a large number of observations from the relatively peaceful period (1830-1913), Karlsson and Hedberg (2021) also show that trade between belligerent and neutral countries was either unaffected or even increased during wars, despite the trade-reducing effects of wars on belligerents.

Simmons (2005) separates territorial conflict from armed conflict to show that even in the absence of military conflict, institutional border disputes decrease trade between partners. Using the Prais-Winston GLS method to estimate the gravity equation, Long (2008) shows that both domestic and interstate conflicts negatively affect bilateral trade. Along with standard gravity variables, the foreign policy similarity index and dummies for joint democracy and being allies are included in the regressions. This finding was supported by Hegre et al. (2010), who simultaneously estimate the reciprocal effects of trade and conflict. However, Li and Sacko (2002) show that the probability, severity, and duration of a conflict affect its impact on trade. Accordingly, for example, if the probability of a conflict is high, then a decline in trade would occur before the outbreak of that conflict. On the other hand, a conflict would reduce trade only if it is unexpected.

More recently, Che et al. (2015) and Du et al. (2017) have explored the impact of political factors on China's trade. The former shows that the Japanese invasion of China from 1937 to 1945 still has a detrimental impact on Chinese trade. The latter investigates the impact of political relations on trade between China and its major trading partners. They employ the political relations index (PRI) to this end. The index was developed based on political events reported in newspapers. These include diplomatic events, military conflicts, and protests against foreign countries. They argue that using aggregated data would cause bias because the effects of political shocks are short-lived. Therefore, they utilise monthly

data to analyse the impact of PRI on trade using the gravity framework. The results show that the adverse impact of political shocks vanishes after the third month.

While various studies have employed different proxies to represent political factors, the GPR index, introduced by Caldara and Iacoviello (2022), has recently emerged as a proxy for political risks. The index has been used to analyse its impact on a range of economic variables, including stock prices, oil prices, financial and non-financial investments, employment, and bilateral trade. The index considers a wide range of political events, from wars and terrorist attacks to nuclear threats. It provides a more comprehensive perspective by incorporating changes in the definition of political risks as well as the globalisation of those risks. Caldara and Iacoviello (2022) show that the GPR had a negative impact on the US's gross trade. Using bilateral trade data for 18 countries with 164 trading partners, Gupta et al. (2019) find that country-level GPR has a decreasing effect on foreign trade. Conversely, Pyo's (2021) study analysing the effects of GPR on macro variables such as employment and industrial production, finds that GPR did not have a significant effect on South Korea's foreign trade. Two further studies have been conducted in South Korea, utilising monthly data on exports and imports over the same period (1991-2020). Jin and Shin (2022) demonstrate that an increase in geopolitical risk led to a decrease in Korea's international trade, with the negative impact stronger on exports. Furthermore, these effects vary by trading partner. In the subsequent analysis, Kim and Jin (2023) produce similar outcomes. However, they found that the impact of GPR was stronger for imports. Finally, considering seven Latin American countries, Singh et al. (2024) employ the gravity model to investigate the effects of GPR on trade in the region. By comparing the effects of GPRs from China, the US, and Latin American countries, they identify a detrimental impact of GPR on trade.

Of the abovementioned studies, only Reuveny and Kang (1998) and Barbieri and Levy (1999) addressed the impact of political factors on Türkiye's bilateral trade. The former investigates the effect in question on trade between Türkiye and Greece during 1962-1991. They conclude that among the conflicts in this dyad, only the Cyprus Peace Operation exhibited reciprocal causality between conflict and trade. The latter uses annual data for the periods 1886-1911 and 1960-1992 for Türkiye (Ottoman)-Greece and Cyprus-Türkiye, respectively, to explore the impact of certain conflicts between these dyads on trade. Although the impact was negative, trade between these dyads increased immediately after the conflicts.

Apart from Reuveny and Kang (1998) and Barbieri and Levy (1999), to the best of our knowledge, only one relatively recent study has examined the effect of political risks on Türkiye's trade. Bilgin et al. (2018) investigate the effect of different definitions of political risks on Türkiye's exports to Islamic countries. They demonstrate that the political instability within these importing partners is inversely correlated with Turkish exports. However, our analyses differ from the aforementioned study in both the political risk indicator used and the specific time frame examined. In particular, the effect of the GPR index on Türkiye's bilateral trade has not previously been investigated. Therefore, this study is the first to fill

this gap in the literature. Moreover, although many studies have analysed the impact of various political factors on international trade, most focus on multilateral trade and trade between major powers at the time. The countries chosen in these studies were mostly those involved in the wars/conflicts in question. The studies' focus on the effects of political factors on the trade of non-belligerent countries is limited and yields mixed findings. Thus, we contribute to this strand by considering a newly established country which was a non-belligerent state during WWII.

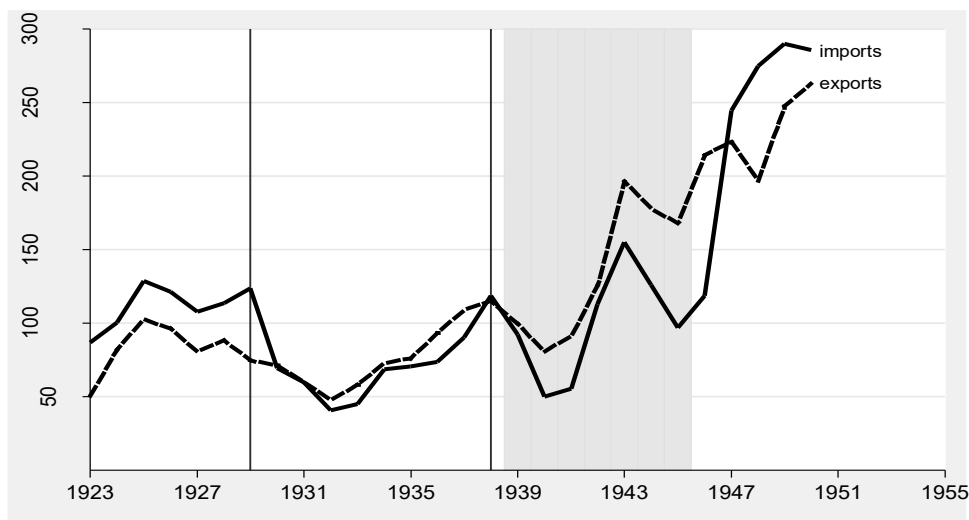
3. Türkiye's Foreign Trade Policy between 1923 and 1950

In the 19th century, the Ottoman Empire's agriculture-based economy was open to foreign investment and trade. However, during the interwar years, protectionism and interventionism gained prominence. After the Republic of Türkiye's founding in 1923, Ankara adopted autonomous economic policies shaped by the unique geopolitical conditions of the interwar period, emphasising protectionism and industrialisation from the Great Depression to WWII (Pamuk, 2018: 157).

In accordance with Pamuk (2018), we analyse Turkish trade policy from 1923 to 1950 in three sub-periods: 1923-1929, marked by limited state intervention and tariff restrictions under the Treaty of Lausanne; 1930-1938, dominated by interventionism and protectionism; and 1939-1950, characterised by postwar recovery and improved economic ties with the West. Fig. 1 illustrates Türkiye's exports and imports from 1923 to 1950, with key sub-periods marked by vertical lines and the wartime period shaded. Under the Treaty of Lausanne, ratified in 1923, Türkiye committed to reducing tariff rates for signatory nations and maintaining existing rates for five years (Alkin, 1983: 5). As a result, the volume of total trade initially increased at the beginning of the first sub-period (1923-1929). However, from 1924 to 1929, a designated import tax was introduced, amounting to five times the 1916 tax value for certain goods, nine times for others, and twelve times for goods intended for protection (Tezel, 2015: 190-191). This led to a decline in total trade.

As shown in Fig. 1, Türkiye also faced a current account deficit during the first sub-period (1923-1929), with imports (mainly consumer goods) exceeding exports (primarily agricultural products). These deficits, driven by the removal of import restrictions and reduced tariffs following the war, were financed by gold and other reserves, leading to the depreciation of the lira (Alkin, 1983: 6). During this time, the lira's value relative to foreign currencies was determined by private market transactions, and the government lacked sufficient reserves and institutional mechanisms to stabilise it. Consequently, the lira depreciated against the pound sterling and the dollar from 1925 to 1928 (Tezel, 2015: 202). Additionally, the Treaty of Lausanne restricted Türkiye's ability to implement protectionist trade policies or adjust customs tariffs until 1929, resulting in a persistent foreign trade imbalance throughout the 1920s.

Figure: 1
Exports and Imports (Million US Dollars) 1923-1950



Note: The figure illustrates Türkiye's exports and imports between 1923 and 1950. The dashed line shows exports, while the solid line represents imports. Vertical lines mark the period of the Great Depression (1929-1939), while a grey-shaded area highlights the WWII era (1939-1945). Source: Turkish Statistical Institute, Statistical Indicators 1923-2013.

In contrast to the era spanning from 1923 to 1929, the period from 1930 to 1938 was characterised by an increased emphasis on interventionist and protectionist policies. Following the Great Depression, the government adopted protectionist economic policies and strengthened its authority over foreign trade and exchange rate management (Pamuk, 2018: 174). The recession resulting from the crisis, combined with the contractionary monetary and fiscal policies adopted by the government, led to a decline in both exports and imports, as shown in Fig. 1 (Yay, 1998: 315-306).

In the 1930s, the government implemented a novel economic program to accelerate industrialisation within its protectionist framework. The government introduced new measures, including exchange controls, bilateral trade agreements, and import restrictions, to better align industrialisation policy with international trade policy. Türkiye's interventionist foreign trade policies were also influenced by the international context, where various countries adopted similar measures. Furthermore, maintaining the value of the Turkish lira was a key objective in implementing these policies. The need to protect the lira's value drove the decision to reduce the trade deficit, which, in turn, influenced the pursuit of import-substitution industrialisation (Tezel, 2015: 197-198).

Following the global economic downturn, the government launched new trade policies (Alkin, 1983: 6). The implementation of the new customs regime began in October 1929, resulting in a significant increase in the average tariffs on imported products from

13% to 46% (Pamuk, 2018: 174; Tezel, 2015: 180-181). These protectionist policies led to a consistent current account surplus from 1930 to 1946, except for 1938, as shown in Fig. 1.

Furthermore, the legislation enacted in 1932 to establish clearing commissions regulated foreign trade relations. As a result, the clearing system became predominant in Türkiye's foreign trade in the second sub-period. Türkiye was compelled to build such a system due to the methods employed by its trading partners. The payment difficulties induced by the Great Depression in 1929 were the primary reason for establishing structures to regulate and oversee international economic transactions (Alkin, 1983: 12). In 1933, Türkiye began signing bilateral trade agreements with countries crucial to its foreign trade. Additionally, starting in 1932, quotas and controls on foreign-exchange allocation were imposed on a significant share of imports (Tezel, 2015: 200). In early 1937, Türkiye established clearing and similar agreements with 23 countries (Tekeli & İlkin, 2016: 212).

The years 1939-1950 can be characterised as a period when the war caused substantial damage to the economy, followed by an improvement in economic relations with the West, which significantly influenced foreign trade policy. Although the country maintained its non-belligerent status, its economy was significantly affected by WWII (Pamuk, 2018: 181). Exports and imports declined at the onset of the war (Fig. 1).

During the third sub-period, the premium exchange rate system was implemented alongside the clearing system in foreign trade. In addition to the officially established exchange rate, a premium bartered exchange rate also emerged. This caused importers to acquire foreign currency at a rate exceeding the official price, with the difference between the official rate and the rate applied to importers given to exporters as a premium. This system was primarily introduced because export prices were above global levels. The government officially announced these premiums in 1939. Moreover, the official exchange rate was lower than the black-market rate (Tekeli & İlkin, 2016: 77-78). Thus, the lack of an increase in exports, despite the depreciation of the lira, can be attributed to high inflation and the maintenance of fixed exchange rates. The substantial increase in inflation, particularly during the wartime period, posed a risk that export goods would remain unsold. To address this issue, the lira was devalued in 1946 (Köklü, 1947: 82). However, the devaluation of the lira was insufficient to ensure a favourable exchange rate-export relationship.

Except for the last three years, there was a trade surplus during this sub-period, as shown in Fig. 1. Consequently, the Central Bank's gold stocks increased continuously (Tekeli & İlkin, 2016: 218). During the war, Türkiye encountered difficulties in international trade, including issues with payments, transportation, and government intervention. Nonetheless, the country saw a rise in trade volume compared with previous years, resulting in a foreign trade surplus. Price differences between exported and imported goods can mainly explain the surplus. During this period, the prices of the former increased threefold compared with those of the latter (Alkin, 1983: 9; Tekeli & İlkin, 2016: 218).

4. Bilateral Political Relations and Trade

During the War of Independence, the borders of the National Pact, which was the main target, were largely achieved, and the Treaty of Lausanne recognised them. After Türkiye was established in 1923, the government aimed to preserve the status quo in foreign policy. During this period, a prudent and peaceful foreign policy was pursued. To this end, Ankara, on the one hand, sought to exploit the rivalry between the Western states and the Soviet Union. On the other hand, it tried to use the status quo-revisionist alignment of the Western powers to further its own interests (Sönmezoğlu, 2015: 254-255).

To establish the link between political relations and international trade within the period in question, it is useful to focus on the assessment of the most important partners. From 1924 to 1929, Italy, the US, Germany, and France were the four countries that received the largest proportion of Türkiye's exports. During the same period, Italy, the UK, Germany, and France ranked as the top four countries by their share of imports (Tezel, 2015: 196). Thus, it is evident that Italy was the most important partner for both exports and imports during this period. However, following Italy's invasion of Abyssinia in 1935, relations between Türkiye and Italy deteriorated. In 1935, the League of Nations decided to impose economic sanctions on Italy. Türkiye adhered to this decision. The political tension between the two countries adversely affected foreign trade. Following this event, Italy's share of Türkiye's international trade declined. Its export share decreased from 11% in 1934 to 10% in 1935 and to 4% in 1936. The proportion of its imports declined from 9% in 1934 to 6% in 1935 and fell further to 2% in 1936 (Mengeş, 2018: 147).

In the 1930s, Germany established dependency by selling manufactured goods to countries from which it bought agricultural products and raw materials. It also increased its trading volume by using the clearing system. Germany played a prominent role in the foreign trade of the Balkan countries, including Türkiye, mainly due to this policy. In 1936, Germany accounted for 51% of Türkiye's exports and 45% of Türkiye's imports (Tekeli & İlkin, 2016: 213-215). However, by the late 1930s, Türkiye's political and military alignment had shifted towards the UK rather than Italy and Germany, who were gaining a significant share of the country's foreign trade (Sönmezoğlu, 2015: 53).

Nonetheless, the onset of WWII brought about significant changes in both the political and economic realms. Türkiye maintained a policy of neutrality throughout WWII and refrained from engaging in any military confrontations. Despite its non-belligerent status, Türkiye supported its military force to defend and protect its home territory against a possible invasion by belligerent countries (Aydın, 2021: 1). When Türkiye was unable to renew its non-aggression pact with the Soviet Union in 1939, it signed the Treaty of Mutual Assistance with the UK and France on 19 October 1939. Germany terminated the German-Turkish Credit Agreement, signed in January 1939, in response to this action. Türkiye reacted by cancelling the Turkish-German Trade Agreements. Due to these political developments, Germany's share of both exports and imports declined. In June 1941, another significant diplomatic event occurred amid the ongoing war between these two nations: the

signing of the Turkish-German Non-Aggression Pact. In October 1941, this event resulted in the re-establishment of bilateral trade agreements. Consequently, Germany regained its position as Türkiye's primary trading partner until 1944, when diplomatic ties with Germany were cut again (Tezel, 2015: 217-218).

The UK made multiple efforts to impede Germany's dominance over Türkiye's foreign trade. To achieve this, it facilitated the construction of the Karabük Iron and Steel Factory in 1936 and signed an agreement with the UK to supply loans. This led to noticeable growth in trade between these dyads since then. Following the signing of the alliance pact with the UK in 1939, a trade payment agreement was signed in 1940 and enforced throughout the war (Tekeli & İlkin, 2016: 213-215).

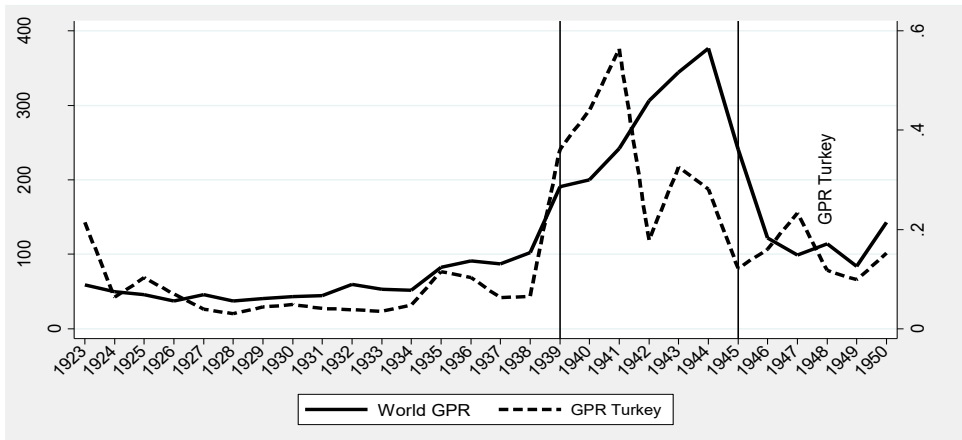
Chromium also played a significant role in shaping Türkiye's political alliances with both the Axis and the Allied powers during the war. The Allies made various attempts to prevent Germany from purchasing chrome ore from Türkiye throughout 1939. Following the 1939 Turkish-British Declaration, trade relations with Germany were severely disrupted. As a result, the UK obtained the exclusive privilege to purchase Turkish chromium, thus establishing a monopoly within the industry. Nevertheless, as a result of the Turkish-German Non-Aggression Pact signed in 1941, the UK's exclusive privilege was revoked, and Türkiye was permitted to sell certain quantities of chrome ore to Germany in 1943 and 1944. However, as the Allies gained an advantage in the war and mounting pressure to cease selling chrome to Germany grew, Türkiye halted its chrome exports to Germany on 21 April 1944 (Önsoy, 2012: 93-120; Karakaş, 2010: 447-482; İnanç, 2006: 908). In return, the Allies promised to increase their imports from Türkiye. The US appeared to have successfully fulfilled this commitment in 1945 (Tekeli & İlkin, 2016: 213-215).

Germany has been a major partner in Türkiye's foreign trade since the 1930s, but the post-war collapse of Germany negatively affected Türkiye's foreign trade. The decline in the significance of clearing agreements in 1945 and 1946, coupled with global prices, had a significant impact on Türkiye's trade. Conversely, Türkiye's shift towards an economic strategy that relied heavily on American aid and loans heightened external efforts to liberalise foreign trade. The devaluation in 1946 was clearly implemented to align with the Bretton Woods Agreement and to enhance trade ties with the Western world (Tezel, 2015: 218-222). The Turkish government devalued the national currency on 7 September 1946 to increase exports. However, this policy did not yield the expected result. In 1947, the long-standing trade surplus transformed into a trade deficit. Exports declined in the subsequent year. Although it started to increase again in 1949, the increase in imports surpassed it (Alkin, 1983: 9). In the post-war period, Germany ceased to be an important trading partner for Türkiye and was replaced by the US and the UK. Nevertheless, by 1950, Germany had regained significance as a crucial trading partner, increasing its share in Türkiye's exports to 25% and in its imports to 20% (Tezel, 2015: 222).

Evaluating these issues shows that WWII, along with the Great Depression, significantly influenced the Turkish economy between 1923 and 1950. The war was

particularly significant for bilateral economic and political relations, with both direct and indirect effects on exports and imports. As illustrated in Fig. 2, geopolitical risks (world GPR) increased substantially during the wartime period. Its relative intensity in Türkiye reflected a similar pattern in world GPR. However, as shown by Türkiye's index (dashed line), war-related news mentioning Türkiye in newspapers began appearing earlier than in the rest of the world. This may imply that the perception of war-related risk was felt earlier in Türkiye than elsewhere in the world. The German invasion of Greece in 1941 was one of the main reasons for this. The fact that the conflict had spread to Türkiye's frontiers emerged as a significant risk concern. However, the risk to Türkiye diminished following Germany's attack on the Soviet Union (Aydın, 2018: 388).

Figure: 2
GPR Index: World vs Türkiye



Note: The figure compares Türkiye's GPR with the World GPR (1923-1950). The dashed line shows Türkiye's GPR, while the solid line represents the World GPR. Vertical lines mark the WWII era (1939-1945).
Source: Caldara and Iacoviello (2022).

Overall, the political relations between Türkiye and its trading partners, as discussed above, significantly influenced Türkiye's exports and imports from 1923 to 1950. Undoubtedly, the war played a key role in shaping these relations. To investigate the effects of political factors on Türkiye's trade, we consider both global political risks and tensions in Türkiye's bilateral relations with its partners. Specifically, we examine the impact of the GPR index on Türkiye's bilateral trade during the first 28 years following its independence. Additionally, as an alternative definition of political risk, we create a variable that represents bilateral tensions; further details are provided in the next section.

5. Data & Methodology

The gravity model, originally inspired by Newton's law of gravitation, has become a cornerstone framework in analysing trade flows between countries. The model has been

labelled the "workhorse" of empirical trade analysis, as it fits existing data well and is readily applicable (Head & Mayer, 2014). In its most basic form, the gravity model posits that bilateral trade flows are positively related to the economic sizes of the trading partners and inversely related to the distance between them. The gravity model established its place in the international trade literature through the pioneering empirical study conducted by Tinbergen (1962). However, significant advancements have since been made, providing a robust theoretical basis. Anderson (1979) offered one of the first microeconomic derivations of the gravity equation, showing that it could emerge from a model of trade based on constant-elasticity-of-substitution (CES) preferences and product differentiation. The incorporation of the gravity model into frameworks of monopolistic competition and increasing returns to scale further enriched its theoretical robustness (Helpman and Krugman, 1985). Eaton and Kortum (2002) demonstrated that the model could also be derived from Ricardian trade theory, linking it to comparative advantage. The simplest form of the gravity equation can be expressed as follows:

$$T_{ij} = G \frac{Y_i Y_j}{D_{ij}^\alpha} \quad (1)$$

where T_{ij} denotes bilateral trade flows (exports or imports) between country i and country j , Y_i and Y_j denote the economic size of country i and country j , respectively. D_{ij} denotes the geographical distance between i and j and is employed as a proxy for bilateral trade costs. Most studies in the international trade literature employ the log-linearised form of this equation which is also augmented D_{ij} with additional variables such as having a common border, common language, common currency, colonial relationship, bilateral tariffs, trade agreement membership, and being landlocked, to measure countries' cultural and geographical characteristics.

Later, Anderson and van Wincoop (2003) addressed the issue of multilateral resistance terms (MRT), emphasising that trade flows depend not only on bilateral trade costs but also on the relative trade barriers with other trading partners. Therefore, in addition to trade costs, they suggested including the MRTs of the exporter and importer in the equation. Baier and Bergstrand (2009) proposed a simpler method for calculating MRT using a first-order log-linear Taylor series expansion, which produces estimates identical to those obtained from the nonlinear estimation of the full system of equations proposed by Anderson and van Wincoop (2003). It has been confirmed that including various pair fixed effects in the model controls for unobserved factors and effectively addresses potential endogeneity concerns (Baier & Bergstrand, 2007; Anderson & Yotov, 2012; Yotov et al., 2016). Subsequently, the issue of endogeneity has been extended to encompass any trade policy variable (Piermartini & Yotov, 2016; Felbermayr & Yotov, 2021). Anderson and Yotov (2010) further highlighted the role of home bias effects, which may influence the estimated effects of other variables included in the gravity equation. To address this, they employed an internal trade dummy variable to differentiate between internal and international trade. Later studies have used the difference between total output (GDP) and total national exports as a proxy for domestic trade (Dai et al., 2014; El Dahrawy et al.,

2021). Yotov (2022) suggests using gross production data rather than GDP to calculate domestic trade.

The estimation approaches employed in the gravity literature have evolved to address critical econometric challenges and improve the robustness of results. Early studies primarily utilised ordinary least squares (OLS) applied to the log-linearised form of the gravity equation. However, this method is highly sensitive to heteroscedasticity and unable to accommodate zero trade flows, often leading to biased and inconsistent estimates. To address these limitations, Santos Silva and Tenreiro (2006) proposed the Poisson pseudo-maximum likelihood (PPML) estimator, which provides consistent estimates under the correct specification of the mean of the dependent variable. The PPML approach handles the presence of zero trade values and heteroskedastic error terms in the multiplicative form of the gravity equation, and, as a weighted non-linear least squares estimator, it eliminates the need to log-linearise the gravity equation.

To estimate the impact of bilateral tensions and geopolitical risks on trade between Türkiye and its trading partners for the period 1923-1950, we also adopt the augmented version of the gravity framework. Our dependent variables are Türkiye's exports and imports with its trading partners. These data are collected from TUIK (2014) and supplemented with data from Fouquin and Hugot (2016). The bilateral trade data (in thousands of dollars) provided by TUIK (2014) cover Türkiye's exports and imports with a limited set of trading partners for the early Republican period. To improve country coverage and reduce missing observations, these data are supplemented with historical trade statistics from Fouquin and Hugot (2016). The latter dataset reports trade values in British pounds, which are converted into US dollars using the pound-to-dollar exchange rate provided in the same dataset. For overlapping observations available in both datasets, the correlations for exports and imports are 92.34% and 94.19%, respectively. This indicates a high degree of consistency between the two sources. Therefore, expanding the sample with the latter dataset yields a more balanced representation of Türkiye's bilateral trade during the period under study⁴.

We use three sets of independent variables. The first one accounts for standard gravity variables such as economic size and physical distance. The second one covers the effects of the main explanatory variables, while the third one includes the control variables. In the gravity literature, economic size is proxied by GDP. The GDP of the exporting country indicates production capacity, whereas the GDP of the importing country indicates potential demand within that country. GDP data is obtained from The Maddison Project Database, which provides it in million Geary-Khamis dollars. The physical distance between two trading partners is a proxy for the transportation costs. It is obtained from the GeoDist dataset

⁴ The countries in the TUIK export dataset are the US, Germany, Austria, Bulgaria, China, France, the Netherlands, the UK, Iran, Spain, Switzerland, Italy, Japan, Egypt, Poland, Romania, the Former USSR, Syria, and Greece. The countries in the TUIK import dataset are the US, Germany, Austria, Bulgaria, Brazil, China, Czechoslovakia, France, the Netherlands, the UK, Iran, Spain, Switzerland, Italy, Japan, Egypt, Romania, the Former USSR, Sweden, Syria, and Greece. Export data for Brazil and Sweden, as well as export and import data for Belgium and Portugal, are supplemented using a dataset from Fouquin and Hugot (2016).

and is measured as the population-weighted great-circle distance between the largest cities in a country (Mayer & Zignano, 2006). In the gravity literature, variables such as colonial ties, shared language, shared religion, and common borders (contiguity) are commonly used to account for trade frictions. However, for the countries included in our analyses, only contiguity is applicable. Thus, this variable, along with physical distance, has been incorporated into the estimations. The contiguity data were obtained from Fouquin and Hugot (2016).

In the current study, Equation 1 is augmented with two additional explanatory variables to investigate the impact of the Great Depression and political events on Türkiye's trade with its partners during the early years of its existence. The former is proxied by a dummy variable that represents the crisis period. In creating this dummy variable, the League of Nations' industrial production index (1939) was considered. This country-specific indicator variable is constructed by identifying the year in which each country's index value returned to its pre-crisis level.

The latter is proxied by two variables in the different models. The first variable is the country-specific historical GPR index proposed by Caldara and Iacoviello (2022). The index provides a more complete perspective by accounting for changes in the definition of political risks and the globalisation of risk. It is calculated monthly at both the global and country levels using automated text-search results from newspaper electronic archives. The global index is measured by the frequency of newspaper articles discussing adverse geopolitical events, based on keywords such as war, nuclear, and terrorism. The *recent* GPR index is based on 10 newspapers (Chicago Tribune, Los Angeles Times, NYT, WSJ, WaPo, Phil. Enquirer, Daily Telegraph, FT, Guardian, The Globe and Mail) from 1985 onwards, whereas the *historical* GPR index starts from 1900 and is based on only four newspapers (NYT, Chicago Tribune, and WaPo).

Both the recent and historical GPR indices are constructed for 44 countries as a country-specific measure of geopolitical risk. They measure the relative intensity of recent and historical GPR in these 44 countries. The country-level GPR index represents the monthly share of all newspaper articles that meet the inclusion criteria and reference the country's name or one of its major cities. As with the recent and historical GPR indices, the *recent country-level* GPR index covers the period from 1985 to the present, while the *historical country-level* GPR index spans the period from 1900 to the present. We use the historical country-level GPR in our analyses, as the recent country-level GPR is not available for the analysis period. The index is available monthly; therefore, we convert it to an annual format by averaging over 12 months. Both Türkiye's and its trading partners' GPR indices have been employed. Since the index is based on exogenous events, it is less likely to be influenced by economic indicators compared to other political risk proxies. This characteristic of the GPR makes it well-suited to estimating the direct effects of geopolitical risk on economic indicators (Pyo 2021). It is unlikely that Türkiye's bilateral trade volumes during this period were sufficiently large to influence geopolitical risk, which was primarily driven by major international events.

The second variable, proxying for political events, is a dummy indicating bilateral tensions between Türkiye and its partners during 1923-1950. The variable takes a value of 1 in years when tensions occurred between Türkiye and the trading partner, and 0 otherwise. The tensions considered in constructing this variable are mainly drawn from Oran (2018) and Sönmezoğlu (2015), with additional support from Hale (2021), Criss (2017), VanderLippe (2001), Beck (1981), De Luca (1977), and Khadduri (1945). Oran (2018) and Sönmezoğlu (2015) identified these tensions based on political disputes between Türkiye and its trading partners. Examples of these bilateral tensions are discussed in Section 4, which details Türkiye's bilateral political relations, and a complete list is provided in Table A1 in the Appendix. Similarly, bilateral political tensions during the period under study were largely shaped by diplomatic and geopolitical developments rather than by fluctuations in bilateral trade volumes.

Finally, we include three control variables. The first is the bilateral trade agreements dummy, constructed from agreements with countries included in the analysis during the specified period. These agreements and their sources are listed in Appendix Table A2. The second control variable is the sterling/TL exchange rate, which is used to account for price competitiveness. The data for the sterling/TL rate are sourced from Köklü (1947) and Tezel (2015). The third control variable comprises multiple dummies that reflect shifts in Türkiye's trade policies. Since Türkiye's trade policy shifted twice during the period in question, dummy variables are created to represent each phase. The first dummy takes the value 1 for the period 1923-1929, representing a period of limited state intervention in the economy and restrictions on changes to customs tariffs under the Lausanne Agreement. The second dummy takes a value of 1 for 1930-1938, reflecting interventionist and protectionist policies, as well as an autarkic approach to foreign trade. The final period, 1939-1950, is divided into two sub-periods. The first sub-period, corresponding to the war years, takes a value of 1 for 1939-1945. The second sub-period, marking Türkiye's accession to the Western Bloc, takes a value of 1 for 1946-1950.

After merging the trade data with other datasets [GPR, Maddison Project Database (MPD), and GeoDist], we are left with 14 countries in both the export and import analyses. Data availability constraints primarily drive the reduction in country coverage. Several trading partners are excluded due to the absence of historical country-level GPR data (Austria, Bulgaria, Greece, Czechoslovakia, and Romania), while Egypt is excluded due to missing GDP data. Iran and Syria are dropped because neither GPR nor GDP data is available for the analysis period. China is also excluded due to non-overlapping missing values in trade and GDP variables. This resulted in an unbalanced panel dataset, containing 381 observations for the export analysis and 384 observations for the import analysis⁵. To assess the effect of geopolitical risks and bilateral tensions on trade between Türkiye and its trading partners from 1923 to 1950, we employ the following equations:

⁵ The countries analysed in the study are the US, Germany, Brazil, France, the Netherlands, the UK, Spain, Switzerland, Italy, Japan, the Former USSR, Sweden, Portugal, and Belgium.

$$T_{j,t}^{TR} = \exp(\mu_j + \beta_1 \ln GPR_{j,t} + \beta_2 \ln GPR_{TR,t} + \sigma_1 \ln Dist_{j,TR} - \sigma_1 MRDist_{j,TR} + \sigma_2 Contig_{j,TR} - \sigma_2 MRContig_{j,TR} + X_{TR;j,t} \boldsymbol{\theta}) \eta_{j,TR,t} \quad (2)$$

$$T_{j,t}^{TR} = \exp(\mu_j + \gamma_1 \text{BilateralTensions}_{j,TR,t} + \sigma_1 \ln Dist_{j,TR} - \sigma_1 MRDist_{j,TR} + \sigma_2 Contig_{j,TR} - \sigma_2 MRContig_{j,TR} + X_{TR;j,t} \boldsymbol{\theta}) \eta_{j,TR,t} \quad (3)$$

where the subindices TR and j represent Türkiye and its trading partners, respectively. $T_{j,t}^{TR}$ denotes real trade flows (exports and imports) between Türkiye and its trading partners. The GDP data used in the analysis are obtained from the MPD version 2023, which reports values in international dollars at constant 2011 prices. To ensure consistency between output and trade measures, nominal bilateral trade flows for the period 1923-1950 are converted into real terms using Türkiye's consumer price index (CPI), with 1939=100, as reported in Doğruel and Doğruel (2005). The CPI series is rebased to 2011 prices before deflating the trade data. This procedure is consistent with previous studies that employ historical trade data in gravity models (e.g., Morrow et al., 1998; Mansfield et al., 2000; Mansfield et al., 2008; Glick & Taylor, 2010).

$GPR_{TR,t}$ and $GPR_{j,t}$ stand for Türkiye's and its trading partners' geopolitical risk indices, respectively. As an alternative measure of political risk, *BilateralTensions* $_{j,TR,t}$ variable is used. It provides data on tensions between Türkiye and its trading partners during the period under study and is obtained from multiple sources (see Appendix Table A1). $Dist_{j,TR}$ is the population-weighted great circle distance between Türkiye and its partners and $Contig_{j,TR}$ is an indicator variable for Türkiye and its partners sharing a border. X is a set of control variables that include real GDPs of Türkiye and its trading partners as proxies for economic sizes of countries, sterling/TL exchange rate as a proxy for external competitiveness, bilateral trade agreements between Türkiye and its partners, and some dummy variables to control for the Great Depression, WWII and the political shifts in Türkiye. Finally, t denotes time, i.e. $t=1923, \dots, 1950$, η_{TRjt} denotes the multiplicative error term which is $E(\eta_{j,TR,t}|X) = 0$ and μ_j captures country fixed effects for partner j . Several standard gravity variables commonly used in gravity models, such as common language, colonial ties, and common religion, are not included in the estimations due to insufficient variation across Türkiye-partner pairs in the final sample. Both equations are estimated using the PPML approach with fixed effects.

Recent developments in the gravity literature suggest using various pair fixed effects to control for unobservable factors and address potential endogeneity. Although full bilateral trade data (trade between all country pairs) is available, the variable *bilateral tensions*, a key focus of our study, is not available for all pairs. In addition, the variable *bilateral trade agreement*, included in the model as a control variable, is also obtained from various sources solely for Türkiye (see Appendix Table A2). Therefore, the estimates rely on $N \times T$ observations rather than $N(N-1) \times T$, as used in Berger et al. (2013). However, following Berger et al. (2013), we incorporated the correction terms proposed by Baier and Bergstrand (2009) into the equation to account for unobservable effects. Baier and Bergstrand (2009)

estimated the MRTs proposed by Anderson and van Wincoop (2003) by modelling unobservable effects with observable variables. Accordingly, the correction terms for bilateral distance and contiguity ($MRDist_{j,TR}$ and $MRContig_{j,TR}$), along with the corresponding trade cost variables, are included in the estimations to control for unobserved relative trade barriers and to mitigate potential endogeneity concerns arising from omitted multilateral trade resistance⁶.

Another potential source of endogeneity in the estimation is reverse causality in the relationship between trade flows and political risk indicators. In the historical context of the period under study, geopolitical risks and bilateral political tensions were largely driven by major international events and diplomatic developments, which are plausibly exogenous to Türkiye's bilateral trade. Nevertheless, the results should be interpreted with caution and not as strict causal effects.

We transform all numeric explanatory variables in Equations 2 and 3 to natural logs and estimate the fixed-effects model, which assumes that individual-specific effects are uncorrelated with the explanatory variables⁷. If the individual-specific effects are uncorrelated with the explanatory variables, then one should proceed with the random-effects model. However, the choice between these two estimators also depends on the sample selection. If the selection of sample countries is random rather than specific, the random-effects model is more efficient (Egger, 2002). As the selection of sample countries in our study is highly dependent on data availability, and the share of these countries in Türkiye's trade ranges from 55% to 87%, we employ the fixed-effects model to estimate Equation 2⁸.

⁶ The correction terms are calculated as follows:

$$MRDist_{ij} = [(\sum_{k=1}^N \theta_k \ln Dist_{ik}) + (\sum_{m=1}^N \theta_m \ln Dist_{mj}) - \sum_{k=1}^N \sum_{m=1}^N \theta_k \theta_m \ln Dist_{km}] \text{ and}$$

$$MRContig_{ij} = [(\sum_{k=1}^N \theta_k \ln Contig_{ik}) + (\sum_{m=1}^N \theta_m \ln Contig_{mj}) - \sum_{k=1}^N \sum_{m=1}^N \theta_k \theta_m \ln Contig_{km}],$$

where $\theta = Y_{i,t}/Y_{W,t}$. We calculated these variables for all country pairs and included them in our regressions. They are constrained to have the same coefficients but opposite signs, as suggested in Baier and Bergstrand (2009).

⁷ Yotov et al. (2016) and Yotov (2022) have demonstrated that incorporating domestic trade flows into gravity models allows for the estimation of heterogeneous intra- and international trade costs, while accounting for home bias. Domestic trade can be calculated either as the difference between gross production and exports or as the difference between GDP and exports. However, gross production data is unavailable for the analysis period. While nominal GDP data could serve as an alternative, it contains missing values for the same period. Consequently, we were unable to include this variable in our analyses.

⁸ More precisely, the exporting partners' share in Türkiye's total exports within the analysis period varies between 59.99% and 85.16%, whereas the share of its importing partners as a proportion of total imports varies between 54.48% and 86.47%. Details on the share of countries included in the analysis are provided in Figure A1 and Figure A2 in the Appendix. As shown in the figures, the shares of both exporting and importing partners decreased noticeably during the war years. This was because countries such as the UK and Italy, which were directly involved in the war, conducted trade through intermediaries such as Romania, India, Hungary, Egypt, and Palestine (Tekeli & İlkin, 2016: 224-225). However, due to data unavailability, these countries could not be included in the analyses, resulting in lower recorded shares for the period.

6. Findings and Discussions

The analysis results examining the impact of political risks on Türkiye's exports and imports during the first 28 years of its establishment are presented in Tables 1 and 2 below⁹. These results are derived from PPML estimates within the gravity model framework. In the first two columns of these tables, the geopolitical risk index is used as a measure of political risk, while in the last two columns, a dummy variable representing the bilateral tensions experienced by Türkiye is employed. The findings provide valuable insights into how these dimensions of political risk influenced trade during the formative years of a neutral country, which coincided with the WWII era.

The difference between Columns 1 and 2 is that Column 2 incorporates countries' multilateral resistance terms, using the Baier and Bergstrand (2009) approximation method. This approach includes correction terms for the trade-cost variables (physical distance and contiguity) used in Column 1, as well as adjustments to these variables themselves. By incorporating these terms, this estimation captures the indirect effects of trade barriers across all trading partners, rather than just bilateral costs. Columns 3 and 4 replicate this approach, but instead of the geopolitical risk index analysed in Columns 1 and 2, they use bilateral tensions as the primary variable of interest.

According to the first two columns of Table 1, the GPR of partner countries (GDP partner), the first main variable of interest, is statistically significant and has a negative effect on Türkiye's exports. The coefficient decreases slightly when corrected trade cost terms are employed. Specifically, a 1% increase in partners' GPR leads to a 0.174 reduction in Türkiye's exports. This result aligns with the growing body of literature suggesting that heightened geopolitical risks increase uncertainty and transaction costs, thereby reducing trade volumes (Caldara & Iacoviello, 2022; Gupta et al., 2019). It is also consistent with earlier studies that use alternative political variables (Anderton & Carter, 2001; Glick & Taylor, 2010).

Türkiye's GPR (*GPR Türkiye*) is, on the other hand, positive and statistically significant. Again, the coefficient decreases slightly after the addition of correction terms. Türkiye's strategic positioning as a neutral country during WWII could explain this finding, as it allowed it to maintain trade relations with both the Axis and the Allied powers. In addition to leveraging its neutral status during the war, Türkiye prioritised development in its foundational years. It is also possible that, as a neutral country, Türkiye benefited from increased trade during periods of heightened geopolitical risk. Hedberg and Karlsson (2015)

⁹ Before performing the regression analyses, a Fisher-type unit root test based on the augmented Dickey-Fuller method was conducted to examine the stationarity of the variables. Before applying this first-generation unit root test, which confirmed that all variables are stationary, the cross-section dependence test developed by Pesaran (2004) was performed, and cross-section independence was identified. These results are available upon request.

demonstrated that countries, particularly neutral ones, often experience trade gains during global conflicts.

Table: 1
Regression Results from the Export Analyses

Independent Variables	Exports			
	(1)	(2)	(3)	(4)
GDP Partner	2.171*** (5.75)	2.615*** (6.49)	1.990*** (5.74)	2.419*** (6.05)
GDP Türkiye	0.535 (0.95)	0.0163 (0.03)	0.463 (0.84)	-0.158 (-0.31)
Bilateral Trade Agreements	-0.112 (-0.80)	-0.0279 (-0.24)	-0.176 (-1.12)	-0.0544 (-0.43)
Sterling/Lira Rate	0.213 (0.52)	-0.0324 (-0.09)	0.129 (0.28)	-0.114 (-0.25)
Great Depression	-0.260** (-2.47)	-0.222* (-1.93)	-0.242** (-2.46)	-0.217* (-1.95)
Corrected Physical Distance		-0.302** (-2.41)		-0.257** (-2.00)
Corrected Contiguity		-5.341*** (-3.97)		-6.105*** (-4.66)
GPR Partner	-0.191** (-2.03)	-0.174** (-3.25)		
GPR Türkiye	0.273*** (2.82)	0.239*** (2.62)		
Bilateral Tensions			-0.0217 (-0.14)	0.0299 (0.16)
# of Obs.	368	368	368	368
MRT	no	Yes	no	yes

*Notes: Estimates are based on Türkiye's exports to 14 trading partners during the period 1923-1950. The dependent variable is export value, and the natural logarithm is taken of the numeric independent variables. The bilateral tensions variable is a dummy indicating whether Türkiye experienced tensions with the respective countries. The Great Depression variable is a country-specific dummy, with the League of Nations' (1939) industrial production index taken into account. The bilateral trade agreements dummy captures agreements such as clearing agreements, treaties of commerce and navigation, and tariff and payment agreements that Türkiye has signed with these countries. Columns 1 and 3 include physical distance and contiguity dummies, which are dropped since they are constant within the group. Columns 2 and 4 incorporate the corrected trade cost variables, calculated using the Baier and Bergstrand (2009) multilateral resistance terms. All regressions include country fixed effects and dummy variables, one of which captures WWII, to represent shifts in Türkiye's trade policies. z-statistics with robust standard errors from PPML estimations are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.*

Columns 3 and 4 in Table 1 present the effects of bilateral tensions, used as a proxy for political factors, as an alternative to the GPR index. In contrast to the GPR index, the effect of bilateral tensions is not statistically significant, and the variable's sign changes after the inclusion of corrected trade costs. The insignificance of this variable suggests that localised political tensions did not substantially affect Türkiye's exports during this period. Moreover, Türkiye's neutral stance during WWII likely helped mitigate the economic consequences of these tensions (Tekeli & İlkin, 2016: 217). The divergent findings for the two variables used to represent political factors suggest that the GPR index, which captures global political risks, plays a more significant role in influencing Türkiye's exports than do bilateral tensions between Türkiye and its trading partners.

Among the control variables, only the GDP of the partner country and the Great Depression dummy are significant across all regressions. The positive coefficient of the GDP partner variable ranges from 1.9 to 2.6. The negative coefficients for the Great Depression variable indicate that the global economic downturn had a significant adverse effect on Türkiye's exports, which is consistent with studies showing that economic crises disrupt trade by reducing demand and increasing barriers to international trade (Madsen, 2001; Broll

& Jauer, 2014). Other control variables, Türkiye's GDP, bilateral trade agreements and the sterling-lira exchange rate, are statistically insignificant in the export analysis. This is not unexpected given the structure of Türkiye's foreign trade during the interwar and early postwar periods. During this period, Türkiye's exports appear to have been largely driven by demand from partner countries rather than by fluctuations in domestic output. Similarly, bilateral trade agreements and exchange rate movements may have played a limited role in shaping export volumes during periods dominated by global economic disruptions, trade restrictions, and wartime controls.

Table: 2
Regression Results from Imports Analyses

Independent Variables	Imports			
	(1)	(2)	(3)	(4)
GDP Partner	2.769*** (4.88)	3.032*** (4.41)	2.571*** (5.24)	2.848*** (4.41)
GDP Türkiye	0.553 (1.08)	0.000969 (0.00)	0.449 (0.81)	-0.169 (-0.39)
Bilateral Trade Agreements	-0.0907 (-0.44)	-0.00888 (-0.05)	-0.166 (-0.76)	-0.0635 (-0.39)
Sterling/Lira Rate	0.607*** (4.08)	0.371** (2.43)	0.485*** (3.58)	0.273 (1.63)
Great Depression	-0.213* (-1.66)	-0.163 (-1.05)	-0.200* (-1.75)	-0.171 (-1.14)
Corrected Physical Distance		-0.173 (-0.77)		-0.111 (-0.50)
Corrected Contiguity		-5.975** (-2.31)		-6.612** (-2.45)
GPR Partner	-0.233*** (-2.91)	-0.178** (-2.40)		
GPR Türkiye	0.333*** (3.05)	0.284*** (3.14)		
Bilateral Tensions			-0.141 (-0.58)	-0.102 (-0.40)
# of Obs.	384	384	384	384
MRT	no	yes	no	yes

Notes: Estimates are based on Türkiye's imports from 14 trading partners during the period 1923-1950. The dependent variable is the value of imports, and the natural logarithm is taken of the numeric independent variables. The bilateral tensions variable is a dummy indicating whether Türkiye experienced tensions with the respective countries. The Great Depression variable is a country-specific dummy, with the League of Nations' (1939) industrial production index taken into account. The bilateral trade agreements dummy captures agreements such as clearing agreements, treaties of commerce and navigation, and tariff and payment agreements that Türkiye has signed with these countries. Columns 1 and 3 include physical distance and contiguity dummies, which are dropped since they are constant within the group. Columns 2 and 4 incorporate the corrected trade cost variables, calculated using the Baier and Bergstrand (2009) multilateral resistance terms. All regressions include country fixed effects and dummy variables, one of which captures WWII, to represent shifts in Türkiye's trade policies. z-statistics with robust standard errors from PPML estimations are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

With some minor differences, the results from the import analyses align with those from the export analyses, as shown in Table 2. According to this table, the geopolitical risk index of Türkiye's partners (*GPR partner*) has a negative and statistically significant effect on Türkiye's imports, while bilateral tensions have a negative but statistically insignificant effect. The import-reducing impact of the trading partner's GPR is similar to its effect on exports, particularly when the regression results in Column 2, which account for corrected trade cost terms, are considered. Specifically, a 1% increase in the partner country's GPR index leads to a 0.178 decrease in Türkiye's imports. This finding is consistent with Pollins (1989a, 1989b), who found a positive impact of cooperation, an alternative definition of political factors, on imports. According to the results in columns 1 and 2, in contrast to the adverse effects of partners' GPR on imports, Türkiye's GPR appears to facilitate imports,

consistent with the findings for exports. However, the positive impact of this variable is slightly stronger for imports than for exports.

In addition to the significant control variables in export analyses (GDP partner and Great Depression), the sterling/lira exchange rate also has a significant effect in the import regressions¹⁰. Contrary to expectations, an increase in the sterling/lira rate leads to an increase in Türkiye's imports. The composition of Türkiye's imports can explain this result during the analysis period, which included essential goods such as consumption and investment goods, allowing imports to continue growing despite the higher exchange rate¹¹. However, two points are noteworthy: first, the coefficient for the sterling/lira rate becomes insignificant in column 4, where bilateral tensions are used to represent political risks and corrected trade costs are accounted for. Second, in columns 2 and 4, the coefficient on the Great Depression becomes insignificant once trade costs are corrected. Moreover, the composition of imports and the global disruptions during this period may have rendered import flows less sensitive to domestic production fluctuations, bilateral policy arrangements, and geographic trade costs. This might explain insignificant coefficients for Türkiye's GDP, bilateral trade agreements and physical distance in the import analysis.

In summary, both the export and import analyses reveal that, considering the early years of Türkiye's foundation, the global risk perceived by its trading partners has a negative effect, while Türkiye's own global risk perception has a positive effect. The effect of bilateral tensions between Türkiye and its partners is statistically insignificant. The overlap of WWII with the analysis period, combined with the involvement of many of Türkiye's trading partners in the war, made it inevitable that both imports and exports would decline amid rising political risks. However, Türkiye's foreign policy, which prevented bilateral disputes from affecting trade and avoided intervention in tensions, helped mitigate these trade-reducing effects. During this time, Türkiye was dependent on imports of essential goods and sought to earn the foreign exchange needed to finance them through exports (Köklü, 1947: 75). As a result, Türkiye avoided conflicts with other countries to prioritise exports, which were crucial for the country's development. The focus was on economic growth, with an emphasis on securing borders and territorial integrity.

7. Concluding Remarks

Whether political factors affect international trade is a fundamental topic in the globalised world. Several studies have indicated that adverse political factors, such as conflicts and wars, reduce trade, while factors such as cooperation and alliances increase

¹⁰ Among the control variables used in this study, the literature highlights concern about the endogeneity of bilateral trade agreements (Baier & Bergstrand, 2007; Dai et al., 2014). To address this, the estimates were repeated without including this variable, and the findings remained unchanged.

¹¹ From the establishment of the Republic until the Great Depression, the proportion of consumer goods among imported products increased significantly. After 1929, the implementation of protectionist policies led to a decline in the proportion of consumer goods imports, while the share of raw materials and investment goods in imports grew (Tezel, 2015: 206-209; Özkardeş, 2015: 33).

trade between partners. Nevertheless, the lack of consensus in the literature on the effects of political factors warrants further study in the field. This study examines the factors influencing Türkiye's exports and imports with 14 trading partners in the early years of its establishment and investigates the effects of political risks using two variables. The first is the geopolitical risk index, a more globalised measure of political risk, while the second is a dummy variable constructed from tensions between Türkiye and its partner. Estimation results from the augmented gravity model show that, unlike the bilateral tensions dummy, the GPR has a significantly negative impact on Türkiye's exports and imports. This suggests that the rise in political risk resulting from global events had a detrimental impact on Türkiye's exports and imports.

The study reveals that tensions in Türkiye's bilateral relations did not significantly affect foreign trade, a finding attributable to factors such as security and economic development. First, it can be argued that Türkiye, as a newly established nation-state between 1923 and 1950, sought to safeguard its borders by prioritising security and avoiding conflicts with other states. Therefore, Türkiye implemented various policies to mitigate the negative impact on foreign trade through diplomatic manoeuvres during periods of heightened political risk. For instance, at the onset of WWII, Germany cancelled its loan agreement with Türkiye due to Türkiye's alliance with the UK and France. In response, Türkiye terminated its trade agreement with Germany. However, in 1941, Türkiye signed a non-aggression pact with Germany and subsequently renewed the trade agreement after German forces approached its borders. In 1944, Türkiye broke off relations with Germany under pressure from the Allies. In addition, the UK and the US pledged to increase trade with Türkiye. However, trade was negatively affected when bilateral tensions escalated to an international and global scale. For instance, Italy's invasion of Abyssinia and Türkiye's compliance with the League of Nations' economic sanctions resulted in a decline in trade between the two countries.

The second factor explaining why the GPR is statistically significant in determining exports and imports, rather than the bilateral tensions dummy, is that international trade played a crucial role in Türkiye's economic development during the period in question. During this time, imports became a key factor, particularly in acquiring essential consumer goods, machinery, and equipment, all of which significantly contributed to Türkiye's economic development. Similarly, exports were of considerable importance, as the foreign exchange needed to finance imports was generated by exports. Consequently, foreign trade was vital to Türkiye's economic development.

These findings carry important policy implications, particularly when evaluated through the lens of Türkiye's neutrality policy during the interwar and WWII periods. The significant negative effect of GPR and the lack of a statistically significant effect of bilateral tensions suggest that Türkiye's deliberate strategy of maintaining neutrality and avoiding prolonged bilateral conflicts played a crucial buffering role, preserving trade relations even amid heightened international uncertainty. By prioritising security, diplomatic flexibility,

and economic continuity, Türkiye was able to mitigate the trade-disrupting effects that typically accompany political frictions.

From a contemporary policy perspective, these historical findings underline the potential advantages of strategic neutrality and diversified diplomatic engagement for non-major economies facing increasing geopolitical fragmentation. Although the global context differs from the interwar period, geopolitical risks, sanctions, and regional conflicts have become increasingly salient today. In such environments, maintaining balanced foreign relations and minimising direct political confrontations with trading partners may help reduce trade volatility and safeguard access to critical imports and export markets. Policies emphasising diplomatic manoeuvrability, multilateral engagement, and trade diversification can serve as effective tools for enhancing economic resilience in the face of global political shocks.

It is important to acknowledge several limitations of this study. First, analysing yearly data restricts the ability to observe certain bilateral tensions, particularly those that last for only a brief period. Furthermore, the findings based on aggregate trade values may differ if the data are disaggregated by commodity group. Ultimately, these results reflect the overall trade patterns across the 14 trading partners examined in this study. Therefore, when trade between Türkiye and a specific country declines due to tensions and that decline is offset by increased trade with another country, it becomes challenging to isolate the precise impact of those tensions. Therefore, these concerns should be addressed in future research.

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Appendices

Table: A1
Event/Conflict List

Country	Conflict	Years
France	Minority and Foreign Schools	1926-1928
France	The accident between the French ship Lotus and the Turkish ship Bozkurt	1926-1927
France	Nationalisation of Mersin-Tarsus-Adana Railway	1929
France	The Hatay Issue	1936-1939
Germany	The Chromium Issue	1939
Germany	Invasion of Greece by Germany	1941
Germany	Cutting off Relations with Germany due to Pressure from the Allies	1945-1947
Germany	Türkiye's Declaration of War on Germany	1945
Italy	Second Italo-Ethiopian War	1935-1936
Italy	Dodecanese Islands	1936
Italy	Italy's 'Mare Nostrum' Policy	1937-1938, 1941
Italy	Italian Invasion of Albania	1939
Italy	Greco-Italian War	1940
Japan	Türkiye's Declaration of War on Japan	1945
Soviet Russia	The Turkish Straits Crisis	1936-1950
UK	Mosul Question	1923-1926
UK	The Political Rapprochement between Türkiye and Germany	1941
UK	The Allied Pressure on Türkiye to Join Their Ranks	1942-1945
US	The Political Rapprochement between Türkiye and Germany	1941
US	The Allied Pressure on Türkiye to Join Their Ranks	1942-1945

Note: The events listed in the table represent the tensions Türkiye experienced in its bilateral relations during the analysis period. Based on these events, we constructed the bilateral tensions dummy variable, assigning it a value of 1 for the time intervals listed in the table and 0 for years with no tensions.

Source: Identified and compiled by the authors, primarily based on Oran (2018) and Sönmezoglu (2015). Additional references include Hale (2021), Criss (2017), VanderLippe (2001), Beck (1981), De Luca (1977) and Khadduri (1945). Further details are provided in Section 4.

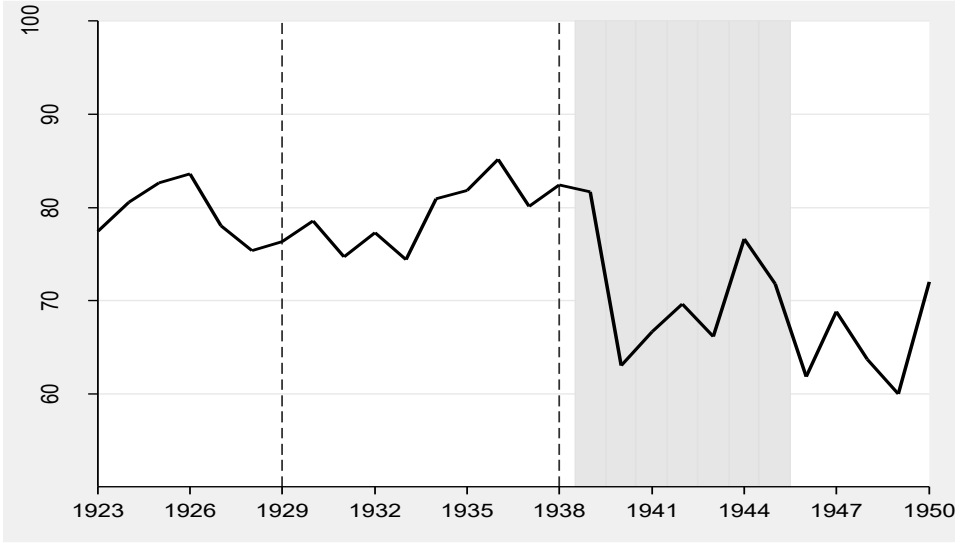
Table: A2
Bilateral Trade Agreements Signed by Türkiye and Their Duration (1923-1950)

Country	The period of the Trade Agreement	Reference
Belgium	1927-1940	Ökçün & Ökçün (1974)
	1947-1950	Sertel & Yedek (2015), Sertel (2015)
Brazil	1933-1950	Sangüzel (2022)
Germany	1927-1938	Tezel (2015)
	1941-1944	Karavar (2019)
	1948-1950	Ökçün & Ökçün (1974)
US	1929-1950	Ökçün & Ökçün (1974)
UK	1930-1950	Ökçün & Ökçün (1974), Arslan (2022)
France	1929-1950	Ökçün & Ökçün (1974)
Netherlands	1926-1950	Ökçün & Ökçün (1974)
Spain	1935-1950	Ökçün & Ökçün (1974)
Sweden	1928-1950	Ökçün & Ökçün (1974)
Switzerland	1927-1950	Ökçün & Ökçün (1974)
Italy	1929-1950	Ökçün & Ökçün (1974)
Japan	1931-1939	Ökçün & Ökçün (1974)
USSR	1928-1938	Ökçün & Ökçün (1974)

Note: We constructed the bilateral trade agreement variable used in the analyses by considering the various agreements Türkiye signed with its trading partners during the analysis period, including trade and navigation agreements, trade agreements, clearing agreements, and trade and payment agreements. It is an indicator variable that takes a value of 1 for the time intervals indicated in the table and 0 for the other years. The agreements and their respective durations were obtained from the sources listed in the table.

Source: Identified and compiled by the authors.

Figure: A1
The Share of the Countries Used in the Analyses of Türkiye's Total Exports



*Note: The figure illustrates the share of countries in Türkiye's total exports between 1923 and 1950. Vertical dashed lines mark the period of the Great Depression (1929-1939), while a grey-shaded area highlights the WWII era (1939-1945).
Source: TUIK (2014) and Fouquin & Hugot (2016).*

Figure: A2
The Share of the Countries Used in the Analyses of Türkiye's Total Imports



Note: The figure illustrates the share of countries in Türkiye's total imports between 1923 and 1950. Vertical dashed lines mark the period of the Great Depression (1929-1939), while a grey-shaded area highlights the WWII era (1939-1945).
Source: TUIK (2014) and Fouquin & Hugot (2016).

The Impact of Immigrants on Economic Growth Through R&D and Innovation in the EU

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AB'de Göçmenlerin AR-GE ve İnovasyon Yoluyla Ekonomik Büyümeye Etkisi

Abstract

Migration, driven by political and economic dynamics, has become an increasingly intense global phenomenon, posing significant challenges for European Union (EU) countries. This study examines the impact of migration on economic growth within EU member states. The effects of migration vary: skilled labour contributes to research and development (R&D) and innovation processes, whereas unskilled labour influences economic, social, and cultural transformations. Although the literature extensively explores the relationship between migration and R&D and innovation, the economic implications of this relationship have been studied to a lesser extent. To address this gap, our research analyses data from 28 EU countries for the period 1996-2021 using the autoregressive distributed lag (ARDL) bounds testing approach. The findings indicate that migration has a substantial positive effect on economic growth in the short term, whereas its long-term impact is relatively lower. Furthermore, foreign direct investment and R&D expenditures have been identified as factors supporting economic growth. While the socio-cultural effects of migration are beyond the scope of this study, they can be considered to parallel its economic impacts. The results of this analysis provide valuable insights for policymakers and researchers seeking to understand the direct and indirect effects of migration on economic growth.

Keywords : Immigrants, R&D, Innovation, Economic Growth, ARDL Bounds Test.

JEL Classification Codes : E22, F22, O32, O40.

Öz

Göç olgusu, siyasi ve ekonomik dinamikler nedeniyle küresel ölçekte giderek yoğunlaşan ve Avrupa Birliği (AB) ülkeleri için önemli sonuçlar doğuran bir sorundur. Bu çalışmada, göçün AB ülkelerindeki ekonomik büyümeye etkileri incelenmektedir. Göçün etkileri, nitelikli işgücü açısından AR-GE ve inovasyon süreçlerine katkı sağlarken, nitelsiz işgücü bağlamında ekonomik, sosyal ve kültürel dönüşümlere yol açmaktadır. Literatürde, göçün AR-GE ve inovasyon üzerindeki etkileri kapsamlı bir şekilde ele alınmış olsa da, ekonomik etkileri nispeten daha az incelenmiştir. Bu bağlamda, çalışmamız mevcut literatürdeki boşluğu gidermeyi amaçlayarak, 1996-2021 dönemi itibarıyla 28 AB ülkesine ait verileri ARDL sınır testi yöntemiyle analiz etmektedir. Analiz sonuçları, göçün kısa dönemde ekonomik büyümeyi yüksek oranda, uzun dönemde ise görece düşük düzeyde etkilediğini ortaya koymaktadır. Ayrıca, doğrudan yabancı yatırımların ve AR-GE harcamalarının ekonomik büyümeyi desteklediği belirlenmiştir. Çalışmada, göçün sosyo-kültürel etkileri inceleme dışında bırakılmış olmakla birlikte, bu etkilerin ekonomik sonuçlarla paralellik gösterdiği söylenebilir. Analiz bulguları, göçün ekonomik büyüme üzerindeki doğrudan ve dolaylı etkilerini anlamak açısından politika yapıcılar ve araştırmacılar için önemli bir referans noktası oluşturmaktadır.

Anahtar Sözcükler : Göçmenler, Ar-Ge İnovasyon, Büyüme, ARDL Sınır Testi.

1. Introduction

The effect of migration on economic growth through productivity largely depends on migrants' qualifications and manifests through various mechanisms (Kangasniemi et al., 2012). Immigrants may contribute to innovation by increasing total factor productivity (Chellaraj et al., 2015) or facilitate knowledge transfer through migration (Møen, 2000). In this study, the impact of immigrants on economic growth through innovation, a subject found to be insufficiently addressed in the literature, is examined using the ARDL bounds testing approach. Research and Development (R&D) encompasses all activities aimed at developing new applications and methods based on accumulated knowledge. The direct and indirect impact of R&D activities on economic growth has been the subject of numerous studies. In today's world, where global competition is intensifying, countries are engaged in fierce rivalry in fields such as information technology, transportation, innovation, and technological advancements. In this competition, R&D emerges as a central factor. Countries and firms that fail to keep pace with this competition often lag in science and innovation, significantly affecting their development levels and production capabilities. Consequently, these dynamics trigger a "brain drain" characterised by the migration of individuals specialised in innovative thinking and problem-solving. A defining feature of this modern economic paradigm, accelerated by globalisation, is the continuous evolution and renewal of technology. Systematic efforts directed toward such technological advancements are conceptualised as Research and Development (R&D) (Yıldırım & Kaya, 2018: 792).

Migration movements, which began in 2011 with Syria and Libya, subsequently spread to other Middle Eastern and North African countries and eventually extended to Afghanistan, now rank among the most pressing global challenges. Additionally, during the study period, events such as the 2008 global financial crisis and the 2019-2020 COVID-19 pandemic have had significant impacts. The productivity-enhancing effects of migration can be observed in the complex interplay among factors such as the characteristics of the sectors that employ migrants, whether migrants serve as substitutes or complements to the local workforce, and the unique attributes of the migrants themselves.

The effects of migrant labour can be direct, indirect, positive, or negative. Innovation, as a key driver of productivity, is influenced both directly by migrants' contributions to R&D and indirectly by the positive externalities generated when migrants' knowledge and skills are transferred to local researchers (Hunt & Gauthier-Loiselle, 2010: 31-56). Fixed capital investments and foreign direct investments (FDI) also directly influence economic growth (Şıklar, 2024: 43-59). The indirect impact of migration on economic growth via productivity largely depends on migrants' unique characteristics and manifests through various channels (Kangasniemi et al., 2012: 333-343). Migrants may affect total factor productivity through their contributions to innovation (Chellaraj et al., 2015: 444-462) or increased knowledge

transfer resulting from migration (Møen, 2000). Addressing a perceived gap in the literature, this study utilises the ARDL bounds testing approach to examine the impact of immigrants on economic growth through the channel of innovation.

2. Literature Review

The relationship between migrants, innovation, and economic growth has not been extensively studied, whereas innovation and economic growth have been the subject of numerous studies. When reviewing the relevant literature in this field:

Table: 1
Literature Table (Migration-Economic Growth)

Author(s)	Sample-Period	Method	Findings
Dustman, Fabbri & Preston (2005)	United Kingdom 2000	Survey Implementation	*
Huber et al. (2010)	EU Countries and OECD Countries, 2007-2013	Regression Analysis	Migration increases productivity and human capital (+)
Kangasniemi et al. (2012)	United Kingdom and Spain, 1990-2000	Cobb-Douglas	United Kingdom + Spain -
Ottaviano & Peri (2012)	USA 1990-2006	Regression Analysis	+
Peri (2012a); Peri (2012b)	USA 1960-2000	Three-Stage Least Squares	Migration increases productivity +
Alesina, Harnoss & Rapoport (2013)	195 Countries, 1990-2000	Generalised Method of Moments (GMM)	+
Bove & Elia (2017)	230 Countries, 1960-2010	Panel Data Analysis	+

Notes: M: Mixed Results, *: No Relationship, +: Positive Relationship, -: Negative Relationship

Table: 2
Literature Table (R&D -Economic Growth)

Author(s)	Sample-Period	Method	Findings
Erdil & Sahin (2015)	15 OECD Countries 1990-2013	Panel Data Analysis	+
Altıntaş & Mercan (2015)	21 OECD Countries 1996-2011	Panel Data Analysis	+
Meçik (2014)	OECD Countries 1990-2012	Panel Data Analysis	+
Oğuztürk & Yuysal(2023)	AB Countries and 21 OECD Countries, 2015-2020	Panel Data Analysis	+
Linhntenberg (1992)	74 Countries, 1964-1989	Granger Causality Test	+
Goel & Ram (1994)	18 Developed, 52 Developing Countries 1960-1980	Causality Test	*
Coe & Helpman (1995)	24 Ülke 1971-1990	Cointegration Test	+
Bronwyn & Mairesse (1995)	Fransa, 1970-1980	Causality Test	+
Sylwester (2001)	16 OECD Countries, 1981-1996	Causality Test	M
Ülkü (2004)	20 OECD Countries, 20 other countries, 1981-1997	Causality Test	+
Zachariadis (2004)	10 OECD Countries, 1971-1995	Panel ARDL	+
Yangun & Mingquan (2004)	8 Asian Countries 1994-2003	Causality Test	+
Yaylalı (2010)	Türkiye 1990-2003	Cointegration	+
Bravo-Ortega & Garcia-Marin (2011)	65 Countries 1965-2005	Panel Data Analysis	+
Göçer (2013)	11 Asian Countries 1996-2012	Causality Test	+
Gülmez & Yardımcıoğlu (2012)	21 OECD Countries 1990-2010	Panel FMOLS	+
Gülmez & Akpolat (2014)	Türkiye and EU Countries 1990-2010	Causality Test	+
Bozkurt (2015)	Türkiye 1980-2013	Cointegration Test	+
Özbay (2020)	Countries from Different Income Groups, 1995-2018	Arrelano-Bond GMM and Driscoll-Kraay	+
Özbay et al. (2020)	China 1986-2018	Causality Test	+
Akarsu et al. (2020)	14 Countries 1996-2017	Causality Test	+
Blanco, Prieger & Gu (2013)	USA 1963-2007	Causality Test	+
Szarowska (2017)	20 EU Countries 1995-2013	Panel Data Analysis	+

Notes: M: Mixed Results, *: No Relationship, +: Positive Relationship, -: Negative Relationship

Studies in the literature examining the relationship between migration and economic growth have predominantly employed regression and panel data analyses. A nearly universal finding across these studies is that migration positively impacts economic growth. Similarly, research investigating the nexus between R&D and economic growth has largely utilised

panel data analysis and causality tests; these studies consistently conclude that R&D expenditures and activities foster economic growth.

3. Data & Methodology

In this section of the study, the variables used in the research will be introduced, followed by a preliminary analysis of these variables.

3.1. Definition and Preliminary Data Analysis

In this section of the study, the impact of migration on economic growth in European Union countries will be examined based on data for the 1996-2021 period. The availability of data for the variables to be used has been a decisive factor in determining the study period. Per capita GDP (y) will be used as the dependent variable to represent the volume of economic activity and growth. In the model to be developed for our purposes, the net number of migrants (nim) and the ratio of R&D expenditures to GDP (rd) for these countries will be included as explanatory variables, while the ratio of fixed capital investments to GDP (inv) and the ratio of net foreign direct investment to GDP (fdi) will be included as control variables.

Considering that the effects of these explanatory and control variables on economic activities will manifest with a certain lag, the model to be estimated can be written as follows:

$$y_t = f(nim_{t-i}, rd_{t-i}, inv_{t-i}, fdi_{t-i}) \quad (1)$$

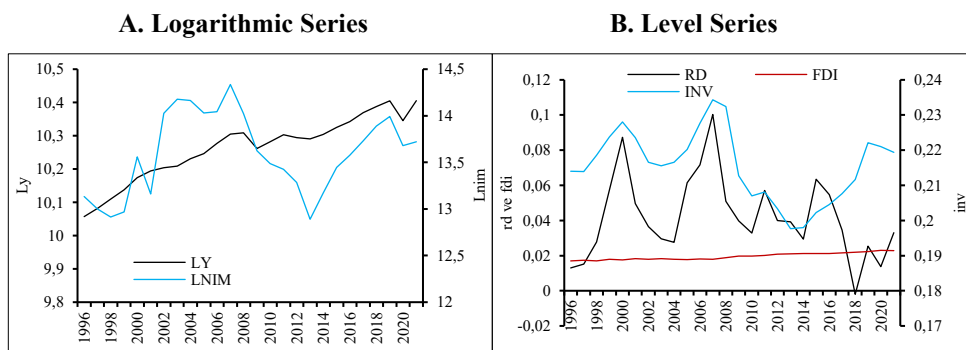
For the EU member countries, annual data for all variables included in the above model for the 1996-2021 period were obtained from the World Bank data portal. Real values measured at 2015 constant prices were used to calculate all data employed in the study. In the estimation process, the y and nim series will be included in the model at their logarithmic levels, while the other variables will be included at their levels.

The trends followed by these variables during the study period are presented in two separate graphs in Figure 1. In Section A of the figure, developments in real per capita income (left axis) and changes in the net number of migrants to these countries (right axis) are shown on a logarithmic scale. In Section B, the observed trends in the ratios of R&D expenditures, fixed capital investments, and net foreign direct investments to GDP are displayed.

As illustrated in Figure 1A, between 2001 and 2008, the relative dominance of global peace and the impact of global financial expansion caused real income (\$ y) to increase at a significantly higher rate than net migration (\$ nim). However, during the 2008-2021 period, this relationship was negatively affected by the global escalation of the crisis that originated in the US, followed by an increase in terrorist attacks and armed conflicts. As shown in Figure 1B, there was a positive linear correlation between R&D (RD) expenditures

and net foreign direct investment (INV) between 1996 and 2011. Similar to the dynamics observed between real income and net migration, this trend can be attributed to the relative prevalence of global peace and financial expansion. Following the terrorist attacks in the US and the subsequent impact of regional wars since 2011, migration patterns have become more selective, and the intensity of foreign capital movements has diminished.

Figure: 1
The Trend of Model Variables During the Study Period



Tables 3 and 4 summarise, respectively, the descriptive statistics of the model variables and the correlation matrix between the variables. According to Table 3, the variable with the highest standard deviation is net migration, while the variable with the lowest standard deviation is direct foreign investment. Given the waves of migration and the political stability experienced by European countries, this situation can be considered natural. In fact, while the skewness values of most model variables are negative, all the time series used follow a normal distribution. On the other hand, according to the correlation matrix, per capita real income shows the highest correlation with direct foreign investments. In this context, the high positive correlation between net migration and per capita real income is also noteworthy. New investments from external sources positively influence economic growth, indicating a synchronised relationship between the two variables. Another interesting point in the correlation table is the negative correlation coefficient between fixed capital investments and per capita income during the study period. This situation contradicts theoretical expectations and is largely due to the rapid and significant decrease in the investment-to-GDP ratio during the 2008 Global Crisis and the subsequent 2010 debt crisis in Europe, particularly during 2008-2014. The ratio, which was 23.4% in 2007, fell to 19.8% by the end of 2014 and increased only moderately, reaching 21% by the end of the study period. All correlation coefficients are statistically significant at the 1% significance level.

Table: 3
Descriptive Statistics of Model Variables

Indicator	<i>ly</i>	<i>lnim</i>	<i>rd</i>	<i>inv</i>	<i>fdi</i>
Mean	10.2636	13.5946	0.0419	0.2154	0.0195
Median	10.2866	13.6003	0.0379	0.2161	0.0192
Maximum	10.4053	14.3358	0.1003	0.2343	0.0230
Minimum	10.0571	12.8898	-0.0020	0.1977	0.0170
Standart Deviation	0.0955	0.4341	0.0233	0.0100	0.0019
Skewness	-0.5386	-0.0987	0.5902	-0.0142	0.3064
Kurtosis	2.5461	1.8347	3.2769	2.2746	1.6702
Jarque-Bera (Probability)	1.4803 (0.4771)	1.5132 (0.4693)	1.5927 (0.4510)	0.5709 (0.7517)	2.3226 (0.3131)
Number of Observations	26	26	26	26	26

Table: 4
Correlation Matrix of Model Variables

	<i>ly</i>	<i>lnim</i>	<i>rd</i>	<i>inv</i>	<i>fdi</i>
<i>ly</i>	1				
<i>lnim</i>	0.4429	1			
<i>rd</i>	0.0155	0.2153	1		
<i>inv</i>	-0.1726	0.4585	0.3878	1	
<i>fdi</i>	0.8587	0.0427	-0.2983	-0.4423	1

3.2. Estimation Methodology

The Autoregressive Distributed Lag (ARDL) method is a forecasting technique that allows testing the relationship between a dependent variable and a set of independent variables, regardless of the stationarity level of the independent variables (Pesaran & Shin, 1999). Following the techniques proposed by Pesaran, Shin & Smith (2001) and Jordan & Phillips (2018), the ARDL model will be used in this study to examine the long- and short-term relationships between economic activities and the explanatory variables specified in equation (1).

First, to test the existence of a long-term relationship between per capita GDP (*ly*) and the four explanatory variables [net migration (*lnim*), R&D expenditures (*rd*), investment expenditures (*inv*), and foreign direct investments (*fdi*)], we will use the ARDL Bound Test proposed by Pesaran, Shin & Smith (2001). The model created for this purpose, within the context of the function given in equation (1), is as follows:

$$\begin{aligned}
 \Delta ly_t = & \alpha_0 + \varphi_1 ly_{t-1} + \varphi_2 lnim_{t-1} + \varphi_3 rd_{t-1} + \varphi_4 inv_{t-1} + \varphi_5 fdi_{t-1} \\
 & + \sum_{i=1}^{q_1} \gamma_1 \Delta ly_{t-i} + \sum_{i=0}^{q_2} \gamma_2 \Delta lnim_{t-i} + \sum_{i=0}^{q_3} \gamma_3 \Delta rd_{t-i} \\
 & + \sum_{i=0}^{q_4} \gamma_4 \Delta inv_{t-i} + \sum_{i=0}^{q_5} \gamma_5 \Delta fdi_{t-i} + \xi_t
 \end{aligned} \quad (2)$$

In this equation, Δ represents the first difference operator, α_0 is the constant term, φ_i (for $i = 1, \dots, 5$) denotes the long-term coefficients, γ_i (for $i = 1, \dots, 5$) represents the short-term coefficients, q_i indicates the lag length, and ξ_t is the error term with traditional properties. The hypotheses to be tested for the coefficients obtained from the estimation of equation (2) are as follows:

$$H_0: \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = 0$$

$$H_1: \varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4 \neq \varphi_5 \neq 0$$

According to the test results, if the null hypothesis (H_0) is accepted, it implies that there is no cointegration between the variables. If the null hypothesis is rejected and the alternative hypothesis (H_1) is accepted, it suggests the presence of a long-term relationship between the variables.

If a cointegrating relationship exists between the variables, the long-term and short-term dynamics of this relationship can be tested through the dynamic ARDL simulation model proposed by Jordan & Phillips (2018). According to this method, the following equation needs to be estimated:

$$\begin{aligned} \Delta ly_t = & \beta_0 + \sum_{i=1}^{m_1} \delta_1 ly_{t-i} + \sum_{i=0}^{m_2} \delta_2 lnim_{t-i} + \sum_{i=0}^{m_3} \delta_3 rd_{t-i} + \sum_{i=0}^{m_4} \delta_4 inv_{t-i} + \\ & \sum_{i=0}^{m_5} \delta_5 fdi_{t-i} \\ & + \sum_{i=0}^{n_1} \theta_1 \Delta lnim_{t-i} + \sum_{i=0}^{n_2} \theta_2 \Delta rd_{t-i} + \sum_{i=0}^{n_3} \theta_3 \Delta inv_{t-i} + \sum_{i=0}^{n_4} \theta_4 \Delta fdi_{t-i} \\ & + \vartheta ECT_{t-1} + \zeta_t \end{aligned} \quad (3)$$

In this equation, β_0 represents the constant term, δ_i (for $i=1, \dots, 5$) represents the long-term coefficients, θ_i (for $i=1, \dots, 4$) represents the short-term coefficients, m_i and n_i represent the lag lengths of the variables, ECT_{t-1} is the error correction term indicating the speed of adjustment towards equilibrium (v), and ζ_t represents the error term with traditional properties.

Compared to the traditional long-term static model, the dynamic ARDL simulation model provided in equation (3) allows testing the effects of both positive and negative shocks in any of the independent variables. This makes the model a widely used forecasting technique in recent literature (Arfaoui, 2018; Sarkodie & Strezov, 2019; Khan et al., 2023).

4. Estimation Results

4.1. Stationary Analysis

The degree of integration $[I(p)]$ of the time series used in this study was examined using the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Structural Break Dickey-Fuller (BDF) tests. In all tests, the presence of a constant term and trend was initially assumed. In cases where the trend coefficient was found to be insignificant, the test was re-run using only the constant term. The estimation results for these three tests are summarised in Table 5.

Table: 5
Unit Root Analysis of Model Variables

Variable	ADF Test			PP Test			Structural Break DF Test			Result
	k^1	t -ratio	ρ^2	z^1	t -ratio	ρ	k	t -ratio	ρ	
ly	0 ³	2.7661	0.22	3 ³	2.6959	0.25	0 ³	3.6228	0.62	$I(1)$
Δly	0	5.1304	0.00	2	5.1334	0.00	0	6.5407	0.00	
$lnim$	5 ³	6.2974	0.00	1 ³	6.8374	0.00	5 ³	8.2458	0.00	$I(0)$
rd	2 ³	4.6564	0.01	0	2.9997	0.04	2 ³	6.2832	0.00	$I(0)$
inv	1	2.5303	0.12	1	1.7655	0.39	1	3.8085	0.23	$I(1)$
Δinv	0	3.0595	0.04	4	2.9039	0.06	1 ³	4.9987	0.03	
fdi	0 ³	2.1268	0.51	2 ³	2.1292	0.51	3 ³	3.8113	0.49	$I(1)$
Δfdi	0	6.0754	0.00	2	5.9858	0.00	0	8.0891	0.00	

Notes: 1. The optimal lag length according to the Schwarz criterion.

2. Represents the probability value.

3. The relevant estimation is conducted with the trend component included.

4. The optimal bandwidth according to the Newey-West criterion.

According to Table 5, the unit root tests yield consistent results for the variables, although the significance levels vary. Specifically, the per capita real GDP (log), investment-to-GDP ratio, and foreign direct investment (FDI)-to-GDP ratio variables are unit root processes in levels but become stationary in first differences. In contrast, the net immigration (logarithmic) and R&D expenditure-to-GDP ratio variables are already stationary at their levels as they do not contain unit roots. Based on these results, the model variables are integrated into different orders. Therefore, the ARDL model is an appropriate method for estimating and examining the short- and long-run relationships among the variables.

4.2. ARDL Bounds Test

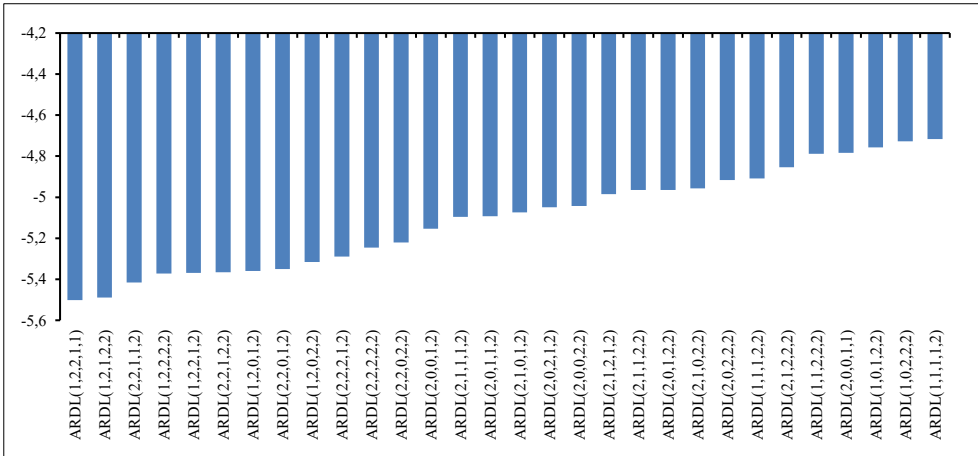
The existence of a cointegration relationship indicates a long-run equilibrium between the explanatory variables and the dependent variable. If at least one cointegrating vector can be identified among the model variables, then the variables move toward an equilibrium value in the long run. The ARDL bounds test is a method used to investigate the presence of this relationship. To this end, the optimal lag lengths of the explanatory variables to be included in the ARDL model must first be determined, and the model selection should be made accordingly. For this purpose, among the 162 estimated models, the one that minimises the Bayesian Information Criterion (BIC) is considered optimal. Figure 2 summarises the BIC values of the top 30 models that yielded the best results. According to the figure, the model that minimises the BIC among the estimated models is the ARDL(1,2,2,1,1) model. The results of the bounds test, calculated using this model, are presented in Table 6.

Table: 6
ARDL(1,2,2,1,1) Bound Test Results

	Critical Values for the F Test			F Test	Probability
	%10	%5	%1		
$n = 30$ Lower Bound	2.525	3.058	4.280	--	--
$n = 30$ Upper Bound	3.560	4.223	5.840	--	--
Asymptotic Lower Bound	2.200	2.560	3.290	--	--
Asymptotic Upper Bound	3.090	3.490	4.370	--	--
Calculated F Value	--	--	--	18.575	0.000

Note: Critical values are obtained using the Stata code provided in Jordan & Phillips (2018).

Figure: 2
Bayesian Information Criterion (Top 30 Models)



According to the boundary test results, regardless of the sample size, the null hypothesis of “no relationship at the level of the variables” is rejected at the 1% significance level based on the upper bound. This implies that there is a long-run cointegrated relationship between the variables included in the model. In other words, the model variables have a long-term relationship. Based on this outcome, we can proceed to estimate the dynamic ARDL model, as previously outlined in Equation (3), to identify the long- and short-term relationships between the variables.

4.3. Dynamic ARDL Simulation Model Estimation Results

The table summarises the error correction estimation results for the dynamic ARDL model. From a long-term perspective, the first notable finding is a positive and statistically significant relationship between immigration and economic activity. Although this effect is relatively small compared to other variables included in the model as control variables, the positive and significant result supports the theoretical expectations outlined in the introduction of this study. In this context, it should be noted that foreign direct investments (FDI) and R&D expenditures have the strongest and statistically significant long-term effects on economic growth. The only result that does not align with the theoretical expectations is the effect of investment expenditures on economic activities. The coefficient obtained for this variable is negative. While all long-term parameters in the model are statistically significant at the 1% significance level, the significance level for investment expenditures is set at 10%. In summary, the two variables with the strongest positive relationship with long-run economic growth are foreign direct investment and R&D expenditures, while the net migration rate has a positive but weak impact on growth.

Table: 7
Dynamic ARDL (1,2,2,1,1) Model Error Correction Estimation Results

Variable	Parameter	Coefficient Estimate	Standard Error	t - ratio	Marginal Significance
<i>Constant</i>	β_0	10.5296	1.6453	6.3998	0.0000
<i>ly_{t-1}</i>	δ_1	-1.2409	0.1969	6.3017	0.0000
<i>lnim_{t-1}</i>	δ_2	0.0939	0.0198	4.7378	0.0005
<i>rd_{t-1}</i>	δ_3	1.8981	0.2776	6.8367	0.0000
<i>inv_{t-1}</i>	δ_4	-0.6991	0.3735	1.8720	0.0858
<i>fdi_{t-1}</i>	δ_5	5.1518	0.8174	6.3029	0.0000
<i>Alnim_t</i>	θ_{11}	0.0133	0.0125	1.0710	0.3053
<i>Alnim_{t-1}</i>	θ_{12}	-0.0480	0.0113	4.2483	0.0011
<i>Ardi</i>	θ_{21}	0.3809	0.1383	2.7542	0.0175
<i>Ardi_{t-1}</i>	θ_{22}	-0.9079	0.1699	5.3430	0.0002
<i>Δinv</i>	θ_3	4.2425	0.6222	6.8180	0.0000
<i>Δfdi</i>	θ_4	3.5732	1.3173	2.7126	0.0189
<i>Diagnostic Tests</i>					
AdjR ² = 0.8390 ¹			Jarque-Bera = 2.6208 (0.2697)		
F = 11.8975 (0.0001) ²			Breusch-Pagan-Godfrey = 0.7829 (0.6539)		
Breusch-Godfrey = 2.5495 (0.1386)			Wald ($\delta_j = 0$) = 9.6425 (0.0016)		

Notes: 1. The determination coefficient adjusted for degrees of freedom.

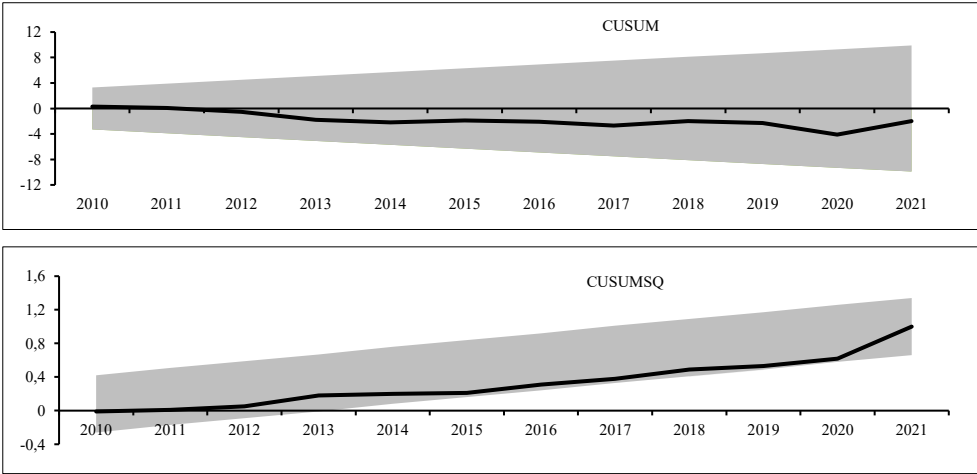
2. Values in parentheses represent the marginal significance level for the corresponding diagnostic test.

The estimated model aligns with theoretical expectations for short-term dynamics. For example, in the short term, the coefficient on immigration is initially positive but not statistically significant, whereas the coefficient on the one-period lag is negative and statistically significant at the 1% level. Taken together with the small but significant coefficient obtained for the long term, these results indicate that an increase in net migration to EU countries has a variable effect on per capita income in the short term, but a supportive effect on economic growth in the long term. However, this contribution is limited.

In terms of short-term dynamics, all coefficients included in the model as control variables are significant at the 5% level or higher and yield results consistent with theoretical expectations.

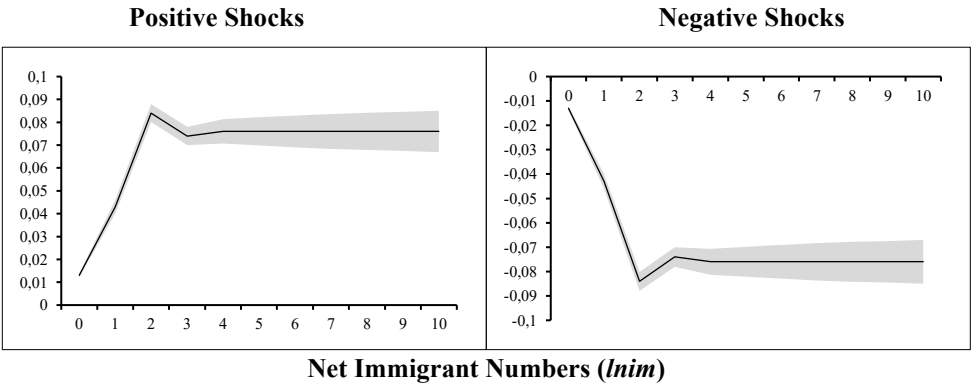
In the context of ARDL model estimation, diagnostic tests play a crucial role in ensuring the consistency and reliability of the estimated results. As presented in the lower section of Table 7, the model demonstrates sufficient explanatory power (AdjR²) and does not exhibit specification errors, as indicated by the F-test. Furthermore, the residuals from the model are free of autocorrelation (as evidenced by the Breusch-Godfrey test), follow a normal distribution (as indicated by the Jarque-Bera test), and do not exhibit heteroscedasticity (as indicated by the Breusch-Pagan-Godfrey test). Moreover, the hypothesis that the long-term coefficient of net migration equals zero is robustly rejected, as shown by the Wald test. The stability of the model is also confirmed by the results of the CUSUM and CUSUMSQ tests, as depicted in Figure 3. These findings collectively suggest that the estimated model is consistent, statistically valid, and free from major econometric issues.

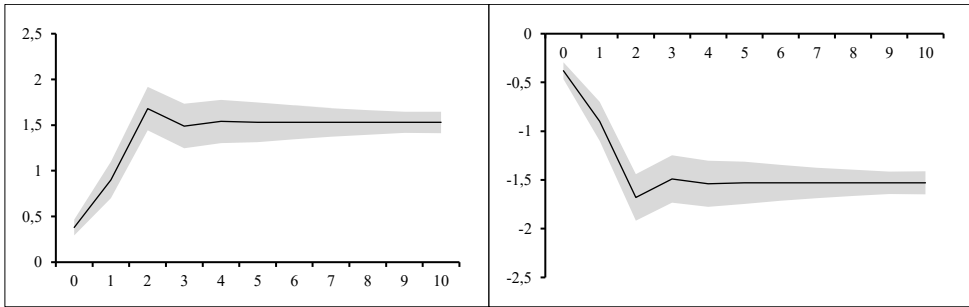
Figure: 3
CUSUM and CUSUMSQ Tests Results



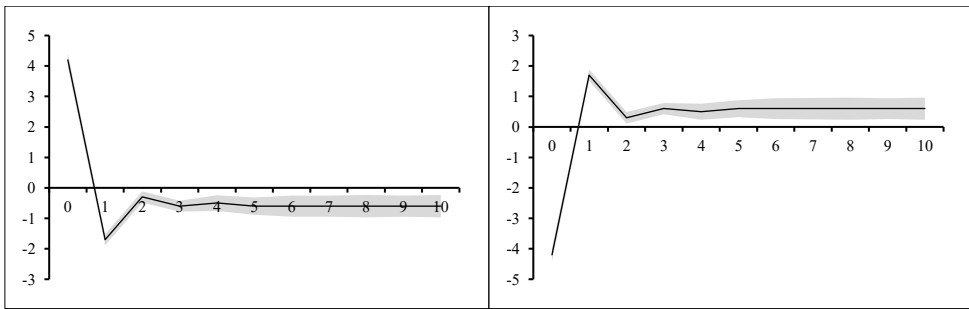
The dynamic ARDL model offers a distinct advantage over the traditional ARDL model by allowing the parameter vector to be simulated based on a multivariate normal distribution. In this context, it becomes possible to assess the impact of 1% positive and negative shocks in each explanatory variable on the dependent variable. Figure 4 presents the corresponding graphs prepared for this purpose. The left panel of the figure illustrates the effect of a 1% positive shock in the explanatory variables on the dependent variable, while the right panel demonstrates the impact of a 1% negative shock. The shaded areas in the graphs represent the 95% confidence intervals.

Figure: 4
Response of the Dependent Variable to Shocks

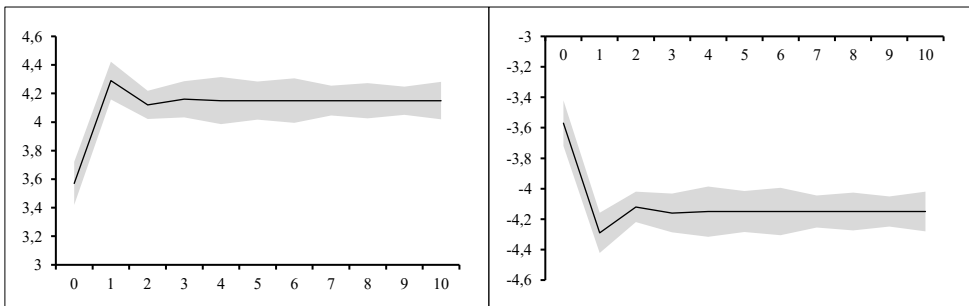




Research and Development Expenditures (*rd*)



Fixed Investment Expenditures (*inv*)



Net Foreign Direct Investments (*fdi*)

In the first row of Figure 4, the response of per capita real income to a 1% positive and a 1% negative shock in the number of immigrants shows a limited yet rapid increase within the first two years, followed by stabilisation in subsequent years. A negative shock, on the other hand, yields the opposite effect. The impact of a 1% positive shock to the number of immigrants on income remains permanent, at 0.076%. Although this effect is limited, it remains positive. Among the explanatory variables included in the model, the most significant impact is observed from foreign direct investments (FDI), followed by R&D expenditures. A 1% positive shock to foreign direct investment and R&D expenditures results in permanent increases in per capita real income of 4.15% and 1.53%, respectively,

from the third year onward. A 1% positive shock to investment expenditures leads to a 4% increase in per capita income during the shock period, but this effect turns negative starting in the first year and remains at -0.6% in subsequent years. This deviation from theoretical expectations can be explained by the rapid, long-term decline in the fixed capital investment-to-GDP ratio observed during 2008-2014.

5. Conclusion

The increasing economic and political instability worldwide has made migration inevitable. In particular, the turmoil and wars in the Middle East have created a migration issue, especially for Western countries, including the European Union (EU), along with the socioeconomic consequences this issue generates. These challenges require special scrutiny and solutions. EU countries tend to regard migration flows as a source of skilled labour, utilising the resulting increase in human capital through R&D and innovation to benefit their economies. All these developments have led to the emergence of new areas in the literature. To contribute to this growing literature, the effects of migration and R&D on economic growth through innovation were investigated using data from 1996-2001 for the 28 EU Countries. The literature review indicates that this is the first study to examine the impact of both migration and R&D on economic growth. Therefore, it is expected to address a significant gap in the existing literature.

According to ARDL model testing, migration to the EU, composed of skilled human capital, positively affects economic growth in the short term at a high rate, while in the long term, its effect, though weaker, remains positive. This suggests that a selective approach to accepting migrants, as seen in Türkiye, without considering their qualifications, could negatively affect long-term economic growth.

When foreign direct investments and R&D expenditures are viewed as sources of innovation, the findings indicate that a 1% shock in these areas positively affects economic growth by 4.15% and 1.53%, respectively. The fact that the effect of investment becomes negative after a period is inconsistent with the literature. Several events, such as the global financial crisis of 2008, the 2011-2013 earthquake in Japan, the increased migration from Syria and Libya, and the negative impacts of the 2019 COVID-19 pandemic, have influenced the results during the period under review. The rapidly increasing R&D activities in East Asia, led by China, highlight the need for the EU to invest more in this field.

In conclusion, it has been determined that migration to the EU, limited to skilled workers, and R&D activities positively affect economic growth. Based on this, Türkiye should reconsider its current migration policy, focusing on the acceptance of skilled labour and placing greater emphasis on R&D activities. The exclusion of Türkiye from the analysis is due to the lack of a dataset containing variables that could define migration and skilled labour, which is not in line with the nature of this study.

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A Valuation of Onshore Wind Energy Investments Using a Real Options Approach: The Case of Onshore Wind Energy in Türkiye

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Reel Opsiyon Yaklaşımı ile Kara Tipi Rüzgâr Enerjisi Yatırımlarının Değerlemesi: Türkiye’de Kara Tipi Rüzgâr Enerjisi Yatırımı Örneği

Abstract

This paper aims to evaluate the investment value of an onshore wind farm in Türkiye using traditional methods and the simple abandonment-option approach, and to demonstrate how real options analysis captures the value of managerial flexibility under uncertainty. The results indicate that the onshore wind farm project is more sensitive to changes in electricity prices, discount rates, installed costs, and capacity factors, respectively. The abandonment option increases the strategic net present value by \$65,583, reaching \$2,811,575, while the project value with flexibility is \$17,120,419. This paper contributes to the literature on the country-specific valuation of onshore wind energy investments.

Keywords : Investment Valuation, Renewable Energy Sources, Real Options, Binomial Tree.

JEL Classification Codes : D81, G11, G31, Q42.

Öz

Bu çalışmanın amacı, Türkiye’de bir kara tipi rüzgâr enerjisi yatırımını geleneksel proje değerlendirme yöntemleri ve terk etme reel opsiyon yaklaşımı kullanarak değerlemek ve reel opsiyon analizinin belirsizlik altında yönetimsel esnekliğin yatırım değerini nasıl etkilediğini tespit etmektir. Duyarlılık analizi sonucunda kara tipi rüzgâr enerjisi yatırımının sırasıyla elektrik fiyatlarındaki, iskonto oranlarındaki, kurulum maliyetlerindeki ve kapasite faktörlerindeki değişikliklere daha duyarlı olduğu sonucuna ulaşılmıştır. Terk etme opsiyonu ile birlikte yatırımın stratejik net bugünkü değeri 65.583 \$ artarak 2.811.575 \$’a ulaşırken, yönetimsel esneklikle birlikte yatırım değeri 17.120.419 \$’a yükselmiştir. Bu çalışma, karasal rüzgâr enerjisi yatırımlarının ülke bağlamında değerlendirilmesine yönelik literatüre katkı sunmaktadır.

Anahtar Sözcükler : Yatırım Değerleme, Yenilenebilir Enerji Kaynakları, Reel Opsiyon, Binom Ağacı.

1. Introduction

The United Nations General Assembly adopted the Sustainable Development Goals in 2015, establishing a comprehensive framework for global collaboration to achieve a sustainable future for the planet. Agenda 2030 includes 17 Sustainable Development Goals and 169 associated goals, which focus on eradicating extreme poverty, combating injustice and inequality, and safeguarding the environment. Energy lies at the core of the 2030 Agenda. Sustainable Development Goal 7 ensures access to affordable, reliable, sustainable, and modern energy for all. Achieving Sustainable Development Goal 7 is increasing the proportion of renewable energy in the world's energy mix and energy efficiency worldwide.

The global transition to renewable energy is essential for sustainable development and for preventing catastrophic climate change. Wind technology is at the forefront of this transition, supporting the goals of the 2015 Paris Agreement (IEA, 2021). In 2024, with 117 GW of wind power installed, this energy source is expanding into new regions and solidifying its role as a key component of the global energy transition. According to GWEC Market Intelligence, new installations are projected to exceed the previous record, reaching 138 GW by 2025. Over the next five years, a total of 982 GW of new capacity is expected to be added under current policies, averaging 164 GW annually until 2030 (GWEC, 2025). Annual financial commitments in onshore wind energy have increased to \$140.70 billion, with a 117% increase (IRENA & CPI, 2023).

Global developments and Türkiye's ratification of the Paris Agreement have compelled the country to take strategic action in renewable energy. These external commitments coincide with domestic pressures; the impressive growth in Türkiye's population and industrial landscape has sparked a dramatic increase in electricity consumption. While this is exciting, it also highlights a challenge: current electricity production struggles to keep up with this rising demand. Consequently, Türkiye relies heavily on foreign energy sources, resulting in a considerable current account deficit and raising serious environmental concerns associated with non-renewable fossil fuels. This situation presents an urgent opportunity to pivot towards more sustainable energy solutions. Research conducted in 2016 revealed that the most significant concern within the Turkish energy system was its dependence on imported energy. Subsequent studies from 2017 to 2019 highlighted the increasing burden of expensive energy (Ediger et al., 2017, 2018, 2019). Leveraging renewable energy sources is crucial for reducing this reliance and mitigating escalating energy costs. Increasing renewable energy production can significantly enhance national energy security, reduce reliance on energy imports, fuel economic growth, and lower trade deficits. Moreover, a substantial increase in renewable energy usage may play a key role in stabilising oil and natural gas prices, ultimately benefiting consumers and businesses (Öztürk, 2014: 2).

Türkiye ranked among the top 10 countries for onshore wind electricity generation in 2022, producing 34.945,4 GWh. The installed onshore wind energy capacity in Türkiye reached 12,973 MW in 2024 (IRENA, 2025). Despite positive developments in the wind

energy sector, progress in the renewables sector is assessed as "slow progress" in Türkiye. Türkiye needs to adopt additional policies and actions to halt emissions growth and begin reducing them to achieve decarbonization. The Roadmap for Renewable Energy to 2035 policy of Türkiye, combined with investments in grid infrastructure, is a crucial step towards decarbonising the grid. The recently announced Roadmap aims to deploy renewables at a rate of "at least" 7.5-8 GW a year until 2035, along with investments of USD 28 bn to upgrade the grid. To improve its climate targets and action rating, Türkiye could strengthen its wind and solar targets to bring 150 GW of capacity online by 2035 and enhance and substantiate its recently submitted long-term climate strategy to reach net zero by 2053. Türkiye could also set a stronger 2030 Nationally Determined Contributions (NDCs) target and submit a 2035 NDCs that go beyond current policies and drive emissions reductions (CAT, 2025).

The increasing investments in wind energy, government incentives, and global sustainable development commitments highlight the importance of valuing wind energy investments. Traditional valuation methods, such as the payback period and net present value, often fail to capture uncertainty and managerial flexibility. More sophisticated financial tools are needed to assess renewable energy investments, as policy, price, and technological uncertainties significantly affect investment decisions in the sector. Frolova et al. (2025) analysed abandoned renewable energy power plants in Europe and South America. They identified reasons for abandonment as economic issues, poor planning, lack of management, technological issues, and other interests. Abandonment of renewable energy plants should be considered in the valuation of renewable energy investments, as Mun (2006:32) states that the strategic abandonment option has significantly increased the investment's value and hedged its downside risk.

Global and domestic developments, as well as national net-zero commitments, underscore the value of renewable energy investments in Türkiye, which has a slowly progressing renewables sector and significant potential. This paper aims to value an onshore wind farm investment in Türkiye using the abandonment options approach and to demonstrate how real options analysis captures the value of managerial flexibility under uncertainty. The results of this paper are significant for wind energy investments in Türkiye, which has high potential but has made less progress in the renewables sector. This paper contributes to the existing literature by modelling onshore wind energy investments in depth using real options for abandonment and sensitivity analysis. This paper fills a gap in the literature concerning country-specific valuation of onshore wind energy investments in Türkiye. This paper contributes to the literature by focusing on future abandonment decisions for onshore wind plants, which pose an increasing risk to valuation and the planet.

The paper is structured as follows. Section 2 details the literature on real option valuation of wind energy investments. Section 3 presents the research model, methods, data, and assumptions for the financial model of onshore wind energy investment. Section 4 discusses the results and their implications. Section 5 is the conclusion.

2. Literature Review

The energy sector faces significant uncertainty due to volatility in energy and energy commodity prices in international markets. Investment projects in this sector are time-consuming, large-scale, and high-cost (Lin & Wesseh Jr., 2013: 475). These uncertainties in the energy sector significantly impact the feasibility of energy investments. Conventional capital budgeting methods often fail to account for expected market uncertainty.

Wu and Sun (2015) conducted a comparative analysis of methods used across different projects by surveying Chinese enterprises about their evaluation practices for wind power projects. Their findings revealed that Chinese enterprises primarily relied on traditional methods, specifically, the income method and the market method, to assess wind power projects. Only a small percentage of companies utilised the relatively new real options method. The enterprises indicated that their reluctance to adopt this method stemmed from its difficulty in meeting the internal rate of return standards.

The real option method, which incorporates management's decision flexibility in response to uncertainty into the model, is widely used in the valuation literature on renewable energy investments, even though the industry has not fully adopted this method, as shown by the results of Wu and Sun (2015). Table 1 summarises various studies that have utilised the real options method to analyse the feasibility of wind energy investments and assess the impact of several uncertainties on these investments. A summary of the references reviewed throughout this work is shown in Table 1.

Table: 1
Literature on Wind Energy Investment Analysis by Real Option Analysis

Year	Authors	Country	Uncertainties
2002	Venetsanos et al.	Greece	Fossil fuel prices, environmental regulations, demand and supply, initial capital cost, and technology
2004	Fleten & Maribu		Price
2006	Yu et al.	Spain	Price and demand
2007	Zhou et al.	California	Price
2008	Kumbaroğlu et al.	Türkiye	Tariff
2008	Dykes & de Neufville	Ohio	Price and policy
2010	Lee & Shih	Taiwan	Fossil fuel price and feed-in-tariff guarantee
2010	Cheng et al.		Price, cost, and policy
2011	Lee	Taiwan	Underlying price, exercise price, time to maturity, risk-free rate, volatility
2013	De Mare et al.	Italy	The selling price of electricity, the plant's annual manufacturability, and the price of green certificates.
2013	Detert & Kotani	Mongolia	Coal price
2014	Abadie & Chamorro	England	The electricity price, the level of wind generation, and the certificate price
2014	Kim et al.	Korea	Price
2014	Barroso & Iñiesta	Germany	Price, cost, technology
2014	Kroniger & Madlener	Germany	Price and wind
2016	Toptaş	Türkiye	-
2017	Loncac et al.	Serbia	Discount rates, capacity factor, FIT guaranteed, inflation rate, capital expenditures, corporate tax, CAPEX, OPEX escalation rate, and electricity FIT premium
2018	Gazheli & van den Bergh	-	Energy prices and technology costs

As shown in Table 1, many studies noted that various factors affect wind energy investments. Those studies demonstrated that the real options evaluation model is appropriate for evaluating the value of wind energy investments. Renewable energy investments face several political and technical uncertainties, and real options modelling

allows for the evaluation of these uncertainties in wind energy investments. Therefore, the research model in this paper utilises the real options method.

The vast real option valuation literature on wind energy primarily focuses on price as an uncertainty, as shown in Table 1. There are no more papers that include a full range of uncertainties in the real option modelling of wind energy investments. The in-depth study by Loncar et al. (2017) demonstrates that incorporating flexibility enhances project value compared to static discounted cash flow (DCF) analysis. They found that, specifically, the sequential and expansion options improve expected returns, while contraction, repowering, and abandonment options provide downside protection under unfavourable scenarios.

Kumbaroğlu et al. (2008) proposed a policy planning model that accounts for both renewable and non-renewable energy costs, availability factors, capacity factors, learning rates, and construction lead times. This model integrates learning-curve information for renewable power generation technologies into a dynamic programming framework that incorporates real options analysis. The empirical data, drawn from the Turkish electricity supply industry, examine six energy portfolio allocation policies and offer valuable insights into how uncertainty influences the adoption of emerging renewable energy technologies. Additionally, Toptaş (2016) assessed a wind energy investment in Türkiye using a delayed real options method.

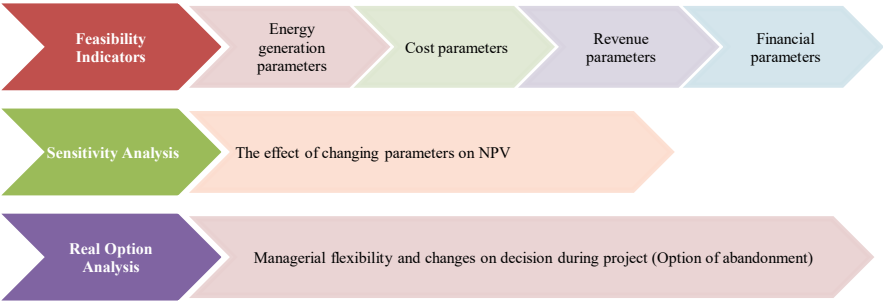
The literature review highlights the need for a more comprehensive and country-specific analysis. Therefore, this study aims to evaluate the investment value of an onshore wind farm in Türkiye using traditional methods and the simple abandonment-option approach, and to demonstrate how real options analysis captures the value of managerial flexibility under uncertainty. This paper also contributes to the country-specific renewable energy investment analysis literature by conducting a sensitivity analysis to examine how investments respond to various operational and economic factors in Türkiye. Accordingly, the following section introduces the methodological design developed to evaluate onshore wind energy investments.

3. Methodology

3.1. Research Model

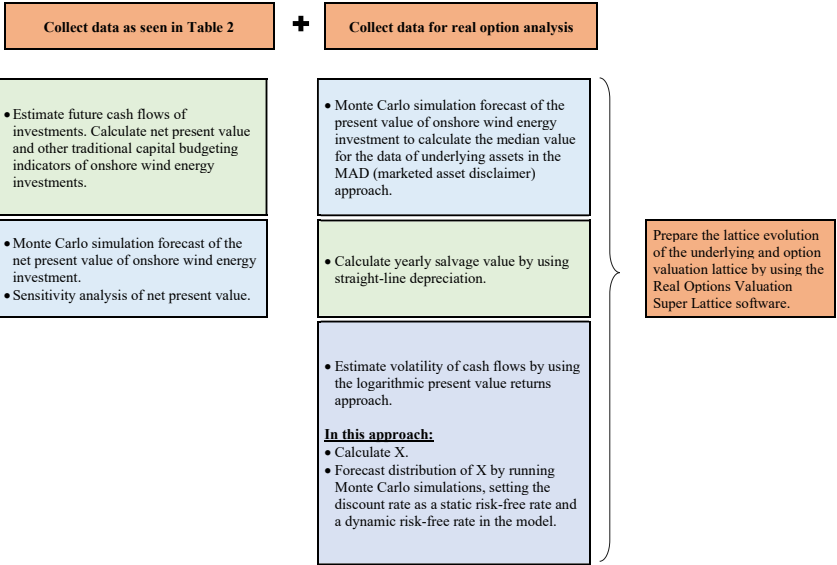
The research model is presented in Figure 1. In the initial stage, the net present value (NPV) of onshore wind energy investments is calculated by evaluating production, costs, revenues, and various financial parameters. Subsequently, a sensitivity analysis is conducted to assess the impact of variations in these parameters on the NPV. Finally, the analysis addresses the implications of management's decision to abandon possible investments, which may arise from the low efficiency of turbines or other materials utilised during installation due to rapid technological advancements, on the feasibility of onshore wind energy investments throughout the economic life.

Figure: 1
The Research Model



The research steps are presented in Figure 2 for clarity.

Figure: 2
The Research Steps



3.2. Real Option Analysis Method

A real option is simply an integrated solution and a systematic approach that applies financial theory, economic analysis, management science, decision sciences, statistics, and

econometric modelling to the valuation of real physical assets, rather than financial assets, in an uncertain and flexible business environment (Mun, 2006: 30).

Traditional capital budgeting approaches, such as discounted cash flow analysis and payback periods, do not fully capture project value for several reasons. They assume that investment decisions are irreversible, overlook interactions between current and future decisions, and ignore management's flexibility in decision-making over the project's economic horizon. However, managerial flexibility adds value to investment because management can utilise it to enhance asset value in favourable conditions or to minimise losses in unfavourable situations by exercising real options (Vintila, 2007: 47). Through the application of real option analysis, investors can analyse market conditions more effectively, as better information is obtained and uncertainty is reduced. Unlike traditional methods, which neglect uncertainty in electricity prices, real options modelling considers such uncertainty and other uncertainties (Santos et al., 2014: 593).

Since energy investments are technology-intensive, rapid technological change significantly affects their valuation. Developments in technology enable turbines, which account for the largest share of the cost in wind farms, to be produced more cheaply, thereby rapidly reducing the cost of power plant installations. With the abandonment option, when market conditions worsen, or capital equipment becomes obsolete due to technological changes, management can abandon the investment by disposing of the power plant at its scrap value (Lee, 2011: 4447). The positive side of abandonment is that it prevents the loss from growing further, which reduces cash outflows, especially in the case of a large-scale, irreversible investment project that was abandoned earlier. If the value of continuing the investment is less than the salvage value, the project should be abandoned. Traditional capital budgeting neglects this option (Myers & Majd, 1983: 2).

The real options method offers several advantages, but personnel may lack the necessary skills to conduct a thorough analysis, necessitating the involvement of external experts. Additionally, real option analysis demands continuous monitoring and evaluation of the available options. This flexibility and the need for options come with a cost in terms of attention and computing power. Moreover, decision-makers often fear that altering their strategy in a politically sensitive context may be viewed as a sign of failure. Thus, they require unambiguous strategies when facing an uncertain future. Implementing the real options method also depends on high-quality data on uncertainty and the costs of flexibility, which can be challenging to estimate, especially in infrastructure projects. To address these challenges, it is beneficial to employ flexible and innovative infrastructure solutions rather than traditional ones, justifying any additional costs through real options analysis (Herder et al., 2011: 963-966).

This paper uses the binomial method for real options analysis. The binomial method is a numerical method used in option valuation. Since the decision can be made at any time using the discrete-time approach, this method is suitable for real options analysis (Brach, 2003: 52).

The input parameters for the binomial lattice approach include the underlying asset's value (S), the strike price (X), the time to maturity (T), the volatility of the underlying asset (σ), the risk-free interest rate (rf), and continuous dividend payments (b) (Mun, 2006: 129).

There are two different approaches to solving binomial lattices. The first approach is the replicating portfolio approach, where a replicating portfolio is created to match the NPV, but its payouts must match those of the deferral option. The second approach is the risk-neutral approach, in which a hedge portfolio is constructed to determine the option's value (Peters, 2016: 21). Mun (2006) states that the results from the market-replicating portfolio approach are identical to those from the risk-neutral probability approach.

The binomial lattices divide the option's life into small time intervals, where the probability of the underlying asset price rising or falling by a specific rate is calculated (Arnold, 2014: 44). In the binomial lattices, it is crucial to compute the factors (u and d) representing the upward and downward movements of the underlying asset value, as specified in Equations 1, 2, and 3, along with the risk-neutral probability measure (p) (Mun, 2006: 128).

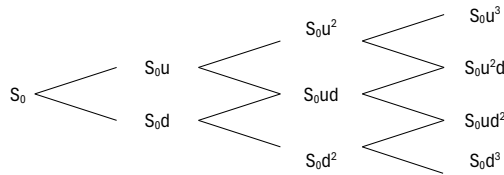
$$u = e^{\sigma\sqrt{\delta t}} \quad (1)$$

$$d = e^{-\sigma\sqrt{\delta t}} = 1/u \quad (2)$$

$$p = (e^{(rf - b)(\delta t)} - d)/(u - d) \quad (3)$$

In the initial stage of the binomial lattices, the first binomial lattice illustrated in Figure 3 is generated by multiplying the underlying asset's current value by both the up and down factors (Mun, 2006: 165).

Figure: 3
Binomial Lattice of the Underlying Asset Value



Calculating the option valuation lattice is the second step. The intrinsic value of the option, $\text{Max} [(X-S), 0]$ for a put option and $\text{Max} [(S-X), 0]$ for a call option, is the option value at each last node of the lattice, or when the option expires (Loncar et al., 2017: 362).

The construction of the option valuation lattice occurs in two phases: first, the valuation of the terminal nodes, and second, the valuation of the intermediate nodes using backward induction. The first lattice values are generated in a forward multiplication of up

and down factors, from left to right. The second lattice calculates values in reverse order, beginning with the terminal nodes, so that the nodes at the end of the lattice are valued first, progressing from right to left using Equation 4 (Mun, 2006: 164).

$$\text{Intermediate Value} = (p * P_u + (1 - p) * P_d) * e^{(-rf * \delta t)} \quad (4)$$

P_u : The value of a put option when the underlying asset's value increases

P_d : The value of a put option when the underlying asset's value decreases

The last step is to calculate the strategic value of NPV, which includes management flexibility, using Equation 5. The expanded net present value (eNPV) is the sum of the base-case net present value and the value of strategic options. The eNPV accounts for both base-case analysis and the added value of flexibility, while the options value considers the value of flexibility, which is the capacity to execute on a strategic choice without being obligated to do so (Mun, 2002: 168).

$$eNPV = NPV + \text{Options Value} \quad (5)$$

3.3. Data

3.3.1. Data for Discounted Cash Flow Analysis

The discounted cash flow method, which is one of the traditional investment valuation models, is used to calculate feasibility indicators such as net present value, internal rate of return, and profitability ratios. The cost, production, revenue, and financial assumptions, which are inputs to the discounted cash flow method, are clearly outlined in Table 2 for the installation of a 10 MW onshore wind power plant. The weighted average cost of capital is used as the discount rate for calculating the net present value. The Capital Asset Pricing Model (Ross et al., 2003: 279) was employed to determine the equity cost of capital for calculating the weighted average cost of capital (WACC), as shown in Equation 6.

$$\begin{aligned} WACC = & \text{Cost of equity} \times \left[\frac{\text{Equity}}{\text{Debt} + \text{Equity}} \right] + \text{Cost of debt} \times \left[\frac{\text{Debt}}{\text{Debt} + \text{Equity}} \right] = \\ & \text{Risk free rate} + (\text{Beta} \times \text{Equity Risk premium}) \times \left[\frac{\text{Equity}}{\text{Debt} + \text{Equity}} \right] + \text{Pretax rate} (1 - \\ & \text{Tax rate}) \times \left[\frac{\text{Debt}}{\text{Debt} + \text{Equity}} \right] \end{aligned} \quad (6)$$

Table: 2
Assumptions and Probability Distributions for Monte Carlo Simulation

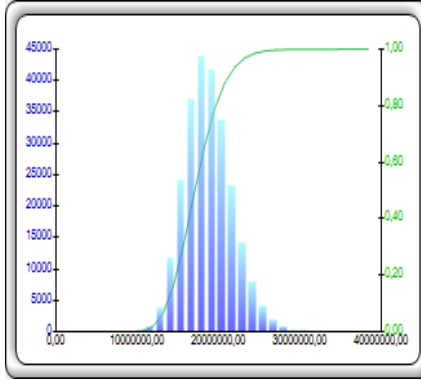
	Assumption	Unit	Value	Distribution	Source
Production	Capacity factor	%	37	Triangular (min 0,3 - max 0,43)	IRENA (2024) Average of 2018-2022
	Rated capacity	MW	10		
	Yearly electricity generation	MWh	32.412	It is calculated using the formula below: Capacity factor=Annual generation MWh / (365 days x 24 hours/day x Nameplate capacity MW)	
Revenue	Electricity price escalation	%	3	Lognormal (mean 0,028 - std. dev. 0,0028)	Inflation in USD is used.
	Electricity price	USD/MWh	83,65	Normal (72,925-94,365)	EPIAŞ Transparency Platform
	Investment horizon	years	25*		
Financial	Debt Ratio	%	70	This capital structure is assumed for the Renewable Energy Resource Area in Türkiye.	
	Equity Ratio	%	30		
	Risk-free interest rate	%	5,75%	Normal (mean 0,0575 - std. dev. 0,00575)	The Eurobond with ISIN US900123CM05 has a coupon rate of 5.750%. The bond will mature on May 11, 2047.
	Equity risk premium	%	12,42	Damodaran Online (Average of 2023-2025) (Damodaran, 2023;2024;2025)	
	Relevered beta		1,375	It is calculated using the unlevered beta for the green energy sector, sourced from Damodaran Online. (Damodaran, 2025 May)	
	Default spread	%	5,84	Damodaran Online data for Türkiye (Average of 2023-2025) (Damodaran, 2023;2024;2025)	
	Pre-tax cost of debt	%	11,59	It is calculated by summing the risk-free rate and the default spread (Damodaran, 2002)	
	Cost of equity	%	22,83	Calculated using the capital asset pricing model.	
	Weighted average cost of capital (WACC)	%	12,93	Normal (0,113 - 0,146)	
	Tax rate	%	25	Uniform (min 0.2 - max 0.3)	
	Operational expenditure (OPEX)	\$	286.800	Triangular (207.530,43 - 366.069,57)	2% of CAPEX
	OPEX escalation	%	3	Triangular (min 0,014 - max 0,042)	
Cost	Installed cost (CAPEX)	USD	14.340.000	Normal (12.502.255,06 - 16.177.744,94)	IRENA (2024)

Note: WindEurope indicated that the standard lifetime of a wind turbine is approximately 20-25 years. Therefore, a 25-year investment horizon was chosen (WindEurope, 2025).

3.3.2. Data for Real Option Analysis

Loncar et al. stated that because each wind farm project is different, regardless of its modular and scalable nature, and depends on a wide range of inputs, it is practically impossible to find such twin assets in the financial or commodity markets or in the world of real projects. The Marketed Asset Disclaimer (MAD) approach is designed to address the challenge of identifying the underlying asset in real option analysis (Guj & Chandra, 2019). The MAD approach uses the present value of the wind farm project as an underlying asset. Once the Monte Carlo simulation with 250,000 trials has been conducted on the discounted cash flow model using Risk Simulator software developed by Mun, the median PVP50 value for the Wind farm project is \$17,054,836, as shown in Figure 4. It is used as the underlying asset value in real option modelling.

Figure: 4
Monte Carlo Simulation Forecasts of Present Value of Onshore Wind Energy Investments (\$)



Number of Data Points	250,000
Mean	17.263.210
Median	17.054.836
Standard Deviation	2.913.813
Variance	8.490.305.859.236
Coefficient of Variation	0
Maximum	38.409.312
Minimum	6.849.983
Range	31.559.329
Skewness	0
Kurtosis	0
25% Percentile	15.211.979
75% Percentile	19.082.432
Error Precision at 95%	0

The salvage value at any time is the market value of the asset in its subsequent most productive use (Myers & Majd, 1983: 9). The strike price of the underlying asset is the salvage value of the asset in the abandonment real option (Smit & Trigeorgis, 2004: 117). The abandonment salvage value can change over time (Mun, 2006: 167). The straight-line depreciation method is used to calculate the investment's salvage value at the end of each year.

Probably one of the most difficult input parameters to estimate in a real options analysis is the volatility of cash flows (Mun, 2002: 197). The Logarithmic Present Value Returns Approach is used to estimate volatility. The cash flows are discounted to Time 0 and then to Time 1, with the Time 0 cash flows ignored (treated as a sunk cost). Then, the values are summed, and the following logarithmic ratio is calculated, as shown in Equation 7, where $PVCF_i$ represents the present value of future cash flows at different periods i . CF shows cash flows, and D is the discount rate in Equation 7.

$$X = \ln \left(\frac{\sum_{i=1}^N PVCF_i}{\sum_{i=0}^N PVCF_i} \right) = \ln \left(\frac{\frac{CF_1}{(1+D)^0} + \frac{CF_2}{(1+D)^1} + \frac{CF_3}{(1+D)^2} + \dots + \frac{CF_N}{(1+D)^{N-1}}}{\frac{CF_0}{(1+D)^0} + \frac{CF_1}{(1+D)^1} + \frac{CF_2}{(1+D)^2} + \dots + \frac{CF_N}{(1+D)^N}} \right) \quad (7)$$

To achieve the forecast distribution of variable X , it is recommended to conduct a Monte Carlo simulation based on the discounted cash flow model using the intermediate value of X . In the context of real option analysis, the risk-free interest rate was specifically employed as the discount rate. When implementing this approach, it is advisable to maintain the discount rate as a fixed risk-free rate. Subsequently, simulate the inputs for the discounted cash flow and calculate the resulting volatility. After completing this process, the discount rate should be reset to its original value (Mun, 2006: 198-199).

As a result of the Monte Carlo Simulation, volatility is determined to be 14.15% and 15.42%, respectively, when the simulation's risk-free interest rate is held constant and allowed to vary. The average volatility of 14,78% is used in binomial lattices.

3.4. Research Limitations

This paper excludes decommissioning costs because reliable decommissioning cost data are not available in any report for Türkiye. Residual value is also negligible because there is no policy in place for recycling or reusing wind turbines and other materials in Türkiye. Revenues from carbon reduction and working capital are not considered in the analysis of this study. Government incentives and subsidies are excluded from the analysis due to their variability.

4. Findings and Discussions

4.1. Risk Modelling Based on Net Present Value

Table 3 presents the results of conventional capital budgeting methods used in the financial modelling of onshore wind energy investments, without accounting for uncertainty.

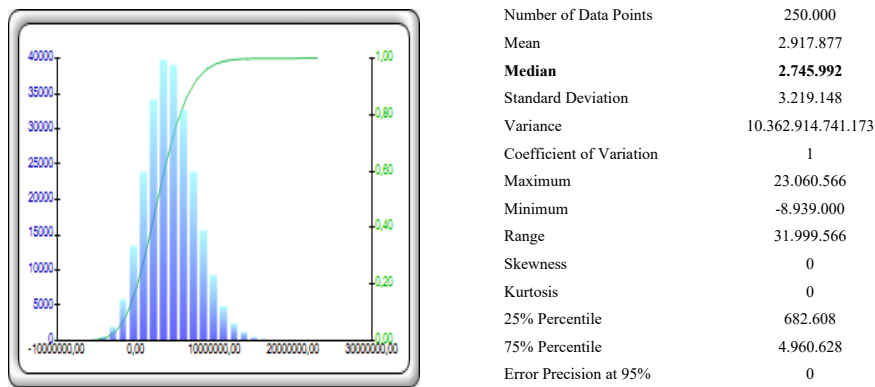
Table: 3
The Results of Discounted Cash Flow Analysis

Indicator	
Net Present Value	US\$ 2,952,412
Internal Rate of Return	%15,60
Payback Period	6,75 years
Discounted Payback Period	11,75 years

The results indicate that the net present value of the investment is positive. The internal rate of return is close to the discount rate. The payback period is short, but this method cannot account for the time value of money. The discounted payback period, considering the time value of money, is too long.

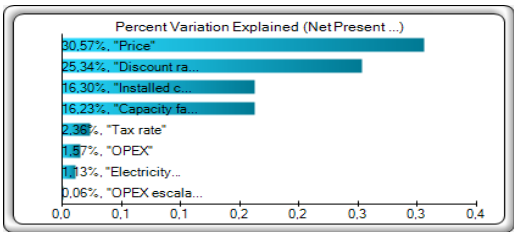
After 250,000 trials have been conducted on the discounted cash flow model, the median NPV_{P50} value for the onshore wind farm project is US\$ 2,745,992, as demonstrated in Figure 5. There is a slight difference between the static net present value in the previous step and the simulated median net present value.

Figure: 5
Monte Carlo Simulation Forecasts of Net Present Value of Onshore Wind Energy Investments (\$)



The net present value sensitivity chart, detailed in Figure 6, shows that the wind farm project is highly sensitive to electricity prices, with a sensitivity rate of 30.57%. The net present value of onshore wind investment is sensitive to the discount rate and installed cost, with a sensitivity of 25.34% and 16.30%, respectively. The wind farm's feasibility is sensitive to the capacity factor, which contributes 16.23%. Sensitivity to all other uncertainties is relatively minor, each being less than 3%.

Figure: 6
Sensitivity Analysis Results



4.2. Real Option Modelling

The Abandonment Option examines the value of a project's flexibility to be abandoned over the life of the option. The American option type is selected to analyse the effect of abandonment flexibility on the value of onshore wind energy investments because American options can be exercised at any time before or on maturity.

Real Options Valuation Super Lattice software, developed by Mun, is employed to address the real-option abandonment problem. Table 4 demonstrates the assumptions used

in the abandonment real option analysis. Monte Carlo simulation using the Risk Simulator software indicates that the volatility of this investment is estimated at 14,78%. The median PV_{P50} value for the wind farm project, \$17.054,836, as shown in Figure 4, is used as the underlying asset.

Table: 4
Assumptions for Real Option Analysis

Assumptions		Intermediate Computations	
<i>PV Asset Value (\$)</i>	\$17.054.836	<i>Stepping Time (dt)</i>	1,0000
<i>Volatility (%)</i>	14,78%	<i>Up Step Size (up)</i>	1,1593
<i>Risk-free Rate (%)</i>	5,75%	<i>Down Step Size (down)</i>	0,8626
<i>Dividends (%)</i>	0,00%	<i>Up Probability</i>	0,6626
<i>Maturity (Years)</i>	25,00	<i>Down Probability</i>	0,3374
<i>Lattice Steps</i>	25	<i>Discount Factor</i>	0,9441
<i>Option Type</i>	American		

Table 5 illustrates the results of a simple abandonment option with a 25-step lattice, while Table 6 shows the option valuation lattice generated from this analysis. The option value (RO) is calculated to be \$65.583. The abandonment option increases the net present value by \$65,583.

$$eNPV = NPV_{P50} + RO = \$ 2.745.992 + \$ 65.583 = \$ 2.811.575$$

while the project value with flexibility is:

$$PV_{P50} + RO = \$ 17.054.836 + \$ 65.583 = \$ 17.120.419$$

Table: 5
Lattice Evolution of the Underlying (\$)

0	1	2	3	4	5	6	7	8	9	10	11	12	13
17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305
	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921
		12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973
			10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975
				9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108
					8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356
						7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348
							6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563
								5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654
									4.509.714	5.228.026	6.060.751	7.026.114	8.145.241
										3.890.096	4.509.714	5.228.026	6.060.751
											3.355.611	3.890.096	4.509.714
												2.894.562	3.355.611
													2.496.860

Table: 5
(continued)

14	15	16	17	18	19	20	21	22	23	24	25
135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769	440.554.341	510.726.284	592.075.286	686.381.640
100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769	440.554.341	510.726.284
74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769
55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987
41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906
30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135
22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305
17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921
12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973
9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975
7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108
5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356
3.890.096	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348
2.894.562	3.355.611	3.890.096	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563
2.153.800	2.496.860	2.894.562	3.355.611	3.890.096	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654
	1.857.876	2.153.800	2.496.860	2.894.562	3.355.611	3.890.096	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241
		1.602.610	1.857.876	2.153.800	2.496.860	2.894.562	3.355.611	3.890.096	4.509.714	5.228.026	6.060.751
			1.382.418	1.602.610	1.857.876	2.153.800	2.496.860	2.894.562	3.355.611	3.890.096	4.509.714
				1.192.478	1.382.418	1.602.610	1.857.876	2.153.800	2.496.860	2.894.562	3.355.611
					1.028.636	1.192.478	1.382.418	1.602.610	1.857.876	2.153.800	2.496.860
						887.305	1.028.636	1.192.478	1.382.418	1.602.610	1.857.876
							765.293	887.305	1.028.636	1.192.478	1.382.418
								660.231	765.293	887.305	1.028.636
									569.517	660.231	765.293
										491.268	569.517
											423.769

Table: 6
Option Valuation Lattice (\$)

0	1	2	3	4	5	6	7	8	9	10	11	12	13
17.120.419	19.777.742	22.920.956	26.571.371	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
	14.904.893	17.074.109	19.772.598	22.920.594	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921
	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
		13.259.329	14.769.611	17.058.672	19.771.492	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973
		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
			12.619.200	12.864.947	14.723.323	17.055.289	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975
			Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
				12.045.600	11.472.000	12.726.277	14.712.984	17.054.839	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108
				Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
					11.472.000	10.898.400	11.056.973	12.694.703	14.711.572	17.054.836	19.771.348	22.920.548	26.571.356
					Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
						10.898.400	10.324.800	9.780.206	10.960.623	12.690.274	14.711.563	17.054.836	19.771.348
						Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue
							10.324.800	9.751.200	9.177.600	9.486.426	10.946.736	12.690.248	14.711.563
							Abandon	Continue	Continue	Continue	Continue	Continue	Continue
								9.751.200	9.177.600	8.604.000	8.282.592	9.442.882	10.946.654
								Abandon	Abandon	Abandon	Continue	Continue	Continue
									9.177.600	8.604.000	8.030.400	7.456.800	8.146.055
									Abandon	Abandon	Abandon	Abandon	Continue
										8.604.000	8.030.400	7.456.800	6.883.200
										Abandon	Abandon	Abandon	Abandon
											8.030.400	7.456.800	6.883.200
											Abandon	Abandon	Abandon
												7.456.800	6.883.200
												Abandon	Abandon
													6.883.200
													Abandon

Table: 6
(continued)

14	15	16	17	18	19	20	21	22	23	24	25
135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769	440.554.341	510.726.284	592.075.286	686.381.640
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769	440.554.341	510.726.284
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
7.028.670	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
6.309.600	6.068.776	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356
Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
6.309.600	5.736.000	5.253.218	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348
Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
6.309.600	5.736.000	5.162.400	4.588.800	5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563
Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
6.309.600	5.736.000	5.162.400	4.588.800	4.015.200	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654
Abandon	Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	Continue	End
	5.736.000	5.162.400	4.588.800	4.015.200	3.441.600	3.890.096	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241
	Abandon	Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	End
		5.162.400	4.588.800	4.015.200	3.441.600	2.894.562	3.355.611	3.890.096	4.509.714	5.228.026	6.060.751
		Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	End
			4.588.800	4.015.200	3.441.600	2.868.000	2.496.860	2.894.562	3.355.611	3.890.096	4.509.714
			Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	Continue	End
				4.015.200	3.441.600	2.868.000	2.294.400	2.153.800	2.496.860	2.894.562	3.355.611
				Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	End
					3.441.600	2.868.000	2.294.400	1.720.800	1.857.876	2.153.800	2.496.860
					Abandon	Abandon	Abandon	Abandon	Continue	Continue	End
						2.868.000	2.294.400	1.720.800	1.382.418	1.602.610	1.857.876
						Abandon	Abandon	Abandon	Continue	Continue	End
							2.294.400	1.720.800	1.147.200	1.192.478	1.382.418
							Abandon	Abandon	Abandon	Continue	End
								1.720.800	1.147.200	887.305	1.028.636
								Abandon	Abandon	Continue	End
									1.147.200	660.231	765.393
									Abandon	Continue	End
										573.600	569.517
										Abandon	End
											423.769
											End

5. Conclusion

Sustainable development goals entail a shift to renewable energy for countries. The increasing investment in renewable energy underscores the importance of financial modelling for long-horizon projects, as traditional capital budgeting methods often fail to account for market uncertainties over the entire horizon. Poor planning, lack of management, economic and technological issues, and other interests can affect the resumption of operations of renewable power plants, as Frolova et al. (2025) identified. Managers would abandon the project and sell facilities to stop the losses during the investment horizon. Therefore, this study discusses the valuation of an onshore wind energy investment using real options with the option to abandon.

Traditional feasibility indicators, such as net present value, internal rate of return, payback period, and discounted payback period, are calculated for onshore wind energy investments in the first step of this study. In real option analysis, the binomial tree method is used as an approach based on the risk-neutral valuation principle. In the valuation of onshore wind energy plant investments with real options, it is almost impossible to determine an asset with a similar risk and return profile that can be used as an underlying asset due to the differences in wind speed, energy loss, incentive amounts received, and various financial parameters of the power plants. Therefore, the Marketed Asset Disclaimer (MAD) approach was used in determining the underlying asset in real option analysis. In line with this approach, the present value of future cash flows from the discounted cash flow model for the onshore wind energy investment was used to determine the underlying asset value in real option modelling. In estimating volatility, the Logarithmic Present Value Returns Approach was used. Salvage value is estimated using the straight-line depreciation method.

Traditional capital budgeting methods determine that the onshore wind power plant project is feasible. The net present value of the investment is above zero. The internal rate of return is close to the discount rate. The payback period is short, but this method does not account for the time value of money. The discounted payback period, considering the time value of money, is too long. Sensitivity results demonstrate that the wind farm project is sensitive to electricity prices, the discount rate, installed costs, and capacity factors.

The value of a simple American-type abandonment option with a 25-step lattice is calculated as \$65,583. The abandonment option increases the strategic net present value by \$65,583, bringing it to \$2,811,575, while the project value with flexibility is \$17,120,419. These results are consistent with the literature, as they reflect the increasing strategic net present value of investments when using real options modelling.

Policymakers should not only focus on improving the legal and regulatory framework but also incorporate real options thinking to provide flexibility in managerial decision-making and address investor concerns in high-risk environments. This paper enhances the existing literature by providing financial modelling that equips decision-makers with sophisticated tools to evaluate market uncertainties and risks, potentially increasing investor interest in wind energy investments by reducing their concerns. Furthermore, the paper demonstrates that real options modelling is an essential tool for investors seeking to adopt flexible investment strategies and manage uncertainties effectively. There is a gap between real options theory and its practical application due to the theory's complexity and investors' limited knowledge of uncertainty modelling in investment. Collaboration between academia and industry on modelling renewable energy investments could help bridge this gap. This paper specifically examines the modelling of abandonment decisions in real options, deliberately excluding decommissioning costs. This exclusion is based on the observation that wind farm decommissioning often falls short of expectations due to insufficient regulatory obligations. However, it is essential to establish effective regulations and policies regarding wind farm decommissioning plans to ensure that these initiatives fulfil their

intended sustainability objectives. Moreover, procedures for abandoning or prematurely stopping projects should be clearly defined. If investors choose to abandon their renewable energy investments, a platform that facilitates the transfer of low-yield renewable power plants would be beneficial, rather than exiting the market entirely.

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Risk Assessment in Motor Insurance Using Generalised Linear Models in Small Markets: The Case of Bosnia and Herzegovina

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Küçük Ölçekli Pazarlarda Genelleştirilmiş Doğrusal Modeller Kullanılarak Motorlu Taşıt Sigortasında Risk Değerlendirmesi: Bosna Hersek Örneği

Abstract

Given the challenges of small and underdeveloped markets, a comprehensive approach to insurance risk analysis is essential. This paper develops and applies an actuarially justified and statistically robust methodology for motor insurance pricing in Bosnia and Herzegovina. The adequacy of Generalised Linear Models (GLMs) is assessed using a portfolio dataset covering 2011-2023, focusing on key policyholder and vehicle risk factors affecting claim frequency and severity. Comparison with existing market tariffs indicates that current premiums are generally underpriced. The proposed approach offers practical guidance for improving pricing accuracy and strengthening actuarial practices in such insurance markets.

Keywords : Risk Assessment, Motor Insurance, Generalised Linear Models, Small Markets.

JEL Classification Codes : G22, C31, C58.

Öz

Küçük ve gelişmemiş pazarların zorlukları göz önüne alındığında, bu pazarlar için kapsamlı bir sigorta risk analizi yaklaşımının geliştirilmesi önemli bir gereksinimdir. Bu çalışma, Bosna-Hersek'te motorlu araç sigortası fiyatlandırmasına yönelik aktüeryal bir bakış açısıyla ve istatistiksel olarak sağlam bir metodoloji geliştirip uygulamayı amaçlamaktadır. Genelleştirilmiş Doğrusal Modellerin (GLM) yeterliliği, 2011-2023 yıllarını kapsayan bir portföy veri seti kullanılarak değerlendirilmiş ve hasar sıklığını ve şiddetini etkileyen temel poliçe sahipliği ile araç risk faktörlerine odaklanılmıştır. Mevcut piyasa tarifeleriyle yapılan karşılaştırma, mevcut primlerin genellikle düşük fiyatlandırıldığını göstermektedir. Önerilen yaklaşım, bu tür sigorta pazarlarında fiyatlandırma doğruluğunu artırmak ve aktüeryal uygulamaları güçlendirmek için pratik bir rehber sunmaktadır.

Anahtar Sözcükler : Risk Değerlendirmesi, Motorlu Taşıt Sigortası, Genelleştirilmiş Doğrusal Modeller, Küçük Pazarlar.

1. Introduction

Pricing, also known as premium determination, is a fundamental aspect of insurance operations. Consequently, the development of a tariff structure that ensures an equitable distribution of claim burdens among policyholders is a key responsibility of actuaries (David, 2015b: 157). When setting insurance premium tariffs, actuaries assess risk and consider various explanatory variables, or risk factors. A common method for calculating motor insurance premiums is to use Generalised Linear Models (GLMs) to model claim frequency separately. Claim severity (Valecký, 2013: 161) as this allows for a clearer understanding of how each risk factor contributes to the premium (Ohlsson & Johansson, 2010: 34). GLMs allow for the modelling of non-linear effects and non-normal residual distributions, making them highly applicable in non-life insurance contexts (Strežo et al., 2019: 452). When setting insurance premium tariffs, actuaries assess risk and consider various observable risk characteristics, or risk factors (David, 2015a: 148).

Nowadays, the actuarial profession faces many challenges in setting adequate prices for insurance products. Given that real motor insurance data are not normally distributed, the class of GLMs based on exponential family distributions is considered a suitable solution. Despite its widespread use, particularly after the deregulation of insurance markets in the 1990s (Valecký, 2016: 683), the GLM approach continues to face significant methodological challenges that remain a key issue in actuarial practice. Throughout the GLM methodology, it is essential to address several key steps. It begins with selecting input variables, or predictors. This is followed by identifying the most suitable model specifications for claim frequency and severity, taking into account the underlying risk factors. Subsequently, the models are fitted and validated using diagnostic tools such as goodness-of-fit tests. The final step involves computing the premium amount by multiplying the frequency and severity relativities. Following this methodological framework is crucial for producing accurate and transparent premium estimates, especially in the context of risk-based pricing.

This is particularly important for small insurance markets, such as those in developing or transitional economies, where pricing errors can result in significant market imbalances, trigger adverse selection, and undermine financial stability. Markets like this encounter many challenges and limitations, such as limited sample size, a shortage of actuarial professionals, a lack of product diversification and the need for continuous professional development. Pricing methodologies such as GLMs offer a structured way to enhance actuarial reliability, support regulatory compliance, and mitigate adverse selection risk. The GLM approach is particularly suitable because it enables a more comprehensive and detailed risk analysis. The use of transparent and reproducible models, such as GLMs, is essential to ensuring the credibility and integrity of the entire insurance pricing system.

Motor insurance (casco or motor hull) covers damage to the insured vehicle resulting from accidents, theft, natural disasters, or other unintentional incidents. This type of insurance is a key component of the non-life insurance market and contributes significantly

to premiums written in many countries. In Bosnia and Herzegovina (BiH), it constituted an average of 10% of non-life insurance premiums over the last 5 years, according to the national Insurance Agency. In contrast to motor insurance, mandatory Motor Third-Party Liability (MTPL) insurance covers damages caused to third parties, transferring the legal liability of the vehicle owner or driver to the insurer. As a result of the liberalisation of the MTPL market, many European countries have recorded a decrease in MTPL premium levels. To compensate for these losses, insurance companies have adjusted tariffs across other lines of business, particularly motor insurance. This development has made it crucial to understand the full structure of motor insurance pricing. Consequently, insurers in BiH must gain a comprehensive understanding of motor insurance pricing methodology and be able to apply it effectively at every stage. Developing and mastering the pricing methodology is not only necessary for regulatory and technical accuracy but also serves as a foundation for gaining a sustainable competitive advantage in the insurance market. According to information from the state national Insurance Agency, the non-life insurance sector in BiH exhibits the characteristics of a highly competitive market despite its small size. The competitive nature of Bosnia's motor insurance sector makes it challenging for insurers to price risk profitably while maintaining competitive rates for existing and prospective policyholders. The market is specific and confronts many difficulties. In general, product diversification in the non-life insurance sector in BiH remains insufficient, limiting the market's growth potential. The insurers' focus on the mandatory MTPL line of business confirms the insurance market's characterisation as underdeveloped. As a small transitional economy, the Bosnian insurance market anticipates the liberalisation process for MTPL by the end of 2026 in both entities¹, which will make the application of the GLM methodology even more important for insurers. Actuaries in BiH face a difficult task in modelling and setting motor insurance tariffs due to complex state regulations, a complex business environment, and a legislative framework.

Therefore, it is essential to propose and implement an actuarially justified and statistically sound methodology for motor vehicle pricing. Moreover, it is important to examine whether the tariffs currently set by insurers in the market significantly differ from the tariff values modelled using GLMs. To establish this, a comprehensive investigation and evaluation of all risk factors influencing tariff setting are required. Although GLMs are a widely accepted standard in actuarial practice, their applicability to small insurance markets warrants further examination. It is feasible to determine the shortcomings of the current tariff by comparing it with the GLM-based approach. This comparison is crucial for insurers to identify shortcomings in the existing tariff, optimise their pricing strategies, strengthen their financial position, and gain a competitive advantage.

¹ *Bosnia and Herzegovina as a state is based on a constitutional system consisting of two entities: the Federation of BiH and Republika Srpska, with the District of Brčko being a separate administrative unit. Insurance operations are regulated at the entity level, but insurance companies from one entity are allowed to operate within the territory of another entity through branches.*

The research is novel in Bosnian insurance market analysis, as no such analysis has been conducted in BiH to date. To the best of our knowledge, apart from the studies by Omerašević & Selimović (2020a, 2020b) on the application of GLMs, no research has been conducted that specifically and directly examines motor insurance pricing in BiH, nor has any proposed a robust methodology for it. This study aims to fill this significant gap in the literature. To that end, we present what is, to the best of our knowledge, the first study of its kind based on a real-world sample from the Bosnian insurance market and possibly the broader South-Eastern European region. It is expected that this study will be stimulative for optimising ratemaking in non-life insurance in BiH and the region. This research is valuable because it provides a methodological framework for pricing that can be replicated in other small markets and other countries seeking to reform or modernise their motor insurance pricing systems. Next, in addition to its methodological contribution, the research examines the extent to which the GLM approach provides an objective basis for tariff setting. It means that the motor insurance tariffs constructed using the GLM approach will be compared with the current tariff, which is set at each insurer's discretion. With the GLM approach, risk factors affecting claims frequency and severity can be effectively identified and distinguished.

The analysis is conducted on a dataset obtained from an insurance company operating in the Bosnian insurance market. The database contains motor insurance policies for the period 2011-2023. Risk factors included in the research are known a priori by the insurer. Separate GLM models are deployed (one for claim frequency and one for claim severity). The authors adopted basic GLM assumptions, including policy independence, time independence (i.e., claims relate to different policies or different time periods), and the homogeneity assumption, which groups policies into relatively homogeneous classes and applies the same premium within each tariff cell (Ohlsson & Johansson, 2010). To apply the GLM methodology, the model selection step is performed first. The suitable GLMs for claim frequency and claim severity were initially specified: three models for claim frequency and ten for claim severity. In this paper, no prior distribution was assumed for claim frequency or severity. The model selection was instead based on the results of deviance analysis and significance testing. In the next step, using the forward selection algorithm, as in Riaman et al. (2018). Significant predictors are selected as input variables for GLMs. Then, multiplicative GLMs are fitted, and risk factors impacting claims frequency and claims severity are identified. To assess model adequacy, diagnostic checks based on deviance residuals were conducted. Finally, the tariff for motor vehicle insurance is calculated. All statistical modelling is done in the R environment.

Accordingly, this research offers both practical and theoretical insights, particularly into pricing methodologies for motor insurance in small transitional economies. Bosnia and Herzegovina, a non-EU economy in the Western Balkans, exhibits the characteristics of a small, underdeveloped insurance market. The market is highly fragmented, and a complex political and legal environment, low public awareness of insurance products, and limited financial literacy constrain its development. The dominance of compulsory MTPL insurance (48% of total premiums in 2024), low market share of life and property insurance and limited

product diversification confirm that the sector remains underdeveloped. According to the 2024 Insurance Annual Bulletin published by the National Insurance Agency, the domestic insurance market recorded a total premium volume of €555 million, a premium-to-GDP ratio of 2,11%, and a per capita premium of €161, significantly lagging behind neighbouring EU markets such as Croatia (€501 per capita) and Slovenia (€1.287 per capita). These indicators reflect limited insurance penetration, low market maturity, and modest growth potential, typical features of small insurance markets. Bosnia and Herzegovina has undergone a transition from a state-controlled to a market-oriented economy. In the context of small insurance markets, this transition, together with post-war economic instability and institutional weaknesses, has slowed the sector's development, which still exhibits characteristics typical of small developing economies (Kozarević et al., 2013: 144-145).

The main goal of this research is to develop a robust methodological framework for motor insurance pricing and to provide an objective evaluation of the current motor insurance tariff in BiH. Our research also investigates whether the GLM approach can be used to assess risk factors and provide an objective evaluation of the current motor insurance tariff in BiH. This paper investigates whether it is possible to develop a robust methodological framework for motor insurance pricing suitable for small insurance markets and to use it to identify relevant risk factors and evaluate the adequacy of the current motor insurance tariff in Bosnia and Herzegovina.

The rest of the paper is organised as follows. The article begins with an introduction that highlights the research problem. Section 2 presents a brief literature review of the GLM methodology in motor insurance pricing. Section 3 presents the methodological framework and information on the data sample. Section 4 analyses our empirical findings. Finally, concluding remarks are presented in Section 5.

2. Literature Review

GLMs have become the most widely used method for tariff analysis in motor insurance and non-life pricing in general. As a pioneering effort, the concept of GLM is found in the work of British statisticians Nelder & Wedderburn (1972), and since then, it has been further explored by numerous researchers. McCullagh & Nelder (1989) were the first to introduce GLM methodology to model claims frequency in marine insurance and claims severity in motor vehicle insurance. As a widely recognised industry standard, GLMs have been used in most applications since the 1990s.

Apart from the research mentioned earlier, various other papers have elevated the application of GLM in automobile insurance and actuarial science. In that sense, Haberman & Renshaw (1996) examined the applications of GLMs to actuarial problems, including both life and non-life insurance. Tariff analysis was conducted using GLMs, as in Brockman & Wright (1992), for motor liability insurance via GLIM software. Renshaw (1994) focuses on GLMs as a comprehensive modelling tool for claims, including the use of covariates. The basic statistical foundations and framework of GLMs are described in numerous

monographs, manuals, and academic papers that address both their practical applications and core statistical principles, including the works of many authors (McCullagh & Nelder, 1989; Ohlsson & Johansson, 2010; Anderson et al., 2007; Kaas et al., 2009; Wüthrich, 2016; Goldburd et al., 2020; Dobson, 2002; Hardin & Hilbe, 2018; Frees et al., 2014 & 2016).

While modelling automobile insurance premiums, many authors examined relevant risk factors as determinants of premium amounts and conducted separate analyses of claims frequency and severity. Valecký (2013) conducted a GLM analysis of motor insurance premiums, with a particular focus on claim severity and the incorporation of large claims into the modelling process. In their work, Kafková & Krivánková (2014) explored extending linear models to GLMs for modelling claim frequency in motor insurance, which better explains the relationship between annual claim frequency and the given risk factors. Valecký (2016) extends the work of Kafková & Krivánková by emphasising that overdispersion, a nonlinear systematic component, and interactions between rating factors should be taken into account when modelling claim frequency. In addition to estimating claim frequency and severity for pricing purposes using GLMs in motor insurance, Strežo et al. (2019) seek to identify significant risk factors and assess their contribution to claim frequency, severity, and expected loss per exposure. David (2015b), in reviewing the theoretical and empirical literature on non-life insurance pricing, notes that, given the complexity of risk evaluation, current actuarial methods remain open to refinement. Further, David (2015a) provides a comprehensive overview of GLM techniques for estimating pure premiums based on policyholders' observable attributes. Garrido et al. (2016) did not assume the traditional independence between claim frequency and severity in non-life insurance. Instead, they explored modelling approaches that incorporate dependency when estimating motor insurance premiums. Putra et al. (2020) examined the use of GLMs to model claim frequency and severity separately. They concluded that GLMs represent a robust modelling framework for the insurance industry's needs. Rahmawati et al. (2023) applied the GLM approach to motor insurance to identify key characteristics influencing the determination of pure premiums, similar to Riaman et al. (2018), who used forward selection to select risk factors. Omari et al. (2018), Antonio & Valdez (2010), and Tomeski (2012) also analysed the application of GLMs in motor insurance across different contexts. All of the aforementioned authors find the separate modelling approach more effective, as it provides deeper insights into risk factors as appropriate determinants of the premium. Otherwise, the important patterns in data could remain hidden, leading to inaccurate estimates (Korn, 2015).

Magri et al. (2019) focused on the challenges of motor insurance pricing in small markets (the case of Malta), highlighting the importance of risk identification and the integration of relevant risk factors into premium models. The authors employed semi-structured interviews and highlighted major limitations in the current approach to risk selection, given the inherent constraints of a small insurance market. In another small-market context, the Montenegrin case study by Kaščelan et al. (2016) applied a nonparametric data-mining approach to risk prediction in car insurance. The authors raised concerns regarding potential limitations in predictive accuracy due to the small market size and relatively low volume of insurance policies. Only a few articles have been published on this subject in BiH

thus far. In contrast to this research, existing empirical studies examine the risk-factor selection process in the context of risk classification and ratemaking in the Bosnian market. For instance, Omerašević & Selimović (2020a) investigate the potential to improve the predictive performance of non-life premium ratemaking. GLM and data mining methods are combined to determine which best fits the BiH insurance market. In their work, Omerašević & Selimović (2020b) use data mining methods to optimise motor insurance premium ratemaking.

Although the GLM methodology is widely used across various disciplines, particularly in motor insurance premium modelling, existing research remains insufficient in both small markets and other transitioning economies undergoing reforms to their non-life insurance pricing systems. These countries typically need to identify shortcomings in their current tariff structures and develop a robust pricing methodology. In this study, unlike much of the existing literature, the objectivity of the GLM approach in motor insurance pricing is emphasised by making a robust methodology tailored specifically for application in small transitional market contexts.

3. Research Methodology

This part of the paper provides a brief description of the GLM methodology and only basic statistical assumptions. For more details and deeper mathematical insights on this matter, see McCullagh & Nelder (1989). This study estimates motor insurance premiums at the policy level using risk factors as predictors within the GLM framework.

3.1. Generalised Linear Models (GLMs)

GLMs are a class of statistical models that extend ordinary linear models. There are two important directions worth noting: expanding to a wider range of probability distributions and building models in which a linear function of the variables is a monotone transformation of the mean (Ohlsson & Johansson, 2010). The purpose of GLMs is to explain variability in the variable of interest (Y) by the changes in one or more explanatory variables (X).

Based on the statistical setting of McCullagh & Nelder (1989), GLMs are specified with the following three components:

- (GLM1) The random component: The response variable (Y) is from one of the exponential family of distributions.
- (GLM2) The systematic component: The linear predictor is a linear function of independent predictors.
- (GLM3) The link function: The link function $g(\mu)$ is a fundamental object in a GLM and links the mean to the linear predictor.

According to the original formulation of Nelder & Wedderburn (1972), the distribution of the dependent variable is a member of the exponential family, including

Gaussian, Poisson, binomial, gamma, inverse-Gaussian, geometric, and negative binomial (Hardin & Hilbe, 2018). Later on, it was extended to multivariate exponential families of distributions as well as non-exponential families, but also special cases in which the distribution Y_i (for each policy i) is not fully specified. The set of basic assumptions for statistical model building is: (1) Policy independence, (2) Time independence and (3) Homogeneity (Ohlsson & Johansson, 2010: 6-7). As part of model diagnostics, the analysis of deviance and the assessment of model fit are not elaborated in detail due to space limitations, but can be found in the relevant literature, including McCullagh & Nelder (1989), Fox (2016), and Kaas et al. (2009).

3.2. Data Sample

Analysis is conducted on a real-world dataset obtained from an insurance company operating in the Bosnian insurance market. Due to data confidentiality, the name of the insurance company will not be disclosed. The research dataset relies on two data sources: the policy database and the claims database. They encompassed risk factors (predictors) and response variables (claim frequency and claim severity) for the given portfolio during 2011-2023. All calculations and modelling are performed using R software (R Core Team, 2024). The initial claims database contains 38,535 records, while the initial policy database includes 168,076 records. Data cleaning and preprocessing were carried out before initiating the tariff modelling process. To ensure the validity of the results, a key step is thorough data quality checking and preparation. This step is crucial for the credibility of the research outcomes. It typically consumes up to 80% of the total time in the insurance premium modelling process (Wüthrich & Merz, 2023: 1). The data must meet the criteria of completeness, accuracy, consistency and timeliness. In the first step, data quality checks were performed on both databases to ensure the technical validity of the variables. Once each record in both databases was uniquely identified using ID variables, it became possible to link the aggregated claims database with the policy database. Next, missing values were identified. As a strategy for handling them, the median was imputed for continuous variables and the mode for categorical variables. As a standard option in actuarial practice, and following the approach proposed by Goldburd et al. (2020), missing values were replaced with the mean (for numerical variables) or mode (for categorical variables). This method treats the imputed value as a neutral or typical point within the variable's distribution, while preserving all observations in the dataset. The intention was to avoid deleting records with missing values and to preserve the dataset's completeness for modelling purposes. Additionally, feature engineering was applied to derive variables such as exposure, claim frequency, and average claim amount, as shown in Table 1. After all preprocessing activities were completed, our portfolio consisted of 116,205 motor insurance policies, their corresponding claims, and 13 predictors.

To deploy GLM methodology for tariff modelling, all numerical predictors, such as Age, Vehicle value, Engine volume, etc., were discretised and divided into levels based on expert judgement, as presented in Table 1. Categorical variables such as Document type and Region were treated as factors and coded using reference-level encoding. As advised, the

base level was set as the category with the highest exposure. This approach helps minimise the standard errors of the parameter estimates (Strežo et al., 2019: 458). Next, the collinearity issue among the 13 predictors was examined. Based on the results of the correlation analysis (at the significance level of 1%), three risk factors- Gender, Branch office, and Driver's Age were excluded due to their high correlation with other variables. Subsequently, the Variance Inflation Factor (VIF) test was conducted to assess multicollinearity. The results indicated that multicollinearity was absent after removing the aforementioned variables, as all VIF values were only slightly above 1. Further analysis is continued with the remaining 10 predictors, along with an intercept. The predictors, or risk factors, are: properties of policyholders (Branch office, Client type, Gender, Driver's age, and Region) and properties of the vehicle (Document type, Car type, Vehicle's age, Vehicle value, Engine power, Engine volume, Load capacity, and Number of seats). The dataset definition for each predictor is presented in Table 1.

The distribution of claim frequency across the entire portfolio indicates that 76,42% of policies had no reported claims, whereas the largest proportion among the remaining policies had exactly one reported claim, accounting for 19,43%. This high proportion of zero-claim policies is typical in motor insurance data and may also be influenced by some insureds' tendency not to report minor claims. The claim severity distribution exhibits a heavy tail along with a pronounced peak. This study did not define a specific threshold for identifying large claims. The average claim size across the portfolio amounts to 585 BAM.

Table: 1
Initial Dataset Description

Predictor	Predictor Type	Definition	# of levels
Document type	Properties of a vehicle	Motor insurance contracts are classified as collective or individual.	2 levels (Individual or collective policy)
Branch office	Properties of the policyholders	Branch office for the contract conclusion.	8 levels (Branch offices across the country)
Client type	Properties of the policyholders	Categorisation of insureds as natural persons or legal entities (companies or organisations).	2 levels (Natural person or legal entity)
Gender	Properties of the policyholders	Categorisation of insureds as male, female and legal entity.	3 levels (Gender and legal entity)
Car type	Properties of a vehicle	Categorisation that distinguishes vehicles by type based on features like weight, height or purpose.	8 levels (Vehicle categories representing different vehicle categories based on type and intended use)
Driver's age	Properties of the policyholders	Age of the insured expressed in years.	6 levels (Levels corresponding to age intervals of the insured)
Vehicle's age	Properties of a vehicle	The age of the vehicle is based on the year of the vehicle's manufacture.	5 levels (Levels representing age intervals of the vehicles)
Vehicle value (in BAM)	Properties of a vehicle	Replacement value of the vehicle.	4 levels (Ranges based on the insured vehicle's value)
Region	Properties of the policyholders	Regional division of BiH to which the insured belongs by their residency according to the company's internal policy.	9 levels (Geographical areas corresponding to Bosnian cities)
Engine power (kW)	Properties of a vehicle	The vehicle's engine power is expressed in kW.	7 levels (Ranges based on vehicle engine power)
Engine volume (ccm)	Properties of a vehicle	The engine volume of the vehicle is expressed in ccm.	3 levels (Ranges based on vehicle engine volume)
Load capacity (tonnes)	Properties of a vehicle	The load capacity of a vehicle is expressed in tons.	4 levels (Ranges based on vehicle load capacity)
Number of seats	Properties of a vehicle	Registered number of seats.	3 levels (Ranges based on the vehicle's number of seats)
Claims number	-	Number of claims per policy for the period 2011 - 2023.	-
Claims severity	-	Claims per policy (BAM) for the period 2011 - 2023.	-
Exposure	-	Exposure is the number of days covered by the policy divided by 365.	-
Claims frequency	-	Claims frequency is the number of claims divided by Exposure.	-
Average claim	-	The average claim is the total claims divided by the number of claims.	-
Premium	-	Premium amount per policy (BAM).	-

* Base level

3.3. Methodological Design

To achieve the research objective, a six-step methodological framework was designed, as presented in Table 2. The steps include: (1) model selection, (2) variable selection, (3) model fitting, (4) goodness of fit analysis, (5) tariff calculation and finally (6) finding differences between estimated and existing motor insurance tariffs in the Bosnian market as a base for the business decision-making process in insurance companies.

Table: 2
Research Design

		Starting point: 13 predictors	
STEP 1	Model selection	Frequency	Severity
		3 GLM models	10 GLM models
		Analysis of deviance: LR tests (chi square significance) & type III test	
		Decision:	
STEP 2	Variable selection	Poisson (log)	Gamma (log)
		Multicollinearity test, 3 predictors removed	
		10 predictors left	
STEP 3	Model fitting	Forward selection	
		GLM for Claims Frequency (Identified 10 predictors from previous step)	GLM for Claims Severity (Identified 8 predictors from previous step)
		Identify predictors with impact on Frequency	Identify predictors with impact on Severity
STEP 4	Goodness of Fit analysis	Deviance residuals	
STEP 5	Tariff calculation	Frequency x Severity	
STEP 6	Find differences	Estimated tariff - Existing tariff	

The six methodological steps followed in this research are presented and explained in the sections that follow.

1) *Model selection* - During the model selection step, it is important to identify the right distribution for claims frequency and severity among various model specifications. Typically, authors base this choice on actuarial practices and general characteristics of the response variable's distribution. It is common practice to assume a suitable distribution from the exponential family. For model frequency, the distribution is Poisson, while for severity, it is Gamma (David, 2015a; Garrido et al., 2016). For example, Antonio & Valdez (2010: 7) state that the Poisson regression model is an archetype of GLM for the claim frequency model. However, this study does not begin with a predefined assumption about the appropriate distribution. Instead, it evaluates three models for claim frequency and ten models for claim severity. The models differ in the link function, assumed distribution, and inclusion of an offset term, as presented in Table 3. The goal of the model selection step in this paper is to find the optimal model specification for claims frequency and severity among all tested models. As a criterion for choosing the optimal model for both components, the deviance analysis results, accompanied by a Wald Type III test for variable significance, are considered.

Table: 3
Specifications of Tested GLMs for Claims Frequency and Severity

Specification for claim frequency models:	
Model 1	glm (claims frequency) ~ factor, family = poisson (link=log), weights = exposure
Model 2	glm (Number of claims) ~ offset (log(exposure)) + factor, family = poisson (link=log)
Model 3	glm (claims frequency) ~ factor, family = poisson (link=sqrt), weights = exposure
Specification for claim severity models:	
Model 1	glm (Average claim ~ factor, family = gaussian (link=identity), weights = Number of claims)
Model 2	glm (Average claim ~ factor, family = gaussian (link=inverse), weights = Number of claims)
Model 3	glm (Average claim ~ factor, family = gaussian (link=log), weights = Number of claims)
Model 4	glm (Claim amount ~ factor + offset (log(Number of claims)), family = gaussian (link=log))
Model 5	glm (Average claim ~ factor, family = gamma (link=identity), weights = Number of claims)
Model 6	glm (Average claim ~ factor, family = gamma (link=inverse), weights = Number of claims)
Model 7	glm (Average claim ~ factor, family = gamma (link=log), weights = Number of claims)
Model 8	glm (Claim amount ~ factor + offset (log(Number of claims)), family = Gamma (link=log))
Model 9	glm (Average claim ~ factor, family = inverse.gaussian (link=identity), weights = Number of claims)
Model 10	glm (Average claim ~ factor, family = inverse.gaussian (link=inverse), weights = Number of claims)

An analysis of deviance was conducted. In most academic papers, the term deviance typically refers to scaled deviance, defined as the ratio of deviance to the scale parameter. For certain distributions, such as the Poisson distribution, the scale parameter is known and equals one (1). However, for distributions other than Poisson, the scale parameter had to be estimated. In the analysis of deviance, the null hypothesis tested was that adding a risk factor to the model has no significant effect, compared to the null model that includes only the intercept. The proposed model refers to a model that includes only one risk factor. The null model and the proposed model are nested models. Therefore, for each of the three specified models for claim frequency, ten separate models were tested, one for each risk factor, using an analysis of deviance to assess its contribution to model fit. This results in a total of 30 models evaluated across the three specifications. For claims severity model specifications, the deviances are also calculated in the same way. For each of the ten specified models for claims severity, a separate model was fitted for each of the ten risk factors, resulting in a total of 100 models being evaluated. The differences in deviance (Δdev) between the proposed and null models are approximately chi-squared distributed with Δdf degrees of freedom.

In accordance with the adopted criterion, the optimal model is the one with the maximum number of risk factors that have the maximum change in the scaled deviance. During deviance testing of nested models, the results will show the deviance difference between the null model and the estimated model with one risk factor added to each model. Delta (scaled) deviance indicates the extent of improvement in the model from including a risk factor, comparing the null model deviance with the deviance of the estimated model. A higher (scaled) delta deviance indicates that including the predictor improves the model fit, suggesting that it explains the variation in the response variable more effectively than the null model. In addition to the deviance analysis, it is crucial to assess the statistical significance of all risk factors influencing the premium amount with the Wald type III test.

To the best of the authors' knowledge, this is the first time that analysis of deviance of nested models has been used in this way, testing each predictor separately in the context

of specifying the best model. Although the process is not automated, its manual implementation is considered to yield more meaningful insights into model selection.

2) *Variable selection* - Following the selection of models for fitting GLMs for frequency and severity, it is essential to choose significant variables or risk factors as inputs for GLMs. Forward selection is an automatic procedure that iteratively adds or removes variables based on predefined statistical criteria. It is an automated form of variable selection. In this research, variable selection was performed using a forward selection algorithm. Forward selection starts with the intercept-only model and adds one variable at a time. Through a recursive process, the algorithm terminates when the optimal criterion is met, typically when the Akaike Information Criterion (AIC) is minimised (see Dobson, 2002, for more details).

3) *Model fitting* - Once the final specifications of both models are determined, GLMs can be fitted. The model assumptions are as follows:

- for a given linear predictor, i.e. a linear function of predictors is:

$$\eta_i = \alpha + \beta_1 X_{i1} + \beta_2 X_{i2} + \dots + \beta_p X_{ip} + \xi_i, \quad i = 1, \dots, n \quad (1)$$

- The link function $g(\cdot)$ that transforms the expected value of the response variable μ_i to the linear predictor is:

$$g(\mu_i) = \eta_i = \alpha + \beta_1 X_{i1} + \beta_2 X_{i2} + \dots + \beta_p X_{ip} \quad (2)$$

- The estimates of the mean response (μ_i) are derived by applying the inverse link function g^{-1} to the linear predictor values:

$$\mathbb{E}[Y_i] = \mu_i = g^{-1}(\eta_i) \quad (3)$$

where:

n represents the number of known observations included in the analysis, p is the number of model parameters, α is the intercept, X_{ij} are the predictors, β_j are the estimated coefficients of predictors (policyholders/vehicle properties), $\mathbb{E}[Y_i]$ is the expected value of the dependent variable, and ξ_i is the offset.

4) *Goodness of fit analysis* - within the goodness of fit analysis, deviance residuals are analysed for the claim frequency model as well as for the claim severity model.

5) *Tariff premium calculation* (P_i) is defined as (Antonio & Valdez, 2010):

$$P_i = F_i \cdot S_i, \text{ where} \quad (4)$$

F_i is the claim frequency per unit of exposure, and S_i is the claim severity. An additional correction to the premium has been made by adding an appropriate estimate of overhead costs per policy.

Correction coefficients for the base premium were obtained through multiplicative GLMs. Finally, the gross premium tariff (at the policy level) was calculated as the product of:

- the base premium (defined as the ratio of the total severity and the total exposure),
- the correction coefficients of the base premium (GLM estimates) and
- the estimated overhead costs.

6) After the calculation of the motor tariff, discrepancies with the existing tariffs are discovered. The computations are conducted at the policy level.

4. Results

In this part, we present the results of the motor tariff premium modelling process using GLMs. Next, we show the differences between current tariffs and estimated tariffs in the Bosnian insurance market.

4.1. Model Selection

Based on the deviance analysis and the Wald Type III test, the optimal models for claim frequency and claim severity were selected.

The results are presented in Tables 4-9. For the frequency model, the results of the analysis of deviance are presented in Table 4, with three columns: Δdf (referring to the change in degrees of freedom), Δdev (referring to the change in deviance), and $Pr(>Chisq)$ (indicating whether the difference in deviance is statistically significant). All significant risk factors are highlighted in light green. With all p -values less than 0,05 the results of the Wald type III test confirmed that all predictors are significant (Table 5). According to the chosen criterion, Model 2 is identified as the optimal specification for claims frequency. While all three model specifications meet the acceptability criteria, Model 2 is preferred because the inclusion of the exposure offset ensures that the expected number of claims scales correctly with the exposure duration. Empirical results confirmed that, in case of multiplicative Poisson model for claims frequency, identical results are obtained whether the model includes an offset term equal to the log of the exposure (and prior weights set to 1) as in Model 2, or whether it is specified without an offset term but with prior weights set to be equal to the exposure of each observation, as in Models 1&3 (Anderson et al. 2007: 21). This provides important empirical support for the theoretical assumptions using real-world data.

Table: 4
Analysis of Deviance for the Frequency Model

		Model 1			Model 2			Model 3		
		Δdf	Δdev	Pr(>Chisq)	Δdf	Δdev	Pr(>Chisq)	Δdf	Δdev	Pr(>Chisq)
	Predictor									
1	Car type	7	1.971,03	0,000	7	1.971,03	0,000	7	1.971,03	0,000
2	Engine power	6	1.376,48	0,000	6	1.376,48	0,000	6	1.376,48	0,000
3	Load capacity	3	710,05	0,000	3	710,05	0,000	3	710,05	0,000
4	Client type	1	628,72	0,000	1	628,72	0,000	1	628,72	0,000
5	Number of seats	2	538,33	0,000	2	538,33	0,000	2	538,33	0,000
6	Vehicle's age	4	514,49	0,000	4	514,49	0,000	4	514,49	0,000
7	Vehicle value	3	256,03	0,000	3	256,03	0,000	3	256,03	0,000
8	Engine volume	2	229,65	0,000	2	229,65	0,000	2	229,65	0,000
9	Region	8	175,73	0,000	8	175,73	0,000	8	175,73	0,000
10	Document type	1	13,93	0,000	1	13,93	0,000	1	13,93	0,000

(at a significance level of 0,05)

Table: 5
Wald Type III Test for Frequency Model

		Model 1			Model 2			Model 3		
		Δdf	Chisq	Pr(>Chisq)	Δdf	Chisq	Pr(>Chisq)	Δdf	Chisq	Pr(>Chisq)
	Predictor									
1	Car type	7	1.527,20	0,000	7	1.527,20	0,000	7	1.527,20	0,000
2	Engine power	6	1.021,66	0,000	6	1.021,66	0,000	6	1.021,66	0,000
3	Load capacity	3	592,58	0,000	3	592,58	0,000	3	592,58	0,000
4	Client type	1	651,27	0,000	1	651,27	0,000	1	651,27	0,000
5	Number of seats	2	621,97	0,000	2	621,97	0,000	2	621,97	0,000
6	Vehicle's age	4	444,13	0,000	4	444,13	0,000	4	444,13	0,000
7	Vehicle value	3	249,54	0,000	3	249,54	0,000	3	249,54	0,000
8	Engine volume	2	222,19	0,000	2	222,19	0,000	2	222,19	0,000
9	Region	8	169,16	0,000	8	169,16	0,000	8	169,16	0,000
10	Document type	1	13,77	0,000	1	13,77	0,000	1	13,77	0,000

(at a significance level of 0,05)

For the severity model, the deviance analysis results are presented in Tables 6 and 7. First, for each risk factor, the model specification (among models 1-10) with the highest delta scaled deviance is highlighted in dark green. All significant risk factors are highlighted in light green. Subsequently, the final model is selected as the one associated with the highest number of risk factors, yielding the maximum delta-scaled deviance. In this case, Model 8 is identified as the optimal specification. The results of the Wald type III test confirmed that all predictors are significant. It is shown in Tables 8 and 9, all p-values are less than 0,05. Model 8 is identified as the optimal specification for claims severity.

Specifications for optimal frequency and severity model, respectively, are outlined as follows:

Model 2: Claims number ~ Factor_i + offset (log(exposure)), family = poisson(link = log),

Model 8: Claims severity ~ Factor_i + offset (log(claims number)), family = gamma(link = log),

for i = (Document type, Client type, Car type, Vehicle's age, Vehicle value, Region, Engine power, Engine volume, Load capacity and Number of seats).

Table: 6
Analysis of Deviance for Severity Model (Model 1-5)

	Predictor	Model 1			Model 2			Model 3			Model 4			Model 5		
		Adf	Δdev	Pr(>Chisq)	Adf	Δdev	Pr(>Chisq)	Adf	Δdev	Pr(>Chisq)	Adf	Δdev	Pr(>Chisq)	Adf	Δdev	Pr(>Chisq)
1	Vehicle value	3	758,86	0,0000	3	758,74	0,0000	3	758,86	0,0000	3	741,43	0,0000	3	971,66	0,0000
2	Engine power	6	691,22	0,0000	6	691,07	0,0000	6	691,22	0,0000	6	686,66	0,0000	6	884,15	0,0000
3	Engine volume	2	324,21	0,0000	2	324,02	0,0000	2	324,21	0,0000	2	312,54	0,0000	2	359,01	0,0000
4	Load capacity	3	81,43	0,0000	3	81,44	0,0000	3	321,36	0,0000	3	89,70	0,0000	3	76,73	0,0000
5	Client type	1	28,14	0,0000	1	28,14	0,0000	1	28,14	0,0000	1	7,23	0,0000	1	30,00	0,0000
6	Region	8	39,54	0,0000	8	39,55	0,0000	8	39,55	0,0000	8	35,72	0,0000	8	25,38	0,001
7	Document type	1	28,17	0,0000	1	28,18	0,0000	1	28,18	0,0000	1	33,81	0,0000	1	31,45	0,0000
8	Vehicle's age	4	11,92	0,0179	4	11,93	0,0179	4	11,93	0,0179	4	8,93	0,063	4	13,02	0,011
9	Number of seats	2	13,19	0,0013	2	13,19	0,0013	2	13,19	0,0013	2	17,19	0,000	2	11,66	0,002
10	Car type	7	179,80	0,0000	7	179,80	0,0000	7	179,79	0,0000	7	203,81	0,0000	7	128,98	0,0000

Table: 7
Analysis of Deviance for Severity Model (Model 6-10)

	Predictor	Model 6			Model 7			Model 8			Model 9			Model 10		
		Adf	Δdev	Pr(>Chisq)	Adf	Δdev	Pr(>Chisq)	Adf	Δdev	Pr(>Chisq)	Adf	Δdev	Pr(>Chisq)	Adf	Δdev	Pr(>Chisq)
1	Vehicle value	3	971,65	0,0000	3	971,66	0,0000	3	979,18	0,0000	3	974,12	0,0000	3	974,12	0,0000
2	Engine power	6	884,14	0,0000	6	884,15	0,0000	6	882,61	0,0000	6	881,01	0,0000	6	881,01	0,0000
3	Engine volume	2	358,99	0,0000	2	359,01	0,0000	2	359,07	0,0000	2	352,79	0,0000	2	352,79	0,0000
4	Load capacity	3	76,73	0,0000	3	76,73	0,0000	3	71,11	0,0000	3	75,65	0,0000	3	75,65	0,0000
5	Client type	1	30,00	0,0000	1	30,00	0,0000	1	47,82	0,0000	1	30,81	0,0000	1	30,81	0,0000
6	Region	8	25,38	0,0013	8	25,38	0,0013	8	34,81	0,0000	8	22,45	0,004151	8	22,45	0,0041
7	Document type	1	31,45	0,0000	1	31,45	0,0000	1	27,08	0,0000	1	33,10	0,0000	1	33,10	0,0000
8	Vehicle's age	4	13,02	0,0111	4	13,02	0,0111	4	17,20	0,0017	4	13,61	0,008652	4	13,61	0,0086
9	Number of seats	2	11,66	0,0029	2	11,66	0,0029	2	10,13	0,0063	2	10,98	0,004133	2	10,98	0,0041
10	Car type	7	128,98	0,0000	7	128,98	0,0000	7	126,51	0,0000	7	112,25	0,0000	7	112,25	0,0000

Legend for Tables 6 & 7:

- Not significant risk factors (at a significance level of 0,05),
- Significant risk factors (at a significance level of 0,05),
- Significant risk factors (at a significance level of 0,05) & risk factors with the largest delta scaled deviance,
- Chosen model

Table: 8
Wald Type III Test for Severity Model (Model 1-5)

	Predictor	Model 1			Model 2			Model 3			Model 4			Model 5		
		Df	Chisq	Pr(>Chisq)	Df	Chisq	Pr(>Chisq)	Df	Chisq	Pr(>Chisq)	Df	Chisq	Pr(>Chisq)	Df	Chisq	Pr(>Chisq)
1	Document type	1	28,17	0,000	1	20,95	0,000	1	24,43	0,000	1	29,61	0,000	1	36,99	0,000
2	Client type	1	28,14	0,000	1	24,41	0,000	1	26,40	0,000	1	0	0,008	1	31,84	0,000
3	Car type	7	179,80	0,000	7	739,78	0,000	7	358,78	0,000	7	419,10	0,000	7	80,81	0,000
4	Vehicle's age	4	11,92	0,017	4	9,78	0,04	4	10,79	0,028	4	8,11	0,087	4	14,87	0,004
5	Region	8	758,86	0,000	8	240,28	0,000	8	85,30	0,000	8	80,13	0,000	8	16,72	0,033
6	Vehicle value	3	39,54	0,000	3	588,20	0,000	3	777,17	0,000	3	737,10	0,000	3	706,56	0,000
7	Engine power	6	691,22	0,000	6	492,84	0,000	6	675,69	0,000	6	653,45	0,000	6	633,47	0,000
8	Engine volume	2	324,21	0,000	2	322,66	0,000	2	352,25	0,000	2	328,90	0,000	2	272,45	0,000
9	Load capacity	3	81,43	0,000	3	124,39	0,000	3	98,18	0,000	3	109,25	0,000	3	73,31	0,000
10	Number of seats	2	13,19	0,001	2	18,25	0,000	2	15,55	0,000	2	19,78	0,000	2	9,25	0,0090

(at a significance level of 0,05)

Table: 9
Wald Type III Test for Severity Model (Model 6-10)

	Predictor	Model 6			Model 7			Model 8			Model 9			Model 10		
		Df	Chisq	Pr(>Chisq)	Df	Chisq	Pr(>Chisq)	Df	Chisq	Pr(>Chisq)	Df	Chisq	Pr(>Chisq)	Df	Chisq	Pr(>Chisq)
1	Document type	1	28,66	0,000	1	32,83	0,000	1	28,29	0,000	1	41,67	0,000	1	33,10	0,000
2	Client type	1	28,77	0,000	1	30,53	0,000	1	48,80	0,000	1	33,36	0,000	1	30,81	0,000
3	Car type	7	193,56	0,000	7	109,06	0,000	7	106,48	0,000	7	69,73	0,000	7	112,25	0,000
4	Vehicle's age	4	12,17	0,016	4	13,46	0,009	4	17,91	0,001	4	16,62	0,002	4	13,60	0,008
5	Region	8	39,75	0,000	8	21,51	0,005	8	31,14	0,000	8	15,11	0,056	8	22,44	0,004
6	Vehicle value	3	959,10	0,000	3	924,12	0,000	3	925,06	0,000	3	616,92	0,000	3	974,12	0,000
7	Engine power	6	861,13	0,000	6	844,38	0,000	6	836,22	0,000	6	514,69	0,000	6	881,01	0,000
8	Engine volume	2	377,18	0,000	2	340,54	0,000	2	337,65	0,000	2	229,35	0,000	2	352,78	0,000
9	Load capacity	3	83,06	0,000	3	74,60	0,000	3	69,51	0,000	3	78,23	0,000	3	75,64	0,000
10	Number of seats	2	13,10	0,001	2	11,00	0,004	2	0	0,008	2	7,72	0,021	2	10,97	0,004

(at a significance level of 0,05)

4.2. Variable Selection

The results for the variable selection step for the frequency and severity model are presented in Table 10. This process is implemented in the R software environment.

Table: 10
Forward Selection for the Frequency and Severity Model

	Frequency Model		Severity Model	
	Predictor	AIC	Predictor	AIC
	Start (null model)	155.851,8	Start (null model)	481.820,5
1	Number of seats	152.142,9	Load capacity	477.870,5
2	Load capacity	152.194,3	Region	478.102,9
3	Region	152.251,6	Engine power	478.227,2
4	Engine power	152.370,9	Vehicle's age	477.906,4
5	Vehicle's age	153.154,4	Document type	477.996,5
6	Document type	152.056,2	Client type	478.418,3
7	Client type	152.739,3	Car type	478.593,2
8	Car type	153.894,8	Vehicle value	478.852,1
9	Vehicle value	152.093,9	-	-
10	Engine volume	152.043,8	-	-

Variables entering the claims frequency model are: Document type, Client type, Car type, Vehicle's age, Vehicle value, Region, Engine power, Engine volume, Load capacity and Number of seats. Variables entering the claims severity model are: Document type, Client type, Car type, Vehicle's age, Vehicle value, Region, Engine power and Load capacity.

4.3. Model Fitting

Two separate models are fitted. Results have confirmed that different risk factors are determinants of frequency/severity models (as discussed in Klugman et al., 2019; and Ohlsson & Johansson, 2010). Risk factors, as determinants of claim frequency (at a significance level of 0,05), are the following: *Car type*, *Vehicle's age*, *Client type*, *Engine power*, *Region*, *Load capacity*, *Number of seats*, *Vehicle value*, *Document type* and *Engine volume*. Risk factors, as determinants of claim severity (at a significance level of 0,05), are the following: *Car type*, *Vehicle's age*, *Client type*, *Engine power*, *Vehicle value* and *Document type*.

Properties of the policyholders that affect the expected value of motor insurance tariff are:

- For frequency model: *Client type* and *Region*,
- For severity model: *Client type*.
- Properties of the vehicle that affect the expected value of motor insurance tariff are:
 - For frequency model: *Document type*, *Car type*, *Vehicle's age*, *Vehicle value*, *Engine power*, *Engine volume*, *Load capacity* and *Number of seats*,
 - For severity model: *Document type*, *Car type*, *Vehicle's age*, *Vehicle value* and *Engine power*.

It is interesting to find that 10 risk factors identify claim frequency, while 6 risk factors identify claim severity. This research corroborates the theoretical assumption that claim frequency is more stable than claim severity. Moreover, a greater number of risk factors influence claim severity, allowing for more accurate premium estimation (Ohlsson & Johansson, 2010: 34).

4.4. Goodness of Fit Analysis

Analysis of deviance residuals for both frequency and severity models confirmed an inherently asymmetric distribution. In both cases, residuals appear to be randomly distributed over time, with no visible patterns. For the frequency model, deviations observed in the Q-Q plot indicate potential overdispersion, suggesting that alternative models such as zero-inflated and hurdle models might be appropriate. Regarding the severity model, the residual histogram shows a concentration near zero, with noticeable skewness and long tails. This indicates that, although the model captures the central tendency well, extreme values or outliers may be influencing the fit.

Residual analysis results indicate that the frequency model needs adjustment to better handle overdispersion, while the severity model requires careful treatment of large claims. Addressing these issues will improve premium accuracy and reduce errors in risk assessment in future research.

4.5. Tariff Calculation and Finding Differences between the Estimated and Existing Tariffs

Correction coefficients were generated by multiplicative GLM models and used to calculate motor tariffs. The overall impact of the new premium model using GLM methodology shows a 19,71% increase in total premiums compared to the current tariff system. Therefore, present motor insurance tariffs on the Bosnian market do not align with the findings of the GLM methodology. According to the GLM results, and after accounting for appropriate overhead cost estimates, the current motor insurance premium tariff is underpriced and should be increased by 19,71%.

5. Discussion and Conclusion

Pricing in non-life insurance in small markets and transitional economies presents a particular challenge, requiring considerable effort and coordination among various stakeholders. In this context, small markets require a more comprehensive approach to risk analysis due to several limitations, such as limited data availability, smaller portfolio sizes, less diversified business lines, lower levels of technical expertise and underdeveloped regulatory and technical infrastructure. While markets like this have so far relied on existing pricing systems and tables in place for many years, transitional economies now need to begin developing their own actuarial pricing frameworks, customised to their markets. As BiH undergoes phased liberalisation of its MTPL insurance market, being an emerging economy, the challenges that accompany such reform must be anticipated and addressed.

This paper presents a pragmatic methodology for assessing the risk of a motor insurance pricing model using GLMs. To the best of our knowledge, the methodology presented in this study is the first to apply a GLM approach grounded in a detailed analysis and assessment of risk factors to evaluate the objectivity of the current motor insurance tariff in BiH and to establish a robust framework for future pricing practices. It provides valuable support for insurance companies in shaping their pricing strategies, on the premise that adjusting the pricing framework can improve insurers' operational efficiency in the Bosnian market and other transitional economies.

The findings of this study underscore the importance of accurate risk assessment and pricing strategies in the automobile insurance industry. The fact that current motor insurance tariffs are underpriced underscores the practical relevance of this research, as such mispricing directly affects the profitability and financial sustainability of insurance companies. These results provide a strong argument for revising existing tariffs and support the transition to data-driven pricing models, particularly in light of upcoming MTPL market liberalisation. Considering the negative outcomes observed in regional markets following liberalisation, comprehensive risk assessment is particularly crucial, as is the adoption of a proactive pricing strategy. The practical implications of this study indicate that Bosnian insurers are not yet adequately prepared to implement a motor insurance pricing methodology, as evidenced by the lack of research in this field. This indicates a need for future research on such an important subject.

Future research could benefit from incorporating additional sets of variables that capture more detailed characteristics of both policyholders and vehicles, depending on the data available in insurance databases. This would help overcome some of the current study's limitations, particularly those related to the limited scope of explanatory variables and data constraints. Using larger motor insurance portfolios is desirable in studies of this kind; however, their inclusion depends on the extent and quality of the available data. In that context, each insurer may consider incorporating specific data sources into its analytical process. To achieve deeper insights and more robust results, it is recommended to explore alternative distributions for modelling claim frequency and severity, particularly those that account for overdispersion. Furthermore, extending the current GLM framework to incorporate more advanced methods, such as data mining techniques, could enhance predictive performance.

Nevertheless, GLMs remain a valuable and widely accepted tool in the motor insurance industry. This study emphasises the principle of simplicity, proposing a methodology that serves as a modelling framework that is not only statistically sound but also practical and accessible to implement. Insurers may use these results to improve their pricing strategies.

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A Qualitative Research on The Applicability of Value-Based Payment Method in The Health System of Türkiye¹

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Değer Bazlı Geri Ödeme Yönteminin Türkiye Sağlık Sisteminde Uygulanabilirliği Üzerine Nitel Bir Araştırma²

Abstract

This study explores value-based payment reforms in healthcare, aiming to enhance productivity, efficiency, and quality of care by shifting the focus from quantity to value. Using a grounded theory approach and the Delphi technique, 28 healthcare stakeholders were selected through purposive sampling. Data were analysed with MAXQDA 2020, and value parameters were ranked by importance. Findings define value in healthcare as "a quality service," with participants supporting value-based repayment despite some limitations. Fifteen key value measurement parameters were identified. The study recommends addressing resistance to change and implementing necessary revisions for Türkiye to adopt this model successfully.

Keywords : Value-Based Reimbursement, Value in Health, Value-Based Healthcare, Health Reimbursement Methods.

JEL Classification Codes : D61, I13, I11, I18, H51.

Öz

Bu çalışma, odağı nicelikten değere kaydırarak üretkenliği, verimliliği ve bakım kalitesini artırmayı amaçlayan sağlık hizmetlerinde değere dayalı ödeme reformlarını incelemektedir. Temellendirilmiş teori yaklaşımı ve Delphi tekniği kullanılarak, 28 sağlık sektörü paydaşı amaçlı örnekleme yoluyla seçilmiştir. Veriler MAXQDA 2020 ile analiz edilmiş ve değer parametreleri önem sırasına göre düzenlenmiştir. Bulgular, sağlık hizmetlerinde değeri "kaliteli bir hizmet" olarak tanımlamaktadır ve katılımcılar, bazı sınırlamalara rağmen, değere dayalı geri ödemeyi desteklemektedir. On beş temel değer ölçüm parametresi belirlenmiştir. Çalışma, Türkiye'nin bu modeli başarılı bir şekilde benimsemesi için değişime karşı direncin ele alınmasını ve gerekli revizyonların uygulanmasını önermektedir.

Anahtar Sözcükler : Değer Esaslı Geri Ödeme, Sağlıkta Değer, Değer Esaslı Sağlık Hizmeti, Sağlık Geri Ödeme Yöntemleri.

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1. Introduction

Countries are seeking solutions to address rising costs of health services, increasing rates of chronic disease, and implementation challenges in health systems. As healthcare stakeholders strive to reduce costs and improve quality, reforms in health financing and reimbursement methods have recently become one of the most discussed topics among radical changes (Kasapoğlu, 2016: 133; Nathaniel, 2021; Tutar & Kılınc, 2007: 31).

With health financing systems, countries pay health service providers. In fact, the simplest form of payment is direct payment. With this payment method, the patient (the first party) pays the service provider (the second party) directly for the service received. The need for a third party arose to protect society against the financial risk of falling ill. The third party can be an individual, a public or private institution. The existence of a third party and the associated payment mechanism in health care is partly due to the uncertainty of health. However, it is also a way of ensuring interpersonal redistribution. To finance health care, the third party collects income, directly or indirectly, from the population it protects, which is used to reimburse health care providers (Casto & Layman 2006: 7; Mossialos & Dixon 2002: 2-3). Health service providers have been reimbursed by the reimbursement agency using various methods to date. These methods include salary- or wage-based payment, per capita payment, payment by the global budget method, payment per service or per day, payment by diagnosis-related groups, and performance-based payment methods. In addition to these payment models, the United States of America (USA) has developed a value-based reimbursement method to improve quality and control costs (Cashin, 2015: 3; Johnson et al., 2019: 539). This study briefly discusses health financing systems and reimbursement methods, with a focus on the value-based reimbursement model.

"Value" should be adapted to the unique circumstances and health system of each country. In health services, value is determined by outcomes, not inputs; therefore, the measurement of value should be based on outcomes rather than the number of services provided. In other words, improvements to the delivery process do not add value to the system unless they affect health outcomes. With the development of value, there will be gain for all parties, such as patients, health service financiers, health service providers, providers of medicines and supplies, and the economic sustainability of the health system will be ensured (Porter, 2010: 2477). These quality-based value-based initiatives that have emerged in the US are also seen in other countries. In addition to developed countries such as the UK and Australia, there are ambitious payment-modality initiatives in many other countries. Moreover, all OECD member countries are struggling to design systems that produce health outcomes that ensure the realisation of social concepts such as effectiveness, responsiveness, safety, efficiency, and equity (Custers et al., 2007: 226). With innovative payment models and team-based approaches, the UK is moving towards a patient-centred system. Other payment-performance models and quality standardisation measures have also been explored and implemented in the UK, and efforts are being made to move towards more standardised and efficient care. Many countries, such as France, the United Kingdom, Italy, Sweden, Spain, China, Malaysia, Pakistan, Japan, South Korea, and Thailand, have started to use

value-based methods as purchasing and reimbursement methods (Godman & Gustafsson, 2013; Kamae, 2010; Sorenson et al., 2013).

2. Data & Methodology

The main objective of this study is to discuss the suitability of the value-based reimbursement method for Türkiye, based on expert opinions, to reveal the pros and cons, and to determine which parameters are more important in the value formula. The concretisation of the concept of "value" based on stakeholders' views in Türkiye and the evaluation of the Turkish healthcare system's suitability for the value-based reimbursement method are expected to contribute to the national and international literature in this field. This study will guide practitioners, administrators, and policymakers on the applicability of the value-based payment method in Türkiye.

2.1. Study Sample

Criterion sampling and maximum variation sampling, among the purposeful sampling methods, were used to select participants for the research. For the research, participants were required to be familiar with the value-based reimbursement method. At the same time, the participants were determined by selecting the relevant key people from the following institutions and groups with maximum diversity sampling (the number of participants is indicated in parentheses): Ministry of Health (4), Social Security Institution (6), academics (4), relevant professionals (3), Non-governmental organization (NGO) representatives (2), Turkish Grand National Assembly Health Commission (2), patients (3), research centers (2), researchers in the United States (2).

2.2. Data Collection

The semi-structured interview form, which is a data collection tool, was discussed and developed by 3 experts and finalised by a qualitative research specialist. The form includes 11 basic questions:

- Explaining and concretising the concept of value,
- Whether or not to include value in reimbursement,
- Which parameters should be included in the value formula,
- Pilot implementation,
- Implementation process,
- Capacity to change the payment method,
- Possible impact on performance,
- Factors that will make the transition to value-based reimbursement more difficult and easier,
- Groups supporting and opposing the value-based payment method,
- What will be the advantages and disadvantages of the method,

- Questions were asked about their views on the suitability and future success of the Turkish health system.

In the second part of the study, the findings obtained from the opinions on which parameters should be included in the value formula, which were asked for during the qualitative interview, and the 40 parameters determined after the literature review, were prepared by 10 experts who are interested in the subject and have conducted studies on the subject using the Delphi technique.

2.3. Data Analysis

Semi-structured interviews were conducted face-to-face with 28 participants. The data obtained from the interviews were transcribed and converted from audio to Word. The data obtained from the transcription process were imported into MAXQDA, a qualitative data analysis package (Kuckartz et al., 2021: 306). After the data collection process was completed, nine participant groups were formed, and the data obtained from the participants were analysed. Before the analysis phase, although it was planned to first code the data belonging to each group within itself to determine the general group tendencies and differentiations from the group, and then to evaluate the group data comparatively, it was seen that the evaluations of the participants were complementary to each other during the data coding phase. Therefore, to avoid repetition and to support the research pattern, the findings were combined and interpreted. In the study, the grounded theory method and the Delphi technique were used as qualitative methods. In grounded theory, the researcher codes the data from the beginning of the research process, compares the data and codes, and defines temporary categories to be developed through further data collection (Charmaz & Belgrave, 2015; Vollstedt & Rezat, 2019: 86). Within the scope of the research, it is aimed to examine the phenomenon of "value" in depth.

The most important reason for choosing the qualitative research method in this study is to obtain detailed information on the subject by interviewing relevant parties face-to-face and investigating the applicability of the value-based reimbursement method in all aspects. To provide structure to the qualitative findings, guided by this study's conceptual framework, interview questions and transcripts were initially coded. Then, as Braun and Clarke (2006) suggest, another round of coding was conducted to reveal specific themes and their relationships. The researcher and another researcher in the field evaluated the thematic results and reached a consensus by assessing areas of agreement or differentiation. The researcher independently reviewed the thematic findings and clarified inconsistencies.

Additionally, the value parameters that emerged from the interviews were compiled in light of information obtained from the literature and sent by e-mail to experts related to the subject and/or who have conducted studies on it, to be scored for degree of importance using the Delphi technique. At this stage, the parameter evaluation was repeated until consensus was reached. It was aimed to reach the parameters that should be included in a value-based reimbursement model that could be implemented in Türkiye. It was decided to

use a Likert-type scale to identify the most important parameters in the value-based reimbursement model and to remove unnecessary parameters.

2.4. Limitations and Ethical Approval

This study was conducted using qualitative research methods with a select sample of experts, and the findings cannot be generalised independently of the context. Participants were assumed to be knowledgeable about the topic. The research was approved by the Hacettepe University Social and Human Sciences Ethics Committee. All participants provided informed consent.

3. Results

3.1. Findings of the Grounded Theory Study

THEME 1. Findings Related to the Explanation of the Concept of Value: The participants were first asked to explain the concept of "Value". The codes for this theme are given in the figure below. Under this heading, the findings were analysed in 3 categories: value as a concept, value as a concrete concept and value as a response in health. In Figure 1, the codes collected under this theme are presented by frequency.

Figure: 1
Word Cloud of the Concept of Value



- *Category 1. Value, as a concept, is coded as a result beyond output: doing the right thing, eliminating waste, achieving the target, superiority, contribution, importance, quality, benefit, and meaning.*

Some of the definitions of the concept of value made by the interviewees participating in the study are given below:

- ✓ "It is possible to define value as the benefit that a product or service provides, and the user clearly feels that or that the user expects to receive from that product or service." (Academician 1)
- ✓ "Anything that provides a cost advantage that creates a positive output for an organisation, or a person, can be defined as value." (Social Security Institution employee 6)
- ✓ "Value is worth, significance." (Health worker 1)
- ✓ "Value is the quality received for the money spent." (Health worker 3)

THEME 2. Findings on Thoughts on Transition to Value-Based Reimbursement Model: The codes were as follows: necessity (those who stated that transition to value-based payment method is necessary), sufficient capacity (those who think that there is sufficient capacity for transition to value-based payment method in the Turkish health system), willingness (those who stated that they are willing to transition to value-based payment method), insufficient (those who stated that there are some insufficiencies for transition to value-based payment method), unclear (participants who did not specify a clear statement for transition to value-based payment). Most respondents agreed that transitioning to a value-based reimbursement model is necessary (23 respondents).

THEME 3. Findings Regarding the Formulation of Value: The 10 most coded parameters that were thought to be included in the formula were patient satisfaction, hospital mortality rates, clinical quality indicators, number of patients recovered, number of days of hospitalisation, cost, complications, drug and material use, readmission rates and number of qualified personnel.

THEME 4. Findings Regarding the Pilot Implementation Method of Value-Based Reimbursement: Pilot implementation should start with the 1st step, begin with the general, and be based on medical equipment, patient-based, unit-based, hospital-based, disease-based, drug-based, and region-based. The most recurrent of these statements is that it should be done on a disease basis.

THEME 5. Findings on the Implementation Process of the Value-Based Reimbursement Method: For the implementation process of value-based reimbursement, the following codes were created: It will take a very long time, it will take 5-10 years, it will take 3-5 years, it will take 1-3 years, and it is difficult to determine the period for this. The most frequently coded term was the idea that it would take a very long time (8 participants).

THEME 6. Findings Regarding the Capacity to Change the Reimbursement System: It was stated that the information system (15) and infrastructure (9) of the Turkish healthcare system are sufficient for transition to a value-based payment system. However, 14 participants also stated that adaptation is necessary for this.

THEME 7. Findings on the Effects of the Value-Based Reimbursement Method on Performance: Participants most frequently reported that overall performance would increase (9). Then, it was stated that physicians' performance would increase the most (7).

THEME 8. Findings on Factors that will make the Transition to Value-Based Reimbursement Difficult and Facilitating: Participants were asked what they thought would make the transition of the Turkish health system to value-based reimbursement more difficult and easier.

Table: 1
Factors that will make the Transition to Value-Based Reimbursement Difficult and Facilitate

Category 1. Challenging Factors	Category 2. Facilitating Factors
The most frequently coded factor that would make the transition to value-based reimbursement difficult is resistance (21). Participants think that patients and healthcare professionals lack education on this issue (14). The next most frequently coded barrier was bureaucracy (12). 9 participants mentioned transparency and the inability to collect quality data. The difficulty of establishing an electronic system (8) and the difficulty of determining measurements (7) were also among the most frequently coded codes. Other emerging codes are; not determining the formula correctly, not explaining the system well to stakeholders, not everyone wanting and participating, decision makers not being on the same side, lack of ownership, low staff motivation, injustices in payment, politics, lack of leadership, lack of know-how, determination, technical preparation, unique characteristics of health services, ethical problem, lack of patient follow-up system, need for cultural change, persuasion of health workers, need for health personnel.	As a facilitating factor for transition to value-based reimbursement, the most frequently coded factor was the unification of the social security system (SGK) under a single roof (16). It is thought that our e-health system is good (9), which will facilitate the implementation of a value-based health system. The reward system (8) and the government's support for this payment system (8) are other factors that will facilitate the transition to the system. Other factors that are thought to facilitate are as follows; incentives, having young healthcare professionals, having willing managers, reducing costs, acting jointly with stakeholders, making it clear, patients' demand, cooperation between SGK and Ministry of Health, high patient satisfaction, existence of criteria, having good practice examples, using the advantages of the system, doing the right thing, TIG system, technology.

THEME 9. Findings Regarding the Groups Supporting and Opposing the Implementation of the Value-Based Reimbursement Method: Participant views on the groups that would support and oppose the implementation of the value-based reimbursement method in Türkiye are given below.

Table: 2
Groups Supporting and Opposing the Implementation of the Value-Based Reimbursement Method

Category 1. Supporting Groups	Category 2. Groups That Will Oppose
The Social Security Institution was coded 22 times as the group most likely to support the transition to value-based reimbursement. Patients are also thought to support the transition to this system (14). Participants also think that service providers (12) and the Ministry of Health (8) would support this payment system.	"Those who do not want extra burden" was coded 8 times by 7 participants as the leading group that would oppose the value-based reimbursement method. Those who are against innovation (7) and physicians (7) are also thought to oppose it. This is followed by health personnel (6) and the manipulators. It is also thought that the Turkish Medical Association (5) and those who do not want to be audited (5) will oppose.

THEME 10. Findings on the Advantages and Disadvantages of Value-Based Reimbursement Method for the Turkish Health System: Table 3 shows that according to the views of the participants, the advantages of the value-based reimbursement method are as follows, and the disadvantages that may be caused by the value-based reimbursement method are listed as follows:

Table: 3
Advantages and Disadvantages of the Value-Based Reimbursement Method

Category 1. Advantages	Category 2. Disadvantages
Quality will increase (28), satisfaction will increase (19), cost will decrease (19), efficiency will increase (12), health expenditures will decrease (8), payment will be made according to quality (8), transparency will be ensured (7), errors will decrease (5), health outcomes will improve (5), benefit to society will increase (5), performance (5) and efficiency (5) will increase.	Failure to address all aspects of the patient, insufficient demonstration of contributions, problematic data accuracy, political interference, risky results, calculation of the number of hospitalization days should be patient-specific, need for an audit mechanism, workload, inability of the needy to access the service, equity problems, penalization, cost of data collection, communication, identification of the source of the problem, rural hospitals, use for profit, difficulty of implementation, inability to calculate payment correctly, increased expenditures, handicap of mortality rate, patient's health literacy, disadvantage to pharmaceutical companies, international attack, lack of personnel, training cost and no disadvantage.

THEME 11. Findings on the Suitability and Future Success of the Turkish Health System for Value-Based Reimbursement Method: The main opinion of the participants on this issue is that it will be successful (coded 20 times). However, the number of those who think that revision is necessary (19) is also not small. Some thought compliance was possible (13), and others stated that we cannot know until we experience it (10).

3.2. Findings of the Delphi Study

As a result of the qualitative analysis and with support from the literature, 40 parameters, identified by the participants as potentially included in the value-based reimbursement model, were presented to 10 experts using the Delphi method. The parameters with a score of 4 or higher in the first round were resubmitted to the same experts until consensus was reached. As a result of the analysis conducted after the second round, it was seen that a consensus was reached among the participants. When the 16 parameters obtained from the 40 parameters in the first round were asked of the participants (10) again in the second round to score them, it was found that 15 parameters were classified as important or very important, with scores of 4 or above. Of the parameters, only "the rate of re-admission of the patient to the outpatient clinic within 30 days" received a score of 3 and was interpreted as not being included in the formula. The results of the second-round scoring and the final list of parameters reaching consensus are shown in Table 4.

4. Discussion

4.1. Evaluation of Grounded Theory Study Results

THEME 1. Evaluating the Concept of Value: Identifying and evaluating what constitutes value in health services is a highly controversial issue that requires detailed examination (Woods, 2016: 60). In literature, the concept of value is defined in many ways. The most frequently coded words explaining the concept of value in general terms, based on the study's findings, are benefit, worth, importance, and contribution. The Oxford Dictionary defines value as the importance or utility of something to a person. Porter (2010) defines value as the benefit gained for every penny spent. According to Diamond and Kaul, value is a "utility fee" (Boden & Redberg, 2018). The participants of the project defined the meaning of value as "benefit" and "worth". It was found to be one-to-one compatible with Diamond and Kaul's definition. In their study, Elf et al. (2017) defined the concept of value

in health as a patient-centred, high-quality service with improved patient safety. In this study, the participants' definitions of the concept of value in health were found to be compatible with those in the literature. The subcodes of the satisfaction code obtained from the study findings overlap with the findings of the study conducted by Seyfioğlu (2019).

THEME 2. Evaluation of Transition to a Value-Based Reimbursement Model: According to the study's findings, more than half of the participants agreed that the transition to a value-based reimbursement model is necessary. Egdom et al. (2019) also stated in their study that there is a need for a payment method that prioritises value for patients. In his study, Philips (2019) stated that innovative payments that share risk and align incentives across providers should be piloted to make healthcare more sustainable.

THEME 3. Evaluating the Formulation of Value in a Reimbursement Model: Lee, Austin, and Pronovost (2016) stated in their study that, in a value-based payment model, there should be a single metric that encompasses multiple variables. This measurement should cover complications, patient satisfaction, adherence to the care process, clinical and patient-based outcomes. The cost here includes all service costs, such as diagnosis, care, surgery, and treatment. Damberg et al. (2014), on the other hand, identify the key constructs underlying the value-based reimbursement model as: (a) clinical care process, (b) patient care experience, (c) outcome and (d) efficiency. These are in line with the study findings. MacLean (2017) defined health outcomes as events such as recovery from illness, death, and complications of medical care. Morris and Bailey (2014) also emphasised survival measures (mortality), disease incidence (morbidity), and health-related quality-of-life parameters as outcome measures. Based on the findings, the proposed grouping is supported by the literature.

THEME 4. Evaluation of the Pilot Implementation Process: In their study, Werner and Emanuel (2021) state that the transition to value-based payment should be based on regional trends. Joseph (2017) believes that change should be implemented in phases to help employees adapt gradually. He states that implementing new changes as a department will help evaluate progress. Ağlamış (2020) stated in his study that value-based purchasing in healthcare services is most common in the pharmaceutical sector.

THEME 5. Evaluation of the Transition Period to the Implementation of the Value-Based Reimbursement Method in Türkiye: According to the study's findings, half of the participants believe that the transition to the value-based reimbursement method will take more than 5 years. Although evaluating new processes takes time, it should be done well (Burgess & Radnor, 2013; Gustavsson et al., 2016; Toussaint & Berry, 2013). McWilliams et al. (2018) found that the transition to a successful value-based payment model will take time, years of experience, and investment to realise savings and practice transformations. Yıldırım et al. (2021) also noted that value-based healthcare and related topics are still very new and that a long, challenging process lies ahead, requiring time, patience, and perseverance.

THEME 6. Assessment of the Capacity of the Turkish Reimbursement System: The study found that the information system (14 participants) and infrastructure (7 participants) of the Turkish healthcare system are sufficient for the transition to a value-based payment method. However, 12 participants stated that adaptation is also necessary, and changes should be made to the system. Bergstrom (2015) stated in his study that healthcare organisations that can adapt to this new payment system and make the necessary changes will gain significant benefits. Seyfioğlu (2019) stated in his study that a National Health Information System was established through e-transformation efforts in Türkiye's health service delivery and that an effective information system infrastructure was developed by aligning with international standards through the E-Nabız system. This supports the findings of this study.

THEME 7. Assessing the Effects of Value-Based Reimbursement on Performance: Value-based payment is an approach that financially rewards physicians for performing better than expected. Participants most frequently reported that value-based payment would improve overall performance. Participants also stated that it could improve the performance of physicians, hospitals, and other healthcare professionals. Only three of the participants thought that it would not directly affect performance. However, the literature also supports this finding. For example, Schuttner et al. (2020) stated in their study that payment reform may not be sufficient to change performance. Eijkenaar et al. (2013) also found little evidence in their study that performance improves with increases in additional payments to providers. In their study, Chambers et al. (2015) stated that changes in payment methods may be associated with changes in hospitals' financial performance. Seyfioğlu (2019) stated in his study that value should be defined to improve performance in health services.

THEME 8. Evaluation of the Factors That Make the Value-Based Reimbursement Method Difficult and Facilitating: Although the idea of focusing on value rather than volume sounds good, it has a few challenges in practice. While the transition to value-based reimbursement requires a major cultural change, it also requires a strong technological infrastructure and detailed planning (Durur, 2020: 180). Among the factors that will make the transition to value-based reimbursement difficult, the most recurring was resistance to change. Other findings were as follows: the need for cultural change, bureaucratic obstacles, not explaining the system well, convincing healthcare professionals, inability to collect quality data, lack of technical preparation, inability to process data, transparency, difficulty in determining measurement, lack of training, lack of determination and the need for healthcare personnel. It is thought that these findings may also be encountered in other change processes to be carried out in the health system. Alsleben (2016) stated that appropriate input data must be defined to expect successful results. Izguttinov et al. (2020) and Yildirim et al. (2021) note that policy support and a coherent policy and regulatory environment play an important role in accelerating the transition to a value-based reimbursement model. Based on the qualitative data analysis, the most frequently cited factor facilitating the transition to a value-based reimbursement model was the unification of SGK under a single roof. When evaluated in Türkiye, it is seen as a valid factor. The fact

that reimbursements are made from a single source suggests that changes in method will progress more easily.

THEME 9. Evaluation of Groups that will Support and Oppose the Value-Based Reimbursement Method: When the value-based reimbursement method is evaluated in the Turkish healthcare system, it is thought to be a natural outcome to expect institutions such as SGK and the Ministry of Health to support this method, which was developed to increase quality and reduce costs in healthcare services. The value-based reimbursement method is supported in the literature by Kuhn and Lehn (2015). In their study, the authors state that value-based payment programs significantly reduce costs, improve quality of care, and increase efficiency by shifting clinical and financial risk from payers to providers. According to the study's findings, the main groups that will oppose the value-based reimbursement method are those who do not want additional workload. 4 of the participants stated that no one would oppose it. It is thought that some of the groups mentioned in the study are likely to oppose any change. Damberg and Reid (2020) also stated in their study that employees who do not want extra work will not support it. Woolhveler and Himmelstein (2014) explained in their study that doctors would not want extra workload, as it is associated with decreased job satisfaction.

THEME 10. Evaluation of the Advantages and Disadvantages of the Value-Based Reimbursement Method: It is evident that the advantages identified in the study align with the factors mentioned in the objectives of the emergence of value-based reimbursement. Since the method was developed to achieve these advantages, the findings are expected to point to them. The fact that the value-based reimbursement method is patient-centred and grounded in patient satisfaction, unlike other payment methods, has highlighted the need to include patients in the system. The idea that patients in the Turkish health system lack health literacy has led to the conclusion that this lack creates disadvantages in the system.

THEME 11. Assessing the Suitability and Future Success of the Turkish Health System for Value-Based Reimbursement: According to the study's findings, revisions are expected to replace the current payment method with value-based reimbursement. In general, it is thought that the method will be successful with revisions. Koç (2017) stated that there are various positive and negative views on value-based payment in Türkiye, as in the rest of the world. Fendrick et al. (2010), on the other hand, stated in their study that any change involves risk factors, but the transition to a value-based reimbursement method will be successful by focusing on the benefits rather than risks. In their study, Şimşir and Altındış (2019) stated that there is potential for a value-based payment program, but that revisions, such as implementing the DRG system, are necessary beforehand. This result is in line with the project's findings.

4.2. Evaluation of Delphi Study Results

The 16 parameters that emerged through consensus among participants from the two rounds of Delphi studies and the top 16 most frequently repeated codes obtained from the

grounded theory study are compared in Table 4. Those found to be similar are shown in green.

Table: 4
Comparison of Delphi and Grounded Theory Study Results

Parameters Considered to be Included in the Value Formula	
Delphi Study Results	Grounded Theory Study Results
Satisfaction of patients and relatives	Patient satisfaction (40)*
Proportion of patients recovering in hospital	Clinical quality indicators (37)*
Skills and competence of hospital staff	Mortality rate (37)*
Complication rate	Number of patients recovered (24)*
Patient readmission rate within 30 days	Cost (22)*
Safe medication practices	Number of days hospitalised (22)*
Correct diagnosis and treatment rate	Use of medicines, materials (17)*
Hospital-acquired infection rate	Complications (17)*
Communication of health personnel with patients	Qualified personnel (15)*
Education of patients and relatives	Readmission rate (14)*
Case mix index	Burden of disease (Qaly Daly) (20)*
Reducing the social burden of disease (Qaly, Daly)	Productivity (12)*
Malpractice rate	Clinical outcomes (12)*
Repeat procedure (examination, film, MR, etc.)	Process quality (10)*
Patient's health status after treatment	Patient safety (9)*
Within 30 days, the speed of re-admission to the outpatient clinic	Infections (9)*

* Those in parentheses indicate the frequency number of the code, i.e., how many times it was coded. Green colour indicates overlapping parameters.

Most of the first 16 most repeated parameters (9) obtained by applying the grounded theory technique overlap with the first 16 of the parameters thought to be included in the formula because of the Delphi study. This reveals that the results of the study found by two different techniques are compatible. In the second round of the Delphi study, "the rate of re-admission of the patient to the outpatient clinic within 30 days" received 3 points out of 5 and was interpreted by the participants as a question of whether it should be included in the formula. The remaining parameters considered important and very important in the value calculation remained. The parameters used to calculate value-based payment in the United States (CMS, 2021) are mortality and complications, healthcare-associated infections, patient safety, patient experience, efficiency, and cost reduction. These headings were found to be consistent with the study's results. In the value-based reimbursement method, calculations should be based on evaluating countries' own systems and determining which indicators or measures create value. The parameters in this study's findings were determined through both grounded theory analysis with 28 participants and the Delphi technique with 10 expert participants.

5. Conclusion

The value-based reimbursement model focuses on measuring success and assessing process effectiveness. To use the model successfully, it will be necessary to measure and analyse data. Healthcare providers need to be patient, as it will take time for outcomes to show measurable improvement in the population. The effectiveness of this model will be seen in the organisation's ability to use it to achieve better health outcomes, less overuse, and lower costs. As each of these may use different measurement metrics, it is important to establish a baseline before the program starts to demonstrate its success. The parameters identified serve this purpose. The study concludes with information that will help health

policymakers redesign the reimbursement model. In this study, the views of academics, health policy thought leaders (employees of the Ministry of Health and Social Security), and other healthcare stakeholders regarding the value-based reimbursement method were collected. As a result of the study, participants mostly defined value as "benefit" and "worth". Participants defined value in healthcare services as "receiving a quality service and leaving the institution in good health". In addition, the participants stated that value can be measured concretely through evaluations of "quality" and "patient satisfaction". The definitions of value in the literature and those obtained from the study's results were found to be compatible.

As a result of the study, the participants stated that the pilot implementation should be disease-based in the first place, hospital-based in the second place and region-based in the third place. According to the frequency of the answers given by the participants, the factors that make it difficult to transition to value-based reimbursement were identified as resistance to change, the need for training first for patients and then for healthcare professionals, bureaucratic obstacles, lack of transparency, lack of quality data collection, difficulty in establishing an electronic system and difficulty in determining measurement. Facilitating factors were identified as the unification of the social security system under a single roof, the existence of a reward system, and the ease of system changes with government approval. The advantages of value-based reimbursement management are widely thought to include improving quality and satisfaction, reducing costs, increasing efficiency, lowering health expenditures, paying according to quality, ensuring transparency, reducing errors, and improving health outcomes. The disadvantages are thought to stem primarily from low health literacy in society. It is also thought that the penalisation system would be a disadvantage, as it would be undesirable. Another disadvantage is that some people will use the system in ways that align with their interests. In addition, while participants stated that value-based reimbursement can increase overall performance, some noted that it cannot be considered performance-based.

Participants were mostly positive about the transition to a value-based reimbursement model. Despite the inadequacies, the necessity of transition was expressed. In addition, the most common view regarding the suitability of the Turkish health system for value-based reimbursement is that it will succeed. The second most common opinion was that it would be successful, the second most common was that it would require revision to be suitable, and the third most common was that Türkiye has the potential for transition. However, some thought that this could not be known without experience.

6. Recommendations

The study's conclusions and recommendations demonstrate its originality. In conclusion, when structured fairly and with the right framework, the value-based reimbursement model offers a realistic, rational, and sustainable blueprint for a new healthcare payment system. It can effectively incentivise and reward high-quality, efficient, patient-centred care. In addition, since an organisational model is expected to be needed for

the planned value-based reimbursement method, one has been proposed in line with the study's results. In addition, in line with the results of this study, the following suggestions were made.

- ✓ The health system should be transformed into one that pays for health and quality rather than disease and procedures, and that supports the provision of higher-quality health care at lower prices and rewards it in a value-based way.
- ✓ The groups that oppose the value-based reimbursement method should be carefully assessed, the reasons for their opposition investigated, and necessary efforts made to obtain their support.
- ✓ Factors such as resistance and bureaucratic barriers that would make the transition to value-based reimbursement difficult should be eliminated.
- ✓ More work is needed to ensure that the systems to calculate value are accurate. Further work could redefine existing elements and propose new ones. However, much work is recommended in this area to move forward successfully.
- ✓ As a result of this study, it is recommended to develop a formula based on the parameters thought to constitute the value.

In future studies, it is recommended to:

- ✓ Test the proposed value formula through pilot implementations in different healthcare settings and measure its impact on cost, quality, and patient satisfaction.
- ✓ Explore patient and frontline healthcare provider perspectives in more detail, as this study mainly included system-level experts.

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Examining the Theory of Planned Behaviour in the Context of Sustainable Clothing

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Planlanmış Davranış Teorisinin Sürdürülebilir Giyim Ürünleri Bağlamında İncelenmesi

Abstract

This study aims to extend the Theory of Planned Behaviour Model (attitude toward the behaviour, subjective norm, perceived behavioural control and behavioural intention) by adding environmental concern, price sensitivity, and love of money - rich, budget, and achievement dimensions - variables. Structural Equation Modelling was conducted using online data collected from 297 participants in Ankara, İstanbul, and İzmir, including individuals who purchased sustainable clothing and those who had not. The analysis reveals that attitude toward the behaviour, subjective norm, perceived behavioural control, environmental concern, and rich dimension of love of money positively affect behavioural intention, whereas the achievement dimension has a negative effect. The budget dimension of the love of money does not directly affect behavioural intention to purchase sustainable clothing. Perceived behavioural control moderates the links between attitude and behavioural intention, and between subjective norm and behavioural intention. Results contribute to the literature on sustainable clothing by examining the Theory of Planned Behaviour with limiting and enhancing variables simultaneously, and support decision-making for sustainable clothing companies.

Keywords : Theory of Planned Behaviour, Price Sensitivity, Love of Money, Environmental Concern, Sustainable Clothing, Sustainability.

JEL Classification Codes : M10, M19, M30, M31.

Öz

Bu çalışma, Planlanmış Davranış Teorisi Modelini (davranışa yönelik tutum, öznel norm, algılanan davranışsal kontrol) modele çevresel kaygı, fiyat duyarlılığı ve para sevgisi-zenginlik, bütçe ve başarı boyutlarını ekleyerek genişletmeyi amaçlamaktadır. Ankara, İstanbul ve İzmir’de yaşayan ve daha önce sürdürülebilir giyim ürünleri satın almış ya da almamış bireyleri kapsayan 297 katılımcıdan çevrim içi olarak toplanan verilerin analizinde Yapısal Eşitlik Modellemesi kullanılmıştır. Analiz sonuçları, davranışa yönelik tutumun, öznel normun, algılanan davranışsal kontrolün, çevresel kaygının ve para sevgisinin zenginlik boyutunun davranışsal niyeti olumlu etkilediğini, başarı boyutunun ise olumsuz etkilediğini göstermektedir. Para sevgisinin bütçe boyutunun davranışsal niyet üzerinde doğrudan bir etkisi bulunmamaktadır. Algılanan davranışsal kontrol, davranışa yönelik tutum - davranışsal niyet ve öznel norm - davranışsal niyet arasındaki ilişkide düzenleyici bir rol oynamaktadır. Araştırmanın sonuçları, Planlanmış Davranış Teorisi kapsamında sürdürülebilir giyim ürünleri satın alma niyetini artıran ve sınırlandıran değişkenleri eş zamanlı olarak ele alarak literatüre katkı sağlamak ve sürdürülebilir giyim ürünleri alanında faaliyet gösteren şirketlerin karar alma süreçlerini desteklemektedir.

Anahtar Sözcükler : Planlanmış Davranış Teorisi, Fiyat Duyarlılığı, Para Sevgisi, Çevresel Kaygı, Sürdürülebilir Giyim, Sürdürülebilirlik.

1. Introduction

The clothing industry has various environmental and social problems. Environmental problems include excessive water consumption, chemical contamination, microplastics, greenhouse gas emissions, and waste generation (Diddi et al., 2019). Social problems involve long working hours, unsafe conditions, underpayment, and child labour (Geiger & Keller, 2018). Research shows that it is one of the main sectors that cause environmental pollution and waste (Alves et al., 2023). However, the exact size of the environmental effects that the clothing industry has on the world is currently being debated and is uncertain (Sohn et al., 2021), and most of the negative consequences of consumption, such as how and why people buy things or how they dispose of clothes are also unknown (Sohn et al., 2021).

Sustainable clothing products are expected to account for 6.1% of the global apparel market in 2026, up from 3.9% in 2021 (Statista, 2023). Despite this upward market trend, La Rosa & Johnson-Jorgensen (2021) note that, although consumer interest in sustainable clothing products is increasing, consumers do not prioritise sustainability when making purchases. In other words, although consumers are becoming more aware of the clothing industry's problems, their purchasing behaviours remain unsustainable due to various barriers and challenges (Schiaroli et al., 2024). Consumers with higher levels of environmental responsibility are more likely to purchase environmentally friendly products (Yue et al., 2020). Therefore, it is recommended to raise awareness of the consequences of purchasing fast-fashion items (Brandão & Costa, 2021). In contrast, this awareness does not always translate into sustainable product purchasing behaviour (Pieters et al., 2022). In this context, this research emphasises understanding the factors that increase consumers' purchase intention for sustainable clothing and identifying the factors that lead to reluctance to make such purchases by extending the Theory of Planned Behaviour.

Ajzen (1985) established the Theory of Planned Behaviour by incorporating perceived behavioural control, as a moderating variable, into the Theory of Reasoned Action (Fishbein & Ajzen, 1975), thereby enhancing the accuracy of predictions of behavioural intention and behaviour. The Theory of Reasoned Action posits that behavioural beliefs and subjective norm ultimately influence behavioural intention and behaviour. Since the majority of empirical studies reveal the direct impact of perceived behavioural control (Ajzen, 2020), subsequent versions of the Theory of Planned Behaviour (Ajzen, 1991, 2012) emphasise the direct impact of perceived behavioural control, attitude toward the behaviour, and subjective norm (e.g., Leclercq-Machado et al., 2022). Besides, it remains essential for the Theory of Planned Behaviour to measure behavioural intention and behaviour within the framework of target, act, context, and time (TACT) (Ajzen, 2005; Ajzen & Fishbein, 1977). The TACT framework comprises four key components: the action itself, the target of that action, the context in which it occurs, and the specific time at which it occurs (Ajzen, 2005;

Ajzen & Fishbein, 1977). Some of the studies measure behavioural intention and/or behaviour based on TACT (Ajzen, 2005; Ajzen & Fishbein, 1977) and consider perceived behavioural control as a moderator (Ajzen, 1985), whereas this is not the case in the sustainable clothing sector [e.g., health behaviour (Hagger et al., 2022); quitting smoking behaviour (Hukkelberg et al., 2014); exercising and reducing energy consumption (La Barbera & Ajzen, 2021)]. Although several studies have examined the Theory of Planned Behavior within the framework of sustainable clothing products while expanding the theory with different variables [e.g., environmental concern (Leclercq-Machado et al., 2022), slow fashion consumption (Lira & Costa, 2022), attitude toward recycling (La Rosa & Johnson Jorgensen, 2021), and consumption of sustainable clothes (Frommeyer et al., 2022)], no prior study has explicitly applied the Theory of Planned Behavior within the TACT framework to examine purchase intention.

In this context, studies extend the theory by incorporating additional variables to understand the factors that contribute to purchase intention or behaviour for sustainable clothing. However, to the best of our knowledge, no research has examined the factors that limit [e.g., price sensitivity (Hsu et al., 2017) and the love of money (Kashif & Khattak, 2017)] and enhance [e.g., environmental concern (Leclercq-Machado et al., 2022)] the intention to purchase sustainable clothing, employing the Theory of Planned Behaviour. Furthermore, studies within the Theory of Planned Behaviour tend to focus on the variables separately, such as the love of money in fast food and price sensitivity in electric vehicles (Hahnel et al., 2014), organic food (Wang et al., 2020), and personal care products (Moslehpour et al., 2021). The relationship between the environment and price has been examined across various fields; however, the literature indicates a need to investigate these two variables simultaneously in the social sciences (Fox et al., 2021). Consequently, this research seeks to examine the variables that limit sustainable clothing purchase intention, such as price sensitivity and the love of money (rich, budget, and achievement dimensions), as well as the enhancing factor, environmental concern, within the Theory of Planned Behaviour. By jointly integrating variables that both limit and enhance sustainable clothing purchase intention within a single TPB framework, this study advances prior research, which has largely examined these variables separately. This integrated approach allows for a more comprehensive understanding of how economic constraints and non-economic factors simultaneously shape sustainable clothing purchase intention.

2. Conceptual Framework

2.1. The Theory of Planned Behaviour

The Theory of Planned Behaviour (Ajzen, 1985, 1991) extends the Theory of Reasoned Action (Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975) by adding the perceived behavioural control variable. According to the Theory of Reasoned Action, if an individual positively views a behaviour (attitude toward the behaviour) and believes that important others in their social circle also support the behaviour (subjective norm), then the individual's

intention of performing that particular behaviour in terms of TACT will be higher, increasing the likelihood of the actual behaviour.

According to the Theory of Planned Behaviour, attitude toward the behaviour, subjective norm, and perceived behavioural control are influenced by behavioural, normative, and control beliefs, which are also interrelated (Ajzen, 1985, 2019). Behavioural beliefs reflect individuals' expectations about the possible outcomes of behaviour, and these beliefs lead to either a favourable or an unfavourable attitude toward the behaviour. Normative beliefs reflect the perceived social pressure an individual feels for a particular behaviour, which directly influences subjective norms. Control beliefs relate to the "perceived ease or difficulty of performing a specific behaviour" and directly affect perceived behavioural control (Ajzen, 2019; Ajzen & Fishbein, 2000). Ajzen (2022) states that the exclusion of these beliefs in research depends on the research's objective, and beliefs and/or behaviour variables could be excluded from the model if needed. If the goal is to understand consumer intentions and behaviours, then attitude toward the behaviour, subjective norm, and perceived behavioural control are sufficient (Ajzen, 2022). Therefore, this research focuses on the variables: attitude toward the behaviour, subjective norm, perceived behavioural control, and behavioural intention.

Ajzen (1985) proposed perceived behavioural control as a moderating role, without a direct influence, in influencing the effects of attitude toward the behaviour and subjective norm on behavioural intention. Due to the difficulty of demonstrating this relationship, researchers have generally focused on direct effects, and few studies have shown this moderation (Ajzen, 2020). Building on these theoretical foundations, this research formulates the following hypotheses:

- H1.** Attitude toward the behaviour positively influences the behavioural intention to purchase sustainable clothing.
- H2.** Subjective norm positively influences the behavioural intention to purchase sustainable clothing.
- H3.** Perceived behavioural control positively influences the behavioural intention to purchase sustainable clothing.
- H4.** Perceived behavioural control moderates the relationship between attitude toward the behaviour and behavioural intention.
- H5.** Perceived behavioural control moderates the relationship between subjective norm and behavioural intention.

2.2. Price Sensitivity

Price sensitivity is "the level of awareness and responsiveness exhibited by consumers toward the changes in product prices" (Monroe, 1973). It is also defined as "the change in consumer demand resulting from an increase or decrease in price" (Low et al., 2013). A high level of price sensitivity indicates a propensity to respond significantly to

price changes, whereas a low level indicates a propensity to respond minimally (Wakefield & Inman, 2003). Consumers with high price sensitivity tend to search for lower prices than those with low price sensitivity (Natarajan et al., 2017). Prices affect consumers' evaluation of products and purchase decisions (Moser, 2016). Although many consumers hold positive attitudes toward environmentally friendly products, high costs often prevent these attitudes from translating into actual purchase intentions or behaviours (Özer et al., 2015). Products with sustainable production processes (e.g., green products) are priced higher than other products that don't follow these processes due to the higher costs of sustainable production (Erdil, 2018). According to Deloitte research, the percentage of consumers who report purchasing sustainable products is declining, with cost cited as the primary reason (Pieters et al., 2022). The high prices of sustainable clothing may influence consumers' purchase intentions, particularly among those with high price sensitivity. Thus, the formed hypothesis is as follows:

H6. Price sensitivity negatively influences the intention to purchase sustainable clothing products.

2.3. Love of Money

The love of money can be defined as "an individual's attitude toward or value attributed to money" (Chen et al., 2014). In this research, the love of money is examined within the affective (rich), behavioural (budget), and cognitive (achievement) dimensions (Tang, 2007). The rich dimension reflects individuals' level of attachment to money and the desire to be rich. The budget focuses on whether an individual uses their money carefully (Luna-Arocas & Tang, 2004). The achievement indicates that money represents the individual's success (Elias & Farag, 2010). Individuals with a strong love of money aim to hold on to their money and avoid unnecessary spending. The love of money leads individuals to avoid purchasing expensive clothing (Bozacı, 2021). The findings indicate that the love of money shapes ethical judgments, and consumers with high levels of love of money are likely to accept unethical behaviour (Chang et al., 2019). Accordingly, it might be proposed that since sustainable consumption is often associated with ethical and prosocial values, individuals with a stronger love of money may be less inclined to allocate resources toward sustainable clothing. The proposed hypotheses are as follows:

H7.a. The achievement dimension of the love of money negatively influences the behavioural intention to purchase sustainable clothing.

H7.b. The budget dimension of the love of money negatively influences the behavioural intention to purchase sustainable clothing.

H 7.c. The rich dimension of the love of money negatively influences the behavioural intention to purchase sustainable clothing.

2.4. Environmental Concern

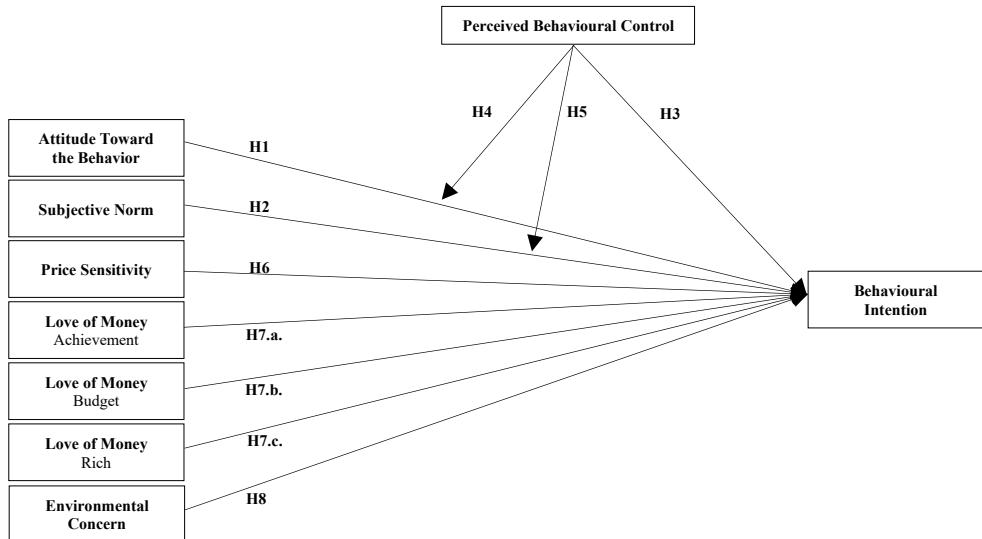
Consumer attitudes toward environmentally friendly products are increasingly influencing their purchase decisions (Rex & Baumann, 2007). This trend may be due to

growing awareness of environmental challenges in recent years (Zencir & Korkmaz, 2024). The rise in consumer awareness of environmental issues, such as protecting natural resources, has led to greater concern about the environment (Krause, 1993), and, as a result, more consumers identify as environmentally conscious and adopt environmentally friendly behaviours (Manaktola & Jauhari, 2007). Environmental concern is defined as "a strong attitude toward protecting the environment" (Crosby et al., 1981) and as "the degree to which consumers perceive environmental issues as important for the well-being of society" (Bickart & Ruth, 2012). Within the framework of the Theory of Planned Behaviour, environmental concern can be considered a background factor shaping consumers' attitudes toward sustainable clothing, thereby fostering purchase intention (Chang & Watchravesringkan, 2018). Consumers with higher levels of environmental concern engage more in environmentally friendly consumer behaviour (Shetzer et al., 1991). Individuals with greater environmental concern not only consider environmental issues but also engage in environmentally friendly purchasing behaviour (Laroche et al., 2001). Environmental concern directly and positively influences the purchase intention for sustainable products (Kamalanon et al., 2022). Individuals with greater environmental concern are more likely to purchase sustainable products than those with lower environmental concern (Kim & Choi, 2005). However, prior research indicates that although environmental concern is a significant predictor of purchase intention, it does not always translate into actual sustainable purchasing behaviour, as economic considerations such as perceived value, socio-demographic factors, and price sensitivity may restrict consumers' decisions (Dangelico et al., 2022). The formed hypothesis is as follows:

H8. Environmental concern positively influences the behavioural intention to purchase sustainable clothing.

Figure 1 illustrates the Model Generated from the proposed hypotheses.

Figure: 1
Extending the Theory of Planned Behaviour with Price Sensitivity, Love of Money, and Environmental Concern Variables



3. Methodology

3.1. Measures and Sampling

This research received ethical approval from Hacettepe University with the E-35853172-300-00002580377 number. Behavioural intention, attitude toward the behaviour, subjective norm, and perceived behavioural control within the framework of the Theory of Planned Behaviour were measured using the Fishbein & Ajzen (2010) scale. Price sensitivity was measured using the Wakefield & Inman (2003) scale. The scale of T.L.-P. Tang (2007) was used to measure the love of money across the rich, budget, and achievement dimensions. The scale of Nekk Mahmud & Fekete-Farkas (2020) was used to measure environmental concern. The variables and measurement items used in the study are given in **Appendix 1**. A 5-point Likert scale ranging from "strongly disagree" to "strongly agree" was used. Permission to use and publish the variables included in the survey was obtained from the authors. Sustainable clothing products were defined and presented to the participants at the beginning as *'garments produced using organic raw materials that do not contain chemicals that are harmful to the environment and human health in their production processes, or recycled raw materials that require less resource consumption'*.

To extend the Theory of Planned Behaviour, the target, action, context, and time (TACT) framework (Ajzen & Fishbein, 1977) was first pre-tested. According to sales data from a particular sustainable clothing company, consumers purchase sustainable clothing

products from the retailer approximately once a year. Then, the first pre-test was conducted with 33 participants, which confirmed this result. A second pre-test was conducted with 59 participants to understand consumers' perceptions of sustainable clothing prices. The majority of participants (67.8%) found sustainable clothing prices high. A third pre-test was administered to 52 participants to assess their understanding of the survey questions. Adjustments were made to statements that were not understood, and six attention-check questions (e.g., "Please select the green box" and "Please choose the highest number") were added.

To test our hypotheses, an online questionnaire was distributed via convenience sampling to 348 participants aged 18 years or older in Ankara, İstanbul, and İzmir. The target population consisted of individuals who had previously purchased sustainable clothing products, as well as those who had not. Nevertheless, 51 individuals were excluded from the study due to inaccurate responses to attention-check questions (Muszyński, 2023) and were considered outliers. As a result, data from 297 participants were included for analysis. This corresponds to a nonresponse rate of approximately 14.6% and a response rate exceeding 85%, both of which are considered acceptable in survey-based behavioural research (Groves, 2006). Out of the 297 participants, 56% are female. The participants have an average age of 36, with 56% of them being university graduates. Moreover, 63% of the participants describe their income level as middle, and 30% as high.

To eliminate common method bias (Podsakoff et al., 2003), each scale was presented to participants not sequentially, one after another, but in a mixed order (Ajzen, 2005). For instance, participants are given a subjective norm item immediately after a behavioural intention item, followed by a perceived behavioural control item. In addition, procedural remedies recommended by Podsakoff et al. (2003), such as varying item wording and scale direction across items, were employed, and reverse-coded items were recoded before data analysis.

3.2. Analysis

To test the proposed hypotheses by extending the Theory of Planned Behavior (attitude toward the behavior (H1), subjective norm (H2), perceived behavioral control (H3)) with price sensitivity (H6), the love of money (achievement (H7.a), budget (H7.b), and rich (H7.c) dimensions), and environmental concern (H8), structural equation modeling (measurement model and path model) was carried out via the AMOS 23 program. First, the measurement model was analysed, and the results indicated an acceptable fit (RMSEA = .056, CFI = .924, CMIN/DF = 1.927, TLI = .911).

Convergent validity was assessed using average variance extracted (AVE), while reliability was evaluated through Cronbach's alpha and composite reliability (CR). The AVE values, as well as the validity and reliability of the scales, are acceptable; **Table 1** presents the mean, standard deviation, Cronbach's alpha (CA), composite reliability (CR), average variance extracted (AVE), and the correlations between the variables. Furthermore,

discriminant validity was assessed using the heterotrait-monotrait ratio (HTMT) criterion (Henseler, 2021). As shown in **Appendix 2**, all HTMT values are below the recommended threshold of 0.85, indicating satisfactory discriminant validity (Henseler et al., 2015).

Table: 1
Mean, Standard Deviation (Std.Dev.), CA, CR, AVE Values, and Correlations

	Mean	Std. Dev.	CA	CR	AVE	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. ATT	4,230	,803	,886	,886	,660	,812								
2. SN	3,422	,771	,802	,798	,445	,452**	,667							
3. PBC	4,139	,704	,775	,676	,302	,508**	,504**	,549						
4. PS	3,549	,722	,691	,704	,448	,022	,065	,132*	,669					
5. AC	2,624	1,077	,938	,938	,835	,063	,075	-,046	,003	,913				
6. BUD	3,557	,853	,814	,824	,612	-,117*	-,058	-,004	,220**	-,042	,782			
7. RIC	4,037	,869	,879	,880	,710	0,78	-,005	,047	,157**	,412**	-,117*	,842		
8. EC	3,768	,694	,651	,658	,391	,210**	,447**	,363**	,164**	-,126*	,232**	-,166**	,625	
9. BI	3,814	,861	,865	,872	,633	,567**	,607**	,609**	,117**	-,085	-,041	,085	,444**	,795

Note: ATT: Attitude Toward the Behaviour, SN: Subjective Norm, PBC: Perceived Behavioural Control, PS: Price Sensitivity, AC: Love of Money Achievement Dimension, BUD: Love of Money Budget Dimension, RIC: Love of Money Rich Dimension, EC: Environmental Concern, BI: Behavioural Intention

The bold numbers represent the square roots of the AVEs.

** $p < 0,01$, * $p < 0,05$

The results of path analysis are summarised in **Table 2**. Attitude toward the behaviour, subjective norm, perceived behavioural control, and environmental concern positively affect behavioural intention. Therefore, H1, H2, H3 and H8 are supported. Perceived behavioural control has a positive and significant moderating role on the attitude toward the behaviour-behavioural intention relationship and a negative and significant moderating role on the subjective norm-behavioural intention relationship. Therefore, H4 and H5 are supported. The achievement dimension of the love of money negatively affects behavioural intention. Therefore, H7.a. is supported. Price sensitivity and budget dimension of the love of money have no significant effect on behavioural intention. Therefore, H6 and H7.b. are not supported. The rich dimension of the love of money has a significant but positive impact on behavioural intention, which is contrary to our proposed hypothesis; therefore, H7.c is not supported.

Table: 2
Structural Model Results

Hypothesis	Path	β	S.E.	t	p	Results
H1	ATT $\rightarrow$ BI	,315	,039		$p < ,001$	Supported
H2	SN $\rightarrow$ BI	,331	,042		$p < ,001$	Supported
H3	PBC $\rightarrow$ BI	,245	,040		$p < ,001$	Supported
H4	ATT $\times$ PBC $\rightarrow$ BI	,159		3,733	$p < ,01$	Supported
H5	SN $\times$ PBC $\rightarrow$ BI	-,120		-2,624	$p < ,01$	Supported
H6	PS $\rightarrow$ BI				$p = ,798$	Not supported
H7.a.	AC $\rightarrow$ BI	-,158	,029		$p < ,001$	Supported
H7.b.	BUD $\rightarrow$ BI				$p = ,694$	Not supported
H7.c.	RIC $\rightarrow$ BI	,146	,036		$p < ,001$	Not supported
H8.	EC $\rightarrow$ BI	,173	,045		$p < ,01$	Supported

4. Conclusion, Discussion and Managerial Implications

Attitude toward the behaviour, subjective norm, and perceived behavioural control positively influence the intention to purchase sustainable clothing. Perceived behavioural

control moderates the association between attitude toward the behaviour and purchase intention, consistent with the literature (La Barbera & Ajzen, 2020). Furthermore, perceived behavioural control has a weakening moderating effect on the relationship between subjective norm and purchase intention, a finding also supported in the literature (La Barbera & Ajzen, 2021). However, studies focusing on the subjective norm-perceived behavioural control relationship also report conflicting results (La Barbera & Ajzen, 2021), as some researchers have reported no significant moderating effect (Hagger et al., 2022). As La Barbera & Ajzen (2021) stated, the moderating role of perceived behavioural control has been increasingly recognised, yet empirical research remains limited. Therefore, the moderating role of perceived behavioural control warrants more attention, especially in non-Western countries (La Barbera & Ajzen, 2021). All of our findings regarding the Theory of Planned Behaviour are consistent with the literature (La Barbera & Ajzen, 2021) and provide support for the theory in a developing country context. Beyond confirming established relations in the Theory of Planned Behaviour, this study contributes theoretically by examining the theory alongside limiting and enhancing factors, including monetary and non-monetary variables. Furthermore, this study contributes theoretically by highlighting the moderating role of perceived behavioural control in sustainable clothing purchase intention, thereby extending prior research that has primarily emphasised its direct effects.

Monetary variables, such as price sensitivity and the budget dimension of the love of money, do not directly affect purchase intention for sustainable clothing. This result differs from prior findings, possibly due to the characteristics of this research's sample. More than half of the participants are in the middle- to high-income range, and more than half have a university degree. The achievement dimension of the love of money negatively affects purchase intentions, as expected, consistent with existing research (Mo et al., 2022). However, prior research suggests that pro-environmental consumption can also be motivated by personal standards and a sense of obligation to do what is perceived as right, indicating that the achievement dimension could be associated with sustainable purchase intentions (Haws et al., 2014; Mastria et al., 2023). The rich dimension unexpectedly has a positive influence on the purchase intention of sustainable clothing, which might be due to the sample's characteristics. The literature identifies the rich dimension as a key dimension of the love of money, emphasising its potential to lead individuals toward unethical behaviour (Tang & Liu, 2012). However, one plausible explanation is that consumers with higher perceived wealth may view sustainable clothing, often associated with health, well-being, and environmental benefits, as more desirable (Dangelico et al., 2022). Prior research shows that perceived value, including functional, economic, and social aspects, increases willingness to pay and purchase intentions for sustainable clothing, suggesting that the positive effect of the rich dimension reflects perceptions of attainability and desirability rather than purely monetary motives (Dangelico et al., 2022). Hence, managers of sustainable clothing companies may incorporate rich, wealth-related cues, which may differ across cultures [e.g., expensive hobbies, charismatic behaviour, self-presentation, and specific possessions (Rinn et al., 2023)], into their marketing communications to reach their target market effectively.

Since the literature indicates the necessity of investigating price and environmental-related issues simultaneously in the field of social sciences (Fox et al., 2021), this study addresses this gap in the literature by demonstrating how environmental concern operates alongside monetary variables within the Theory of Planned Behaviour framework, rather than being examined as an isolated antecedent of purchase intention. Besides monetary variables, environmental concern is positively associated with behavioural intention, as expected and supported by the literature (Kamalanon et al., 2022). The findings of this study would assist researchers and managers operating in the sustainable clothing sector.

Marketing managers in the sustainable clothing sector should highlight the environmental aspects of their products. By conveying the sustainability of their production processes in advertisements, they can more effectively communicate that the product is environmentally sustainable. Since variables such as price sensitivity and the budget dimension of the love of money do not affect the intention to purchase sustainable clothing, firms should focus their marketing communications on environmental and sustainability issues rather than on price. Additionally, given the positive impact of the rich dimension of love of money on purchase intention, firms should explore how their target audience perceives the richness of sustainable clothing and incorporate this concept into their marketing strategies. The present study integrates monetary variables with environmental concern within a single Theory of Planned Behaviour framework, providing a more comprehensive explanation of sustainable clothing purchase intention. Thus, the key insights derived from this research can guide marketing professionals in targeting customers with high levels of environmental concern and adopting environmentally focused communication strategies. To conclude, marketing managers may prioritise the effects of variables in the Theory of Planned Behaviour while also considering environmental concerns [e.g., green messages (Muralidharan et al., 2024)] and rich- or wealth-related cues in their marketing communication strategies and operations.

This study offers key theoretical contributions to the literature on sustainable clothing. First, it examines the moderating role of perceived behavioural control within the framework of the Theory of Planned Behaviour, extending prior research that has primarily focused on its direct effects. Second, it integrates monetary variables (price sensitivity and the love of money) into a single Theory of Planned Behaviour framework and addresses a gap in the literature, in which these factors have been examined separately. Third, shows that environmental concern operates alongside monetary factors rather than as an isolated antecedent of sustainable clothing purchase intention. Together, these contributions provide a more comprehensive theoretical understanding of the underlying sustainable clothing consumption.

The findings of this study suggest that public policies aimed at promoting sustainable clothing consumption should primarily focus on increasing environmental awareness and shaping consumer attitudes (Hong et al., 2024). Given the positive impact of environmental concern on purchase intention, policymakers can support consumer education campaigns, sustainability labelling standards, and practices that increase transparency (Agrawal et al.,

2023). Furthermore, framing sustainable clothing as a valuable, desirable option associated with quality, health, and well-being can enhance the effectiveness of policy implementation (Mizrachi & Sharon, 2025). Overall, behavioural policies that target attitudes, subjective norms, and perceived behavioural control can play a significant role in increasing purchase intention for sustainable clothing (Dangelico et al., 2022; La Rosa & Johnson-Jorgensen, 2021).

5. Limitations and Future Research Directions

This research focuses solely on sustainable clothing products and is limited to the analysis of data collected from participants in this study. It is important to note that non-probability sampling does not permit generalisation of findings to the broader population; instead, the results are limited to the individuals who participated in the study (Stratton, 2021). Future research could encompass additional sectors, cross-country analysis, and subsequent investigations to assess behavioural intention. The Theory of Planned Behaviour has been applied in various contexts of goods and services, such as clothing (Leclercq-Machado et al., 2022), health (Hagger et al., 2022), sports (La Barbera & Ajzen, 2021), and the service industry (green hotels) (Özer et al., 2015). However, sustainable products are available in many categories. Therefore, future studies could explore different product categories within the scope of sustainable products (e.g., personal care and cleaning products).

As a result of this research, it was found that the target audience purchasing sustainable clothing products is more environmentally focused rather than price-focused. In future studies, not only environmental concern but also other variables, such as environmental awareness, environmental knowledge, and green brand image, could be examined. Additionally, different sub-dimensions in the love of money scale, such as goodness, evil, and power (Tang et al., 2005), could also be included in the research. Behavioural, normative, and control beliefs, actual behavioural control, and behaviour (Ajzen, 2022) were not included in this research. Future studies may incorporate other variables and relationships as suggested (Ajzen, 2022). Moreover, Ajzen clearly emphasises that the concepts of target, action, context, and time (TACT) should be explicitly defined in the wording of survey items (Ajzen, 2005; Ajzen & Fishbein, 1977). In this research, target, action, and time were specified in the questionnaire items; however, more specific details regarding the context (e.g., store- and/or non-store-based retailer) might be investigated in future studies.

According to the literature, aesthetics plays a crucial role in consumers' clothing purchases, including sustainable clothing (Niinimäki, 2010). According to research by Bocti et al. (2021), consumers believe that sustainable clothing products are more durable and of higher quality, but they are not fashionable and do not align with current fashion trends. However, Brandão & Costa (2021) state that unfashionable options and the perceived lack of style of sustainable clothing products are among the constraints that discourage consumers from purchasing sustainable clothing. Furthermore, sustainable clothing products

are perceived as unfashionable, unexciting, and lacking style (Ozdamar-Ertekin & Atik, 2015), which creates an obstacle to purchasing them (Brandão & Costa, 2021). Consumers choose based on a multitude of utilities, among which sustainability is only one; therefore, ignoring the remaining could damage the viability of clothing companies that emphasise sustainable fashion (Tsogas, personal communication, September 26, 2024). Consequently, sustainable clothing brands should prioritise the design and fashion aspects of their products to align with consumers' perceptions of style and fashionability (Tsogas, personal communication, September 26, 2024).

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Appendix 1: Scales Used in the Study

Variables	Items	Source
Attitude Toward the Behaviour	My purchasing at least 1 sustainable clothing product, for the next 1 year is <i>good</i> : 1: 2: 3: 4: 5: <i>bad (R)</i>	Fishbein & Ajzen (2010)
	My purchasing at least 1 sustainable clothing product for the next 1 year is unpleasant: 1: 2: 3: 4: 5: <i>pleasant</i> .	
	My purchasing at least 1 sustainable clothing product for the next 1 year is harmful: 1, 2, 3, 4, 5: <i>beneficial</i> .	
	My purchasing at least 1 sustainable clothing product for the next 1 year is worthless: 1: 2: 3: 4: 5: <i>valuable</i> .	
Subjective Norm	Most people who are important to me think that I <i>should</i> : 1 : 2 : 3 : 4 : 5 : I <i>should not</i> purchase at least 1 sustainable clothing product in the forthcoming 1 year.	Fishbein & Ajzen (2010)
	It is expected of me to purchase at least 1 sustainable clothing product within the next 1 year.	
	<i>extremely likely</i> : 1 : 2 : 3 : 4 : 5 : <i>extremely unlikely</i>	
	The people in my life whose opinions I value would <i>approve</i> : 1, 2, 3, 4, 5 <i>disapprove</i> of me purchasing at least 1 sustainable clothing product in the forthcoming 1 year.	
	Most people who are important to me purchase at least 1 sustainable clothing product each year.	
	<i>completely true</i> : 1 : 2 : 3 : 4 : 5 : <i>completely false</i>	
Perceived Behavioural Control	The people in my life whose opinions I value <i>purchase</i> : 1, 2, 3, 4, 5 <i>do not purchase</i> at least 1 sustainable clothing product each year.	Fishbein & Ajzen (2010)
	I am confident that I can purchase at least 1 sustainable clothing product, for the next 1 year.	
	My decision to purchase at least 1 sustainable clothing product over the next 1 year is completely up to me.	
	If I really wanted to, I could purchase at least 1 sustainable clothing product, for the next 1 year.	
	For me, purchasing at least 1 sustainable clothing product over the next 1 year is within my control.	
Price Sensitivity	I'm willing to make an extra effort to find low prices on sustainable clothing products.	Wakefield & Inman (2003)
	I will change what I had planned to buy to take advantage of a lower price on sustainable clothing.	
	I am sensitive to differences in the prices of sustainable clothing products.	
Love of Money (Achievement)	Money represents my achievement.	T. L.-P. Tang (2007)
	Money is a symbol of my success.	
	Money reflects my accomplishments.	
Love of Money (Budget)	I budget my money very well.	T. L.-P. Tang (2007)
	I use my money very carefully.	
	I am proud of my ability to save money.	
Love of Money (Rich)	I want to be rich.	T. L.-P. Tang (2007)
	It would be nice to be rich.	
	Having a lot of money (being rich) is good.	
Environmental Concern	I am pleased to purchase sustainable clothing products.	Nekmahmud & Fekete-Farkas (2020)
	I consider the potential environmental impact of my purchase when making many of my decisions.	
	I would describe myself as an environmentally responsible person.	
Behavioral Intention	I intend to purchase at least 1 sustainable clothing product, in the next 1 year.	Fishbein & Ajzen (2010)
	I will purchase at least 1 sustainable clothing product, in the next 1 year.	
	I am willing to purchase at least 1 sustainable clothing product, in the next 1 year.	
	I plan to purchase at least 1 sustainable clothing product, in the next 1 year.	

Appendix 2: Heterotrait-Monotrait (HTMT) Ratios

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. ATT									
2. SN	,553								
3. PBC	,601	,616							
4. PS	,032	,092	,188						
5. AC	,068	,086	,060	,004					
6. BUD	,137	,070	,008	,295	,057				
7. RIC	,091	,004	,052	,205	,451	,141			
8. EC	,269	,604	,493	,244	,161	,326	,220		
9. BI	,649	,738	,721	,154	,095	,044	,098	,584	

Yeşil Örgüt Kültürü, Sürdürülebilir İş Modeli İnovasyonu ve İşletme Performansı İlişkisi: KOBİ'ler Üzerinde Bir Araştırma¹

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The Relationship Between Green Organisational Culture, Sustainable Business Model Innovation, and Business Performance: A Study for SMEs²

Abstract

This research aims to examine the relationships between green organisational culture, sustainable business model innovation, and business performance in SMEs. In this context, data were collected from 406 SMEs operating in the manufacturing industry sector in Konya province. Statistical analyses revealed significant positive relationships among green organisational culture, sustainable business model innovation, and business performance. A mediation analysis further demonstrated that sustainable business model innovations mediate the effect of green organisational culture on business performance. This study is a pioneering work that examines the relationships among these variables holistically, with a specific focus on SMEs.

Keywords : Green Organisational Culture, Sustainable Business Model Innovation, Business Performance, SME.

JEL Classification Codes : M1, M14, L2.

Öz

Bu araştırma KOBİ'lerde yeşil örgüt kültürü, sürdürülebilir iş modeli inovasyonu ve işletme performansı arasındaki ilişkileri incelemeyi amaçlamaktadır. Bu doğrultuda Konya'da imalat sanayisinde faaliyette bulunan 406 KOBİ'den veri toplanmıştır. Yapılan istatistikî analizler sonucunda yeşil örgüt kültürü, sürdürülebilir iş modeli inovasyonu ve işletme performansı değişkenleri arasında anlamlı ve pozitif ilişkiler saptanmıştır. Yapılan aracı analiziyle, yeşil örgüt kültürünün işletme performansı üzerindeki etkisinde sürdürülebilir iş modeli inovasyonlarının aracı rolü olduğu ortaya konmuştur. Bu çalışmanın ilgili değişkenler arasındaki ilişkileri KOBİ'ler özelinde bütüncül bir yaklaşımla inceleyen öncü çalışmalardan biri olması nedeniyle alan yazına katkı sağlayacağı düşünülmektedir.

Anahtar Sözcükler : Yeşil Örgüt Kültürü, Sürdürülebilir İş Modeli İnovasyonu, İşletme Performansı, KOBİ.

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1. Giriş

Sürdürülebilir iş modeli inovasyonu son yıllarda akademide ve uygulamada çok fazla ilgi gören bir kavram haline gelmiştir. Bu kavram, işletmenin kâr elde etmekle birlikte daha sürdürülebilir sonuçlara ulaşması için ürünlerini/hizmetlerini, süreçlerini, hammaddelelerini, enerjilerini ve işbirliklerini yenilemesi anlamına gelmektedir. Bocken vd. (2014)’e göre, sürdürülebilir bir iş modeli oluşturma temelinde insanlar ve çevre üzerinde olumlu bir etki yaratmak yatmaktadır. Sürdürülebilir iş modelleri, işletmelerin kendi devamlılıklarını sağlarken aynı zamanda toplumsal etkilerini artırarak genel refahın iyileştirilmesine de katkıda bulunabilmektedir. Günümüz işletmeleri sürdürülebilir iş modeli inovasyonlarının uzun vadeli başarı ve rekabetçilik için temel bir stratejik gereklilik olduğunun farkına varmaya başlamışlardır.

Sürdürülebilir iş modeli inovasyonları, toplum ve çevre sorunlarını birlikte ele alarak rekabet avantajı sağlamada önemlidir (Massa et al., 2017). Sürdürülebilir iş modeli inovasyonları olumlu çevresel ve sosyal etkileri, uzun süre hayatta kalma eğilimleri (Islam et al., 2022) ve kârlılığa olan katkıları (Caldera et al., 2019) nedeniyle KOBİ’ler tarafından dünya genelinde rağbet görmektedir. Sürdürülebilir iş modeli inovasyonları, genel olarak olumsuz çevresel ve sosyal etkileri azaltmayı amaçlamaktadır (Faber et al., 2005).

KOBİ’lerde gelişmeye başlayan “yeşil düşünce”, kârlılığı artıran başarılı ve sürdürülebilir iş uygulamalarına yol açmıştır. KOBİ’lerde iş modeli inovasyonları kritik öneme sahiptir (Salavou & Avlonitis, 2008). Çünkü bu inovasyon ve yeni fırsatlar firma performansını artırmaya yardımcı olur (Schneider & Spieth, 2013; Jantunen et al., 2005). KOBİ’lerin pazarlardaki performansı, iş modellerinin ne kadar yaratıcı ve yenilikçi olabildiğine bağlıdır (Bianchi et al., 2017).

Bu araştırma örgütsel performansı değerlendirmek için kullanılan yeşil örgütsel uygulamalara da odaklanmaktadır. Yeşil örgütsel uygulamalar, işletmelerin çevreye duyarlı adımlar atarak hem doğal kaynakların korunmasına destek olduğu hem de daha sürdürülebilir bir geleceğe yatırım yaptığı çevre dostu faaliyetlerdir. Çevresel çabalar, uzun vadeli performans açısından kritik öneme sahiptir (Ainin et al., 2016). Çevresel çabalarla birlikte, örgütte yeşil bir kültürün benimsenmesi ve uygulanması örgütsel performansı artırabilir (El-Kassar & Singh, 2019). Yeşil örgüt kültürü, literatürde araştırmacıların dikkatini çeken ve anlamlı bir olgu olarak kabul edilen bir kavram haline gelmiştir (Yang et al., 2017). Yeşil örgüt kültürü, bir örgütün çevreye ilişkin davranış ve faaliyetlerini yöneten değer, ilke ve inançların bütünü olarak tanımlanabilir. Günümüzde çoğu işletme kâr odaklı olsa da, zaman değişmekte ve işletmelerin çevreye daha fazla odaklanmaları gerekmektedir (Bennett & James, 2017). Bazı araştırmacılar işletme performansı kavramını yeşil örgüt kültürü perspektifinden değerlendirmiştir (Chandra et al., 2021). Ayrıca, yeşil örgüt kültürüne sahip olmanın örgütsel performansı önemli ölçüde artırdığı tespit edilmiştir (Wang, 2019). Çeşitli çalışmalar yeşil örgüt kültürünü bir işletmenin performansı ile ilişkilendirmiş olsa da, kesin bulguların eksikliği nedeniyle araştırmacılar bu ilişki üzerinde yoğunlaşmaya devam etmektedir (Muisyo & Qin, 2021).

Bu araştırma, KOBİ’lerde yeşil örgüt kültürü, sürdürülebilir iş modeli inovasyonu ve işletme performansı arasındaki ilişkilerin incelenmesini amaçlamaktadır. Araştırma, işletmelerin çevreye ve topluma karşı duyarlılık geliştirmesine katkıda bulunması açısından önemli görülmektedir. Aynı zamanda, bu alanda yapılan özgün çalışmalardan biri olarak literatüre değer katması beklenmektedir. Ulusal yazında sürdürülebilir iş modeli inovasyonu konusunda yapılan çalışmalar daha çok kavramsal nitelikte olup saha çalışmasına rastlanmamıştır. Sürdürülebilirlikte yeşil örgüt kültürü de nispeten gelişmemiş bir çalışma konusudur. Literatürde yeşil örgüt kültürü, sürdürülebilir iş modeli inovasyonu ve işletme performansı kavramları genellikle ayrı ayrı ya da ikili ilişkiler çerçevesinde incelenmiş; ancak bu üç kavramın bütüncül etkileşimini ele alan bir çalışmaya rastlanmamıştır. Bu sebeple çalışmanın özellikle alan yazına katkı sağlayacağı düşünülmektedir. Ayrıca bu çalışma yöneticilere sürdürülebilir iş modeli inovasyonlarına ulaşmak için yeşil örgüt kültürüne odaklanmaları konusunda uygun bir rehber olabilecektir.

2. Kavramsal Çerçeve

2.1. Yeşil Örgüt Kültürü

Örgüt kültürü, bir kurumdaki bireylerin tutum ve eylemlerini şekillendiren ve üyeler tarafından paylaşılan inançlar, değerler ve ilkeler olarak tanımlanmaktadır (Schein, 2010). Yeşil örgüt kültürü, örgütte herkes tarafından kabul edilip paylaşılan, çevre dostu olma ile ilgili değerler, inançlar, ilkeler, semboller ve sosyal kalıplardan oluşmakta ve örgüt çalışanlarının davranışlarını etkilemektedir (Aggarwal & Agarwala, 2021; Chang & Lin, 2015). Başka bir tanımda yeşil örgüt kültürü, örgütlerin girişimlerinin çevre dostu olması için yönlendiren standartlar ve ilkeler olarak tanımlanmıştır (Afum et al., 2020).

Yeşil kültüre sahip örgütler, performans sorunlarını ele almak için farklı yolların değerlendirilmesi ve geliştirilmesi olasılığı daha yüksek olan örgütlerdir. Bu nedenle, performans iyileştirme yöntemleri bu tür örgütlerin amacı ve vizyonu içinde yer alır. Güçlü bir yeşil kültür üreticileri iş ilkelerine uymaya zorlar ve bu konuda teşvik eder. Özetle, yeşil kültür örgüt üyelerinin davranışlarını etkilemektedir (Chang & Lin, 2015). Kaynak temelli görüş teorisine göre, bir örgüt çevreyle ilgili konuları kültürüne entegre ettiğinde, rakipleri tarafından taklit edilmesi güç olan ve rekabet avantajı sağlayan çevre dostu girişimleri teşvik ettiği varsayılmakta; bu durum da yeşil örgüt kültürünün gelişimini desteklemektedir (Rizvi & Garg, 2021; Wang, 2019).

Yeşil örgüt kültürü, çevresel sürdürülebilirlik ve kirlilikle mücadele gibi konulara öncelik verdiğinden, örgütün marka imajının güçlenmesine de katkı sağlamaktadır (Aggarwal & Agarwala, 2021). Fok vd. (2023) yeşil örgüt kültürü, toplam kalite yönetimi uygulamaları ve sürdürülebilir performans arasındaki ilişkinin pozitif yönlü olduğunu belirterek çevre dostu girişimlere yapılan yatırımların kârlılığa ve sürdürülebilirliğe katkı sağlayabileceğini vurgulamaktadır. Sürdürülebilirlik sorunlarına karşı yeşil örgüt kültürünü benimsemek, bir kurumun uzun vadede varlığını sürdürebilmesi için çok önemli görülmektedir (Cherchem, 2017).

Sonuç olarak, yeşil örgüt kültürü, örgütlerin çevresel olarak proaktif hedeflerini örgütsel performansa dönüştürmelerine destek olmak için önemli bir araç olabilir (Glisson, 2015; Pham et al., 2018). Yeşil örgüt kültürü, tüm işletmelerin uzun süre üretken ve rekabetçi kalabilmesi için benimsemesi gereken kritik bir fikirdir (Masri & Jaaron, 2017). Yeşil örgüt kültürü, çevresel olarak sürdürülebilir faaliyetlerle ilgili örgütün gereksinimlerini ve beklentilerini temsil eden beklentiler, nitelikler ve nesneleri içermektedir (Tahir et al., 2019).

2.2. Sürdürülebilir İş Modeli İnovasyonu

Sürdürülebilir iş modellerinin yaratılması ve hayata geçirilmesi sürdürülebilir iş modeli inovasyonu olarak adlandırılır. Bu, tamamen yeni iş modellerinin geliştirilmesini, ek iş modellerinde çeşitlendirmeyi, yeni iş modellerinin edinilmesini veya mevcut bir iş modelinden başka bir modele dönüşümü kapsayabilir (Geissdoerfer et al., 2018: 407). Roome ve Louche (2016: 12) sürdürülebilir iş modeli inovasyonunu işletmelerin ve yöneticilerinin yeni iş modelleri geliştirdiği, işletmelerin sürdürülebilir kalkınmaya katkıda bulunmak için iş modellerini gözden geçirip dönüştürdüğü bir süreç olarak tanımlamaktadır. Sürdürülebilir iş modeli inovasyonu, örgütlerin değer yaratma, sunma ve yakalama süreçlerini veya değer önerilerini değiştirmesi yoluyla çevre ve toplum için önemli olumlu etkiler yaratmayı ve olumsuz etkileri önemli ölçüde azaltmayı amaçlayan bir inovasyon olarak tanımlanabilir (Bocken et al., 2014).

İş modeli inovasyonu, değer yaratma, sunma ve yakalamada inovasyonu ifade etmekte; müşteri çekmeye katkı sağlayarak kârlılığı artırmaktadır (Teece, 2010). Başka bir ifadeyle, iş modeli inovasyonu müşterilerin değer için ödeme yapmaya ve bunu kâra dönüştürmeye teşvik etmek amacıyla işletmelerin değer yaratma, sunma ve yakalama mekanizmalarında yenilik yapmakla ilgilidir. Sosyal faktörleri iş modeli inovasyonu süreçlerine yerleştirme arayışı sürdürülebilir iş modeli inovasyonu olarak adlandırılmaktadır. Sürdürülebilir iş modeli inovasyonunun değeri, ekonomik, sosyal ve çevresel olarak daha geniş bir anlamda ele alınmakta ve odak noktasını müşterilerden ve hissedarlardan daha çok topluma doğru kaydırmaktadır (Bashir et al., 2022).

Sürdürülebilir iş modeli inovasyonu, çevresel ve toplumsal sorunlara çözüm bulurken aynı zamanda işletmelerin rekabet avantajı elde etmelerini sağlayan stratejik bir yaklaşımdır (Massa et al., 2017). Bir iş modeli inovasyonunun sürdürülebilir iş modeli inovasyonu olarak nitelendirilebilmesi için iki temel amaca hizmet etmesi gerekir. Bu amaçlardan ilki, sürdürülebilir kalkınmayı desteklemek; çevre, toplum ve işletmenin uzun vadeli refahı ile paydaşları üzerinde olumlu etkiler yaratmak ya da olumsuz etkileri azaltmaktır. İkinci temel amaç ise işletmenin değer önerisi, değer yaratımı ve değer yakalama süreçleri ile değer ağında sürdürülebilirliği teşvik eden çözümleri veya özellikleri benimsemektir (Geissdoerfer et al., 2018: 406).

Sürdürülebilir iş modeli inovasyonu, dünya genelinde karşılaşılan iklim değişikliği ve yoksulluk gibi temel sorunlara çözümler sunarak pazarları ve toplumu bazen kanun koyuculardan ve sivil toplum kuruluşlarından daha fazla şekillendirebilir; genellikle de

onlarla iş birliği içinde hareket eder (Schaltegger et al., 2016). Sürdürülebilir iş modeli inovasyonunun temel faaliyeti, değer önerisini sürdürülebilir bir değer önerisine dönüştürmektir. Bu dönüşüm, müşterilerin, hissedarların, tedarikçilerin, iş ortaklarının, toplumun ve çevrenin ihtiyaçlarını dikkate alarak değer yaratmayı mümkün kılar (Baldassarre et al., 2017).

Sürdürülebilir iş modeli inovasyonu, genellikle dört farklı şekilde ortaya çıkmaktadır. Bunlar (Geissdoerfer et al., 2018: 407):

- Sürdürülebilir girişimler: Sürdürülebilir iş modellerinin üretildiği yeni işletmeler,
- Sürdürülebilir iş modeline dönüşüm: Mevcut bir iş modelinin sürdürülebilir hale getirilmesi,
- Sürdürülebilir iş modeli çeşitlendirme: Mevcut iş modelinde büyük değişiklikler yapmadan ek bir sürdürülebilir iş modeli oluşturma,
- Sürdürülebilir iş modeli edinme: Yeni bir iş modeli entegre ederek veya satın alarak sürdürülebilirlik sağlama.

Sürdürülebilir iş modeli inovasyonu yürütülen faaliyetlerde değer yaratmayı ve bu değerini ekososyal fayda olarak tüm paydaşlar arasında dengeli bir şekilde dağıtılmasını da göz önünde bulundurur. Örneğin, sanayide kullanılan enerji girdilerini güneş ve rüzgâr başta olmak üzere yenilenebilir enerjiye yönlendirmek veya ürünlerin pazara ulaşma biçimini değiştirmek (örneğin, taşımacılık yöntemlerini dönüştürmek) gibi uygulamalar sürdürülebilir iş modeli inovasyonu kapsamında değerlendirilebilir (Ferlito & Faraci, 2022: 224).

2.3. İşletme Performansı

Lebens ve Euske (2006)’ya göre performans, hedeflerin ve sonuçların ne kadar başarıyla gerçekleştirildiğine dair bilgi sunan finansal ve finansal olmayan göstergelerden oluşan bir bütün olarak tanımlanmaktadır. İşletme performansı, örgütün belirlediği hedeflere ulaşırken kullandığı girdiler ile elde ettiği çıktıların ölçülmesinde ortaya koyduğu çabanın etkinliği ve verimliliği şeklinde ifade edilmiştir (Elitaş & Ağca, 2006: 362). Başka bir ifadeyle, örgütün belirlenen hedeflere ulaşma düzeyini ve derecesini ortaya koyan çok yönlü bir terimdir (Karaman, 2009: 414).

İşletme performansının etkili bir biçimde yönetilmesi, firmalara rekabet avantajı kazandırırken sürdürülebilir büyümeyi destekler ve uzun vadeli başarıya ulaşmalarında önemli bir rol oynar. Performansın düzenli olarak izlenmesi, yöneticilere stratejik karar alma süreçlerinde yol gösterir ve paydaşların memnuniyetini artırarak işletmenin genel itibarının oluşmasına katkı sağlar (Porter, 2008: 81).

İşletme performansının ölçülmesinde iki temel yaklaşım bulunmaktadır: finansal performans ve finansal olmayan performans (Gözen, 2018: 74). Bir örgütün performansını değerlendirmede genellikle finansal göstergeler ön planda tutulmakta; kârlılık, verimlilik,

maliyetler, yenilikçilik, büyüme, kalite ve pazara odaklanma gibi unsurlar bu kapsamda dikkate alınmaktadır (Soylu & Ayanoğlu, 2022: 207). Bununla birlikte, finansal olmayan performans boyutları da en az finansal ölçütler kadar önemli değerlendirme araçları arasında yer almaktadır. Kurumların mali tabloları ve yapıları kârlılık ve finansal başarı hakkında bilgi sunabilirken, çalışanların yetkinlikleri ve bilgi birikimleri gibi unsurlar bu raporlar aracılığıyla yansıtılamamaktadır (Ersoy et al., 2014: 3).

3. Yeşil Örgüt Kültürü, Sürdürülebilir İş Modeli İnovasyonu ve İşletme Performansı İlişkisi

Yeşil örgüt kültürü, araştırmacıların büyük ilgisini çekmiş ve önemli bir olgu olarak kabul edilmiştir (Yang et al., 2017). Yeşil örgüt kültürü, bir örgütün çevreye ilişkin davranış ve faaliyetlerini yöneten değerler, ilkeler ve inançlar olarak tanımlanabilir. Günümüzde genellikle tüm işletmeler kâr odaklıdır, ancak zaman değişmektedir ve işletmelerin çevreye odaklanması gerekmektedir (Bennett & James, 2017). Birkaç çalışma yeşil örgüt kültürüne sahip olmanın örgütsel performansı önemli ölçüde artırdığını ortaya koymuştur (Wang, 2019; Chandra et al., 2021). Yeşil örgüt kültürünün işletme performansı üzerinde olumlu ve anlamlı bir ilişkiye sahip olduğu yapılan çalışmalarla ortaya konmuştur (García-Machado & Martínez-Ávila, 2019; Chandra et al., 2021; Imran et al., 2021). Karakuş ve Erdiñcelebi (2018) yaptıkları çalışmada yeşil yönetim algısının ve yeşil işletme fonksiyonlarının işletme performansı ile anlamlı ve pozitif yönde ilişkili olduğunu ortaya koymuşlardır.

Bhatti vd. (2024) yaptıkları çalışma ile yeşil örgüt kültürünün sürdürülebilir iş modeli inovasyonu üzerinde anlamlı ve belirgin bir etkisi olduğunu bulmuşlardır. Bununla birlikte, Tahir vd. (2019) yeşil örgüt kültürünün işletme performansı ile karmaşık bir ilişki ağına sahip olduğunu ortaya koymuştur. Kaplan (2023) tarafından yeşil örgüt kültürünün iş tatmini ve örgütsel bağlılık üzerinde anlamlı ve pozitif bir etkisi olduğu belirlenmiştir.

Bashir vd. (2022) araştırmalarında sürdürülebilir iş modeli inovasyonlarının KOBİ performansını doğrudan ve olumlu yönde etkilediğini ortaya koymuşlardır. Bu bulgu, Caldera vd. (2019) ile Schneider ve Spieth’in (2013) sürdürülebilir iş modeli inovasyonlarının olumlu sosyal ve çevresel etkilerinin daha yüksek kârlılıkla sonuçlanabileceği yönündeki bulguları da desteklenmektedir. Shakeel vd. (2020) sürdürülebilir iş modeli inovasyonlarının: sürdürülebilir değer önerisi inovasyonu, sürdürülebilir değer yaratma ve teslim inovasyonu ile sürdürülebilir değer yakalama inovasyonu yoluyla örgütsel çıktıyı geliştirerek çevresel, sosyal ve ekonomik düzeylerde sürdürülebilir performans elde ettiğini savunmaktadır. İş modeli inovasyonu, örgütlerin faaliyetlerini daha etkin bir şekilde gerçekleştirmelerini sağlayarak satış, pazarlama ve stok maliyetlerini azaltır; böylece işletme performansının artmasına katkı sunar (Gronum et al., 2016).

4. Araştırma Yöntemi

4.1. Araştırmanın Amacı, Önemi ve Özgün Değeri

Bu çalışma, KOBİ’lerde yeşil örgüt kültürü, sürdürülebilir iş modeli inovasyonu ve işletme performansı arasındaki ilişkilerin incelenmesini amaçlamaktadır. Tüketicilerin daha bilinçli hale geldiği günümüzde, işletmeler daha iyi bir finansal performans ve daha iyi bir çevresel ve toplumsal sürdürülebilirlik için iş modellerinde inovasyona öncelik vermelidir. Bu çalışma, işletmelerin faaliyetlerinde çevresel ve toplumsal etkileri göz önünde bulundurmalarına yardımcı olması bakımından önem taşımaktadır.

Sürdürülebilir iş modeli inovasyonu literatürü son yıllarda hem akademisyenlerin hem de yöneticilerin ilgisini çekmeye başlamıştır. Kavram bir işletmenin kârlılığı ve sürdürülebilirliği açısından önem arz etmektedir. Bu artan önem ve ilgiye rağmen, kavramın bileşenlerinin kavramsallaştırılması ve ampirik olarak doğrulanması başlangıç aşamasındadır; bu konuda daha fazla çalışma yapılması gerekmektedir. Sürdürülebilir iş modeli inovasyonları ile ilgili daha önce yapılmış çalışmaların büyük çoğunluğu kavramsaldır. Shakeel vd. (2020) kavramın bileşenlerinin ve bu bileşenler arasındaki ilişkilerin ortaya konulması için bu konuda daha fazla araştırma yapılmasını önermektedir.

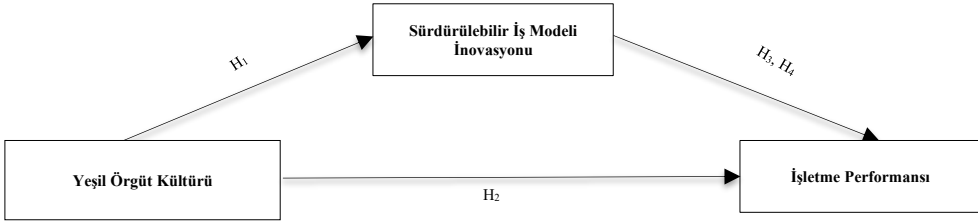
Daha önce çeşitli çalışmalar iş modeli inovasyonları ile işletme performansı arasındaki bağlantıyı araştırmıştır (Bashir & Verma, 2019; Foss & Saebi, 2017; Dunford et al., 2010; Zott & Amit, 2008). Fakat sürdürülebilirlik noktası ihmal edilmiştir. Bu çalışmanın sürdürülebilir iş modeli inovasyonu ile işletme performansı arasındaki ilişkiyi inceleyen öncü çalışmalardan biri olacağı düşünülmektedir. Ayrıca yeşil örgüt kültürü ve KOBİ performansı konusundaki literatüre katkı sağlayabilecektir. KOBİ’ler, dünya çapındaki atık kirliliğinin %70’inden fazlasını temsil etmektedir (Revell et al., 2010). Bu nedenle, dünya genelinde hükümetler KOBİ’lere sürdürülebilir iş modellerine geçmeleri için baskı yapmaktadır.

Bu araştırma özellikle işletmelere çevre ve toplum bilinci kazandıracağı düşünüldüğünden önem arz etmektedir. Araştırma ulusal ve uluslararası yazında bu konuda yapılan öncü araştırmalardan biridir. Ulusal yazında sürdürülebilir iş modeli inovasyonu konusunda yapılan çalışmalar daha çok kavramsal nitelikte olup saha çalışmasına rastlanmamıştır. Sürdürülebilirlikte yeşil örgüt kültürü de nispeten gelişmemiş bir çalışma konusudur. Literatürde yeşil örgüt kültürü, sürdürülebilir iş modeli inovasyonu ve işletme performansı kavramları genellikle ayrı ayrı ya da ikili ilişkiler çerçevesinde incelenmiş; ancak bu üç kavramın bütüncül etkileşimini ele alan bir çalışmaya rastlanmamıştır. Bu sebeple özellikle alan yazına katkı sağlayacağı düşünülmektedir. Ayrıca bu çalışma yöneticilere sürdürülebilir iş modeli inovasyonlarına ulaşmak için yeşil örgüt kültürüne odaklanmaları konusunda uygun bir rehber olabilecektir.

4.2. Araştırma Modeli ve Araştırmanın Hipotezleri

Araştırmanın amacı doğrultusunda oluşturulan araştırma modeli ve hipotezler Şekil 1’de gösterilmektedir.

Şekil: 1
Araştırma Modeli



H₁: Yeşil örgüt kültürünün sürdürülebilir iş modeli inovasyonları üzerinde pozitif etkisi vardır.

H₂: Yeşil örgüt kültürünün işletme performansı üzerinde pozitif etkisi vardır.

H₃: Sürdürülebilir iş modeli inovasyonlarının işletme performansı üzerinde pozitif etkisi bulunmaktadır.

H₄: Yeşil örgüt kültürünün işletme performansı üzerindeki etkisinde sürdürülebilir iş modeli inovasyonlarının aracı etkisi bulunmaktadır.

4.3. Veri Toplama Aracı ve Ölçekler

Bu araştırmada veri toplamak amacıyla anket uygulaması kullanılmıştır. Anket formu güvenilirliği ve geçerliliği önceden kanıtlanmış ölçekler temel alınarak hazırlanmıştır. Bu form dört kısımdan oluşmaktadır. Formun ilk kısmında işletme ve formu dolduran kişi hakkında genel bilgiler yer almaktadır. İkinci kısımda yeşil örgüt kültürü, üçüncü kısımda sürdürülebilir iş modeli inovasyonu, son olarak da dördüncü kısımda işletme performansı ölçeğine ilişkin ifadeler yer almaktadır. Yeşil örgüt kültürünü ölçmek için Bhatti, Al Mamun, Wu, Naznen, Kanwal ve Makhbul’dan (2023) uyarlanan toplam 5 maddelik bir ölçek kullanılmıştır. Bhatti (2024) tarafından güvenilirliği Cronbach Alfa değeri 0,87 ile test edilmiştir. Sürdürülebilir iş modeli inovasyonu ölçeği Bashir, Alfalih ve Pradhan (2022) tarafından geliştirilmiştir. Ölçek 12 ifadeden oluşmaktadır. Ölçek için Bashir vd. (2022) tarafından güvenilirliği (Cronbach Alfa değeri 0,75’in üzerinde) test edilmiştir. İşletme performansını ölçmek için Venkatraman ve Ramanujam (1986) tarafından geliştirilen ölçekten yararlanılmış; ölçeğin yapısal geçerliliği (CR: 0,91, AVE: 0,68) Bashir vd. (2022) yılında yapılan çalışmada test edilmiştir. Ölçek toplamda 5 ifadeden oluşmaktadır.

Ölçekler 5’li Likert formatında düzenlenmiştir. “1” = “Kesinlikle katılmıyorum”, “2” = “Katılmıyorum”, “3” = “Ne katılıyorum ne katılmıyorum”, “4” = “Katılıyorum”, “5” = “Kesinlikle katılıyorum” şeklinde kodlanmıştır.

Bu çalışmada kullanılan ölçekler için Selçuk Üniversitesi İktisadi ve İdari Bilimler Fakültesi Bilimsel Etik Değerlendirme Kurulu’ndan 04/06/2024 tarihli ve 09/66 sayılı kararıyla izin alınmıştır.

4.4. Evren ve Örneklem

Araştırma evrenini Konya ilinde imalat sanayisinde faaliyette bulunan KOBİ’ler oluşturmaktadır. Evrenin geniş bir alanı kapsamayı ve evrenin tamamına ulaşılmasının zaman, hız, maliyet ve fırsat açısından olanaksız olması nedeniyle örneklem belirlemeye ihtiyaç duyulmuştur. Örneklem büyüklüğünün hesaplanmasında Yazıcıoğlu ve Erdoğan’ın (2004: 50) oluşturduğu evren-örneklem tablosundan yararlanılmıştır. Buna göre %95 güven aralığında 25.000 evren büyüklüğü için örneklem büyüklüğü 378 olarak hesaplanmıştır. TÜİK’ten alınan verilere göre 2022 yılı itibarıyla Konya ilinde imalat sanayisinde faaliyette bulunan 18037 adet KOBİ bulunmaktadır. Bu bilgiler doğrultusunda 406 KOBİ’ye anket uygulanmıştır. Her bir işletmeden yalnızca 1 katılımcı çalışmaya dahil edilmiştir. Çalışma konusu ile ilgili bilgilerde karmaşıklığa neden olmamak için ankete cevap veren katılımcılar genel müdür, genel müdür yardımcısı ya da bölüm müdürü gibi karar verme yetkisi bulunan pozisyonlardan seçilmiştir.

Enerji tüketimi, üretim süreçleri ve atık yönetimi gibi nedenlerle imalat sanayisi önemli çevresel etkilere sahip bir alan olarak görülmektedir. Bu durum, imalat sanayisindeki KOBİ’leri kamuoyu baskısı, çevresel düzenlemeler ve sürdürülebilirlik beklentileri açısından hassas bir konuma getirmiştir. Ayrıca KOBİ’lerin esnek yapısı, sürdürülebilir iş modellerini ve yeşil düşüncüyü benimseme ile inovasyon yapma konusunda kolaylık sağlamaktadır. Bu durum onları araştırma için değerli bir alan haline getirmektedir.

5. Veri Analizi ve Bulgular

Elde edilen araştırma verileri, SPSS for Windows 25.0 yazılımı kullanılarak analiz edilmiştir. Verilerin değerlendirilmesinde (sayı, yüzde, ortalama, standart sapma) tanımlayıcı istatistiksel yöntemlere başvurulmuştur. Ölçeklerin güvenilirliği “Güvenilirlik Analizi” ile test edilmiştir. Oluşturulan modeller çerçevesinde, aracı rol ise Hayes (2017) tarafından geliştirilen ve SPSS programına entegre edilmiş PROCESS macro (Model 4) eklentisi kullanılarak incelenmiştir.

Kullanılan verilerin normal dağılıma uygunluğu sınanmıştır. Normal dağılımın görsel incelemesi Q-Q Plot grafiği (Chan, 2003: 280-285) ile yapılmıştır. Bununla birlikte, verilerin normal dağılım göstermesi için çarpıklık ve basıklık değerlerinin ± 3 aralığında (Shao, 2002) olması kriteri dikkate alınmıştır. Normal dağılım gösteren verilerde, iki bağımsız grubun karşılaştırılmasında bağımsız örneklem t testi, ikiden fazla bağımsız grubun karşılaştırılmasında ise tek yönlü varyans analizi uygulanmıştır; anlamlı fark tespit

edildiğinde, bu farkı oluşturan grupları belirlemek için Bonferroni düzeltmesi kullanılmıştır. Değişkenler arasındaki ilişki Pearson korelasyon katsayısı ile incelenmiş, kurulan modellerde bağımsız değişkenin bağımlı değişken üzerindeki etkisi ise basit doğrusal regresyon analizi ile araştırılmıştır.

İşletme ile ilgili bilgilere göre dağılım Tablo 1’de verilmiştir. Faaliyet alanının sınırlarına göre dağılımı incelendiğinde, işletmelerin yaklaşık üçte ikisi (%69,4) ulusal ve uluslararası/global düzeyde faaliyet göstermektedir. Bu, işletmelerin önemli bir kısmının yerel pazarın ötesine de erişim sağladığını gösteriyor. Gıda/yiyecek/içecek (%15,8) ve giyim/tekstil/deri (%13,3) sektörleri işletmelerin yoğunlaştığı temel sektörlerdir. Çalışan sayısına göre işletmelerin %47’si 51-250 çalışan aralığında yer almaktadır; bu da orta ölçekli işletmelerin ağırlıkta olduğunu göstermektedir. İşletmelerin önemli bir kısmı, yaklaşık %60’ı, 11 yıldan daha uzun süredir faaliyet göstermektedir. Bu durum, işletmelerin pazarda belirli bir deneyime ve istikrara sahip olduğuna işaret etmektedir.

Tablo: 1
İşletme ile İlgili Bilgilere Göre Dağılım

Değişkenler		n	%
Faaliyet Alanının Sınırları	Bölgesel	124	30,5
	Ulusal	158	38,9
	Uluslararası/Global	124	30,5
Faaliyet Gösterdiği Alt Sektör	Otomotiv	35	8,6
	Mobilya	27	6,7
	Sağlık/Kimya/İlaç	47	11,6
	Elektrik-Elektronik	43	10,6
	Çimento/Cam/Seramik	39	9,6
	Gıda/Yiyecek/İçecek	64	15,8
	Metal/Demir-Çelik/Makine	52	12,8
	İnşaat	39	9,6
	Giyim/Tekstil/Deri	54	13,3
	Diğer (Lojistik, Plastik, vb.)	6	1,5
Çalışan Sayısı	10’dan az	31	7,6
	10-50 arası	184	45,3
	51-250	191	47,0
Firmanın Faaliyet Gösterme süresi (yıl)	5 yıldan az	46	11,3
	5-10 yıl	112	27,6
	11-20 yıl	150	36,9
	21-40 yıl	71	17,5
	40 yıldan fazla	27	6,7
Toplam		406	100,0

Katılımcıların bilgilerine göre dağılım Tablo 2’de verilmiştir. Katılımcıların büyük bir çoğunluğu üst ve orta düzey yöneticilerden oluşmaktadır. Özellikle orta düzey yöneticiler %51’lik bir oranla en kalabalık grubu oluşturmaktadır. Bu durum, araştırmanın yönetim kademesindeki kişilere odaklandığını göstermektedir. Katılımcıların %70’inin erkek, %30’unun kadın olduğu görülmektedir. Katılımcıların eğitim durumları incelendiğinde, eğitim düzeyinin genel olarak yüksek olduğu görülmektedir. Yaklaşık %80’i ön lisans, lisans, yüksek lisans veya doktora derecesine sahiptir. Katılımcıların önemli bir kısmı 4 yıl ve üzeri süredir işletmede çalışmaktadır. Bu durum, katılımcıların mevcut işyerlerinde belirli bir deneyime sahip olduğunu ve işletmeyi yakından tanıdığını göstermektedir.

Tablo: 2
Katılımcıların Bilgilerine Göre Dağılım

	Değişkenler	n	%
İşyerindeki Konumu	Üst Yönetici	147	36,2
	Orta Düzey Yönetici	207	51,0
	Diğer (Alt Düzey Yönetici, İK Müdürü, Üretim Müdürü, vb.)	52	12,8
Cinsiyet	Erkek	284	70,0
	Kadın	122	30,0
Eğitim Durumu	İlkokul	2	0,5
	Ortaokul	14	3,4
	Lise	66	16,3
	Ön Lisans	109	26,8
	Lisans	150	36,9
	Yüksek Lisans	58	14,3
	Doktora	7	1,7
İşletmede Çalışma Süresi	1 Yıldan az	19	4,7
	1-3 Yıl	91	22,4
	4-6 Yıl	151	37,2
	7-9 Yıl	89	21,9
	10 Yıl ve üzeri	56	13,8
Toplam		406	100,0

Araştırmada kullanılan ölçeklerin güvenirlik analizi sonuçları Tablo 3’te sunulmuştur. Ölçek güvenirliği hesaplanmış ve yüksek düzeyde güvenirliğe sahip olduğu tespit edilmiştir. Cronbach Alfa değerlerinin 0,50’den büyük olması, kullanılan ölçeklerin güvenilir olduğunu göstermektedir (Özdamar, 2015). Değişkenlerin normallik analizi sonuçlarına göre, çarpıklık ve basıklık değerlerinin ± 3 aralığında olması, verilerin normal dağılım gösterdiğini göstermektedir. Araştırmada kullanılan ölçeklere ait tanımlayıcı istatistikler incelendiğinde, yeşil örgüt kültürü ölçeği ortalamasının $3,39 \pm 1,06$, sürdürülebilir iş modeli inovasyonu ölçeği ortalamasının $3,42 \pm 1,03$ ve işletme performansı ölçeği ortalamasının $3,46 \pm 1,02$ olduğu görülmektedir. Bu ortalamalara bakarak, her üç ölçek için de orta düzeyde bir algı olduğu söylenebilir.

Tablo: 3
Araştırmada Kullanılan Ölçeklerin Güvenirlik ve Normallik Analizi Sonuçları, Tanımlayıcı İstatistikleri

Değişkenler	Cronbach’s Alpha	Çarpıklık	Basıklık	Minimum	Maksimum	Ortalama	Standart Sapma
Yeşil Örgüt Kültürü Ölçeği	0,909	-0,451	-1,153	1	5	3,39	1,06
Sürdürülebilir İş Modeli İnovasyonu Ölçeği	0,965	-0,577	-1,07	1,5	5	3,42	1,03
İşletme Performansı Ölçeği	0,922	-0,618	-0,947	1,4	5	3,46	1,02

Analiz sonucunda ölçeklerin Kaiser-Meyer-Olkin değerlerinin sırasıyla 0,87, 0,97 ve 0,89 olduğu belirlenmiştir. Bu değerin 0,50’nin üzerinde olması beklenmektedir (Altunışık vd., 2010: 266). Bu değerlere göre, örneklem yeterliliğinin faktör analizi yapmak için “yeterli” olduğu kabul edilmektedir. Bartlett Küresellik testi sonuçlarına göre de ölçeklerin istenileni ölçme noktasında yeterli olduğu ve her bir ölçeğin maddelerinin birbirleriyle ilişkili olduğu söylenebilir.

Tablo: 4
Açıklayıcı Faktör Analizi Sonuçları

Ölçek	Ölçek Maddeleri	Faktör Yüğü	Toplam Açık Varyans (%)
Yeşil Örgüt Kültürü Ölçeği	Firmamız her çalışanın çevreyi korumann önemini anlamasını sağlamak için yoğun bir çaba göstermektedir.	0,872	73,369
	Firmamızın her alanda çevre bilincini teşvik eden net bir politika beyanı bulunmaktadır.	0,859	
	Çevrenin korunması firmamızda yüksek öncelikli bir faaliyettir.	0,842	
	Firmamız çevresel hedeflerimizi diğer kurumsal hedeflerimizle ilişkilendirmektedir.	0,861	
	Firmamız çevresel etkiyi en aza indiren ürün ve süreçler geliştirmektedir.	0,849	
	<i>Açıklanan Varyans (%)</i>	73,369	
	<i>Özdeğer</i>	3,668	
Sürdürülebilir İş Modeli İnovasyonu Ölçeği	Kaiser-Meyer-Olkin Değeri: 0,876; Bartlett Küresellik Testi: 1288,78; p<0,001		72,530
	Odak noktamız sürdürülebilirlik arayan müşterilere doğru yönelmiştir.	0,882	
	Ürünlerimiz ve hizmet tekliflerimiz yıllar geçtikçe daha sürdürülebilir hale geldi.	0,832	
	Kendimizi ‘sürdürülebilir’ olacak şekilde yeniden konumlandık.	0,861	
	Temel yetkinliklerimizi ve kaynaklarımızı daha sürdürülebilir hale getirmek için düzenli olarak çaba gösteriyoruz.	0,871	
	Şirket içi değer yaratma faaliyetlerini daha sürdürülebilir hale getirmek için düzenli olarak çaba gösteriyoruz.	0,849	
	Sürdürülebilirliğe odaklanan firmalarla ortaklık kurmak için düzenli olarak çaba gösteriyoruz.	0,829	
	Dağıtım kanallarımızı sürdürülebilir kılmak için düzenli olarak çaba gösteririz.	0,856	
	Değişen sürdürülebilir pazar gereksinimlerine uyum sağlamak için geliştirilmesi gereken yeni yetkinlikleri değerlendirmek için düzenli çaba sarf ediyoruz.	0,831	
	Düzenli olarak kısa vadeli gelir kaynaklarını sürdürülebilir (uzun vadeli) yinelenen gelir modelleriyle (örneğin leasing) değiştirmeye çalışıyoruz.	0,874	
	Sürdürülebilir ürünler sunarak kar marjlarımızı artırdık	0,842	
	Sürdürülebilir uygulamalara yer vererek üretim maliyetlerini düşürmek için düzenli olarak çaba gösteriyoruz.	0,855	
	Farklılaştırılmış sürdürülebilir ürünler daha yüksek primler talep etmemize yardımcı oluyor.	0,837	
	<i>Açıklanan Varyans (%)</i>	72,531	
	<i>Özdeğer</i>	8,704	
İşletme Performansı Ölçeği	Kaiser-Meyer-Olkin Değeri: 0,972; Bartlett Küresellik Testi: 4643,6; p<0,001		76,354
	Rakiplerimize kıyasla finansal performansımız çok daha iyiydi	0,884	
	Rakiplerimize göre işletmemizin pazar payı çok daha iyiydi	0,851	
	Rakiplerimize kıyasla işletmemizin satış büyümesi çok daha iyiydi.	0,854	
	Rakiplerimize göre işletmemizin ürün gelişimi çok daha iyiydi	0,882	
	Rakiplerimize göre işletmemizin gelişimi çok daha iyiydi	0,897	
	<i>Açıklanan Varyans (%)</i>	76,355	
	<i>Özdeğer</i>	3,818	
	Kaiser-Meyer-Olkin Değeri: 0,894; Bartlett Küresellik Testi: 11456,20; p<0,001		

Açıklayıcı faktör analizi sonucuna göre, yeşil örgüt kültürü ölçeğindeki maddeler tek bir boyut altında toplanmıştır. Toplam açıklanan varyans %73,36 olarak bulunmuştur. Tek boyutlu ölçeklerde, açıklanan varyansın %40’ı ve üzeri olması yeterli kabul edilir (Büyüköztürk, 2007). Sürdürülebilir İş Modeli İnovasyonu Ölçeği ve İşletme Performansı Ölçeği’nde de maddeler tek bir boyut altında toplanmıştır. Toplam açıklanan varyans ölçeklerde sırasıyla %72,50 ve %76,30 olarak bulunmuştur.

Tablo: 5
İşletmenin Faaliyet Alanı Sınırlarına Göre Ölçeklerin Karşılaştırılması

Değişkenler		Yeşil Örgüt Kültürü Ölçeği		Sürdürülebilir İş Modeli İnovasyonu Ölçeği		İşletme Performansı Ölçeği	
		$\bar{X}$	SS	$\bar{X}$	SS	$\bar{X}$	SS
Faaliyet Alanının Sınırları	Bölgesel (1)	3,05	1,05	3,08	1,05	3,08	1,01
	Ulusal (2)	3,41	1,04	3,41	1,03	3,47	1,03
	Uluslararası/Global (3)	3,69	0,98	3,78	0,89	3,81	0,89
	Test değeri	12,189**		15,093**		16,884**	
	p	0,000*		0,000*		0,000*	
	Bonferroni	2>1, 3>1		2>1,3>1, 3>2		2>1,3>1,3>2	

* p<0,05, ** Tek yönlü varyans analizi.

İşletmenin faaliyet alanının sınırlarına göre yeşil örgüt kültürü ölçeği, sürdürülebilir iş modeli inovasyonu ölçeği ve işletme performansı ölçeği puanları arasında istatistiksel olarak anlamlı bir fark olduğu görülmektedir ($p<0,5$). Genel olarak, faaliyet alanı genişledikçe (Bölgesel’den Uluslararası/Global’e doğru), tüm değişkenlerin ortalama puanlarında artış gözlemlenmektedir. Bu, daha geniş bir alanda faaliyet gösteren KOBİ’lerin genellikle daha güçlü bir yeşil örgüt kültürüne, daha fazla sürdürülebilir iş modeli inovasyonu uygulamasına ve daha yüksek işletme performansına sahip olduğuna işaret etmektedir.

Tablo: 6
İşletmenin Faaliyet Gösterdiği Alt Sektöre Göre Ölçeklerin Karşılaştırılması

Değişkenler		Yeşil Örgüt Kültürü Ölçeği		Sürdürülebilir İş Modeli İnovasyonu Ölçeği		İşletme Performansı Ölçeği	
		$\bar{X}$	SS	$\bar{X}$	SS	$\bar{X}$	SS
Faaliyet Gösterdiği Alt Sektör	Otomotiv (1)	3,88	0,82	3,66	1,00	3,74	0,87
	Mobilya (2)	3,04	1,11	3,11	1,10	3,13	1,06
	Sağlık/Kimya/İlaç (3)	3,41	1,07	3,42	1,08	3,45	1,10
	Elektrik-Elektronik (4)	2,86	1,05	2,89	1,03	3,00	1,12
	Çimento/Cam/Seramik (5)	3,39	1,04	3,38	1,03	3,42	1,00
	Gıda/Yiyecek/İçecek (6)	3,58	0,91	3,54	0,91	3,56	0,91
	Metal/Demir-Çelik/Makine (7)	3,38	1,05	3,56	0,87	3,62	0,97
	İnşaat (8)	2,98	1,21	3,10	1,19	3,09	1,18
	Giyim/Tekstil/Deri (9)	3,70	0,97	3,77	0,93	3,76	0,87
	Diğer (10)	3,63	0,76	4,08	0,80	4,03	0,37
	Test değeri	4,076**		3,546**		3,211**	
	p	0,000*		0,000*		0,001*	
Bonferroni		1>4,1>8 6>4,6>8 9>4,9>8		1>4,6>4,9>4		9>4	

* $p<0,05$, ** Tek yönlü varyans analizi.

Firmanın faaliyet gösterdiği alt sektöre göre yeşil örgüt kültürü ölçeği, sürdürülebilir iş modeli inovasyonu ölçeği ve işletme performansı ölçeği puanları arasında istatistiksel olarak anlamlı bir fark olduğu görülmektedir ($p<0,05$). Otomotiv ve giyim/tekstil/deri sektörleri yeşil örgüt kültürü açısından en yüksek ortalamalara sahiptir. Bu sektörler, daha sıkı çevresel düzenlemelere tâbi olmaları ya da müşteri beklentilerinin yüksek olması gibi nedenlerle çevreye daha duyarlı bir kültüre sahip olabilir. Giyim/tekstil/deri sektöründeki KOBİ’lerin işletme performansı ölçeği puanlarının elektrik-elektronik sektöründeki KOBİ’lere göre daha yüksek olduğu görülmektedir. Otomotiv, gıda/yiyecek/içecek ve giyim/tekstil/deri sektöründeki firmaların sürdürülebilir iş modeli inovasyonu ölçeği puanlarının elektrik-elektronik sektöründeki KOBİ’lere göre daha yüksek olduğu görülmektedir. Yapılan bu analiz, sürdürülebilirlik uygulamalarının ve işletme performansının sektörden sektöre önemli ölçüde farklılaştığını ortaya koymaktadır. Sektöre özgü politika ve uygulama önerileri geliştirmenin ne kadar önemli olduğunu vurgulamaktadır.

Firmanın çalışan sayısına göre yeşil örgüt kültürü ölçeği, sürdürülebilir iş modeli inovasyonu ölçeği ve işletme performansı ölçeği puanları arasında istatistiksel olarak anlamlı bir fark olduğu görülmektedir ($p<0,05$). Çalışan sayısı 51-250 olan firmaların yeşil örgüt kültürü ölçeği, sürdürülebilir iş modeli inovasyonu ölçeği ve işletme performansı ölçeği puanlarının 10’dan az ve 10-50 arası olan KOBİ’lere göre daha yüksek olduğu görülmektedir. Tablo genelinde dikkat çeken en önemli bulgu, çalışan sayısı arttıkça

incelenen her üç değişkenin ortalama puanlarında da artış olmasıdır. Bu durum, daha büyük KOBİ'lerin genellikle daha güçlü bir yeşil örgüt kültürüne, daha fazla sürdürülebilir iş modeli inovasyonu uygulamalarına ve daha iyi bir işletme performansına sahip olduğunu göstermektedir.

Tablo: 7
İşletmenin Çalışan Sayısına Göre Ölçeklerin Karşılaştırılması

Değişkenler		Yeşil Örgüt Kültürü Ölçeği		Sürdürülebilir İş Modeli İnovasyonu Ölçeği		İşletme Performansı Ölçeği	
		$\bar{X}$	SS	$\bar{X}$	SS	$\bar{X}$	SS
Çalışan Sayısı	10'dan az (1)	2,61	0,88	2,59	0,95	2,68	0,97
	10-50 arası (2)	3,23	1,09	3,25	1,07	3,29	1,07
	51-250 (3)	3,66	0,96	3,73	0,89	3,75	0,88
	Test değeri	18,178**		23,298**		20,951**	
	p	0,000*		0,000*		0,000*	
	Bonferroni	3>1, 3>2, 2>1		3>1, 3>2, 2>1		3>1, 3>2, 2>1	

* $p<0.05$, ** Tek yönlü varyans analizi.

Firmanın faaliyet gösterme süresine göre yeşil örgüt kültürü ölçeği, sürdürülebilir iş modeli inovasyonu ölçeği ve işletme performansı ölçeği puanları arasında istatistiksel olarak anlamlı bir fark olduğu görülmektedir ($p<0.05$). Tablodaki genel eğilim, firmaların faaliyet gösterme süresi arttıkça, yeşil örgüt kültürü, sürdürülebilir iş modeli inovasyonu ve işletme performansı ölçeklerinin ortalama puanlarında bir artış gözlemlenmesidir. Özellikle 21-40 yaş aralığında faaliyet gösteren firmalar, çoğu alanda en yüksek ortalamalara sahiptir. Bu durum, daha köklü firmaların çevresel bilinci ve uygulamaları kültürel olarak daha iyi entegre edebildiğini, sürdürülebilir inovasyon süreçlerini daha etkin yönetebildiğini ve uzun süreli deneyimin işletme performansına olumlu katkıda bulunduğunu düşündürmektedir. Ancak 40 yıldan fazla faaliyet gösteren firmalardaki düşüşler dikkat çekmektedir. Bu durum, çok eski firmaların bazılarının değişen çevresel normlara uyumda yavaş kaldığı anlamına gelebilir.

Tablo: 8
İşletmenin Faaliyet Süresine Göre Ölçeklerin Karşılaştırılması

Değişkenler		Yeşil Örgüt Kültürü Ölçeği		Sürdürülebilir İş Modeli İnovasyonu Ölçeği		İşletme Performansı Ölçeği	
		$\bar{X}$	SS	$\bar{X}$	SS	$\bar{X}$	SS
Firmanın Faaliyet Gösterme Süresi (Yıl)	5 yıldan az (1)	2,74	1,04	2,75	1,03	2,82	1,01
	5-10 yıl (2)	3,17	1,05	3,21	1,07	3,21	1,05
	11-20 yıl (3)	3,49	1,02	3,52	1,01	3,58	0,99
	21-40 yıl (4)	3,91	0,79	3,90	0,74	3,88	0,79
	40 yıldan fazla (5)	3,44	1,18	3,64	0,88	3,81	0,88
	Test değeri	11,287**		11,684**		11,557**	
p		0,000*		0,000*		0,000*	
	Bonferroni	3>1, 4>1 5>1, 4>2 4>3		3>1, 4>1, 5>1 4>2		3>1, 4>1 5>1, 3>2 4>2, 5>2	

* $p<0.05$, ** Tek yönlü varyans analizi.

Araştırmada kullanılan ölçekler arasındaki ilişkilerin gücünü ve yönünü belirlemek amacıyla Pearson korelasyon analizi uygulanmıştır. Bu analize göre yeşil örgüt kültürü ölçeği ile sürdürülebilir iş modeli inovasyonu ölçeği arasında ($r=0,899$, $p<0,05$) ve işletme performansı ölçeği arasında ($r=0,870$, $p<0,05$) istatistiksel olarak anlamlı ve pozitif bir ilişki saptanmıştır. İşletme performansı ölçeği ile sürdürülebilir iş modeli inovasyonu ölçeği arasında ($r=0,921$, $p<0,05$) istatistiksel olarak anlamlı ve pozitif bir ilişki saptanmıştır.

Tablo: 9
Araştırmada Kullanılan Ölçekler Arasındaki İlişki

Değişkenler		Yeşil Örgüt Kültürü Ölçeği	Sürdürülebilir İş Modeli İnovasyonu Ölçeği	İşletme Performansı Ölçeği
Yeşil Örgüt Kültürü Ölçeği	r	1,000	0,899	0,870
	p	-	0,000*	0,000*
Sürdürülebilir İş Modeli İnovasyonu Ölçeği	r		1,000	0,921
	p		-	0,000*
İşletme Performansı Ölçeği	r			1,000
	p			-

* $p < 0,05$, $N = 406$.

Araştırma hipotezlerini test etmek amacıyla basit regresyon analizi uygulanmıştır. Yeşil örgüt kültürünün sürdürülebilir iş modeli inovasyonu üzerinde istatistiksel olarak anlamlı düzeyde pozitif bir etkisi olduğu görülmüştür ($\beta = 0,877$; $p < 0,05$). Kurulan modelin %80,8’inin açıklandığı görülmektedir ($R^2 = 0,808$). Modelde otokorelasyon sorunu yoktur; Durbin-Watson değeri 1,5 ile 2,5 arasındadır (DW=2,011). Sürdürülebilir iş modeli inovasyonunun işletme performansı üzerinde istatistiksel olarak anlamlı düzeyde pozitif bir etkisi olduğu görülmüştür ($\beta = 0,917$; $p < 0,05$). Kurulan modelin %84,9’unun açıklandığı görülmektedir ($R^2 = 0,849$). Modelde otokorelasyon sorunu yoktur; Durbin-Watson değeri 1,5 ile 2,5 arasındadır (DW=1,854). Yeşil örgüt kültürünün işletme performansı üzerinde istatistiksel olarak anlamlı düzeyde pozitif bir etkisi olduğu görülmüştür ($\beta = 0,845$; $p < 0,05$). Kurulan modelin %75,7’sinin açıklandığı görülmektedir ($R^2 = 0,757$). Modelde otokorelasyon sorunu yoktur; Durbin-Watson değeri 1,5 ile 2,5 arasındadır (DW=1,913).

Tablo: 10
Regresyon Analizi Sonuçları

Model	Bağımlı Değişken	Bağımsız Değişken	β	Standart Hata	Beta	t	p	F	p	R^2	Durbin Watson
1	İşletme Performansı	Sabit	0,319	0,069	-	4,637	0,000*	2270,789	0,000*	0,849	1,854
		Sürdürülebilir İş Modeli İnovasyonu	0,917	0,019	0,921	47,653	0,000*				
2	İşletme Performansı	Sabit	0,596	0,085	-	7,055	0,000*	1256,551	0,000*	0,757	1,913
		Yeşil Örgüt Kültürü	0,845	0,024	0,870	35,448	0,000*				
3	Sürdürülebilir İş Modeli İnovasyonu	Sabit	0,453	0,076	-	5,994	0,000*	1697,380	0,000*	0,808	2,011
		Yeşil Örgüt Kültürü	0,877	0,021	0,899	41,199	0,000*				

* $p < 0,05$.

İlk olarak bağımsız değişkenin bağımlı değişken üzerindeki temel etkisi analiz edilmiş, aracı değişkenin potansiyel rolü ise sonraki aşamada ele alınmıştır. Yeşil örgüt kültürünün işletme performansı üzerindeki etkisi incelendiğinde, istatistiksel olarak anlamlı pozitif bir etkisi olduğu görülmüştür ($\beta = 0,8446$; $p < 0,05$).

Tablo: 11
Aracı Rolü Analizi Sonuçları

Etki	Tahmin (B)	Standart Hata	t	p	Durum
Yeşil Örgüt Kültürü → İşletme Performansı	0,8446	0,0238	35,4479	0,000*	Kabul
Yeşil Örgüt Kültürü → Sürdürülebilir İş Modeli İnovasyonu → İşletme Performansı	Doğrudan Etki	0,2111	0,0416	5,0786	0,000*
	Dolaylı Etki	0,6335	0,0556	Güven Aralığı (0,5241; 0,7410)	Anlamlı

* $p < 0,05$.

Bağımsız değişkenin bağımlı değişken üzerindeki anlamlı etkisinin ardından, aracı rolü de incelenmiştir. Elde edilen sonuçlara göre %95 güven aralığındaki değerlerin 0’ı içermemesi aracı rolünün istatistiksel olarak anlamlı olduğunu göstermektedir (0,5241; 0,7410). Aracı rolün varlığı belirlendikten sonra, doğrudan etkinin anlamlılığı aracı modelin türünü belirlemiştir. Bu sonuçlara göre doğrudan etkinin anlamlı olduğu, ancak etki katsayısının azaldığı görülmüş ve kısmi aracı olduğuna karar verilmiştir ($\beta=0,2111$; $p<0,05$). Yani, yeşil örgüt kültürünün işletme performansına etkisiyle sürdürülebilir iş modeli inovasyonunda kısmi aracı rolü vardır.

6. Tartışma ve Sonuç

Bu çalışma, KOBİ’lerde sürdürülebilir iş modeli inovasyonları ve yeşil örgüt kültürünün işletme performansı üzerindeki etkilerini araştırmakla birlikte, sürdürülebilir iş modeli inovasyonlarının bu ilişkideki rolünü de incelemiştir. Kabul edilen hipotezler ışığında elde edilen bulgular hem literatüre önemli katkılar sunmakta hem de KOBİ’ler için pratik çıkarımlar sağlamaktadır.

Çalışma Konya ilinde imalat sanayisinde 406 KOBİ üzerinde uygulanmıştır. Araştırma sonuçları incelendiğinde, araştırmaya katılan KOBİ’lerin çoğunluğunun ulusal firma olduğu ve gıda/yiyecek/içecek sektöründe faaliyet gösterdiği görülmektedir. İşletmenin çalışan sayısına göre dağılımı incelendiğinde, %47’sinin 51-250 kişi aralığında olduğu görülmektedir. Yapılan güvenilirlik analizlerinde Cronbach Alfa değerleri kullanılan ölçeklerin güvenilir olduğunu göstermektedir.

Uluslararası/global nitelikteki firmaların yeşil örgüt kültürü ölçeği, sürdürülebilir iş modeli inovasyonu ölçeği ve işletme performansı ölçeği puanlarının ulusal ve bölgesel firmalara göre daha yüksek olduğu görülmektedir. Otomotiv, gıda/yiyecek/içecek ve giyim/tekstil/deri sektörlerinde faaliyette bulunan firmaların yeşil örgüt kültürü ölçeği puanlarının elektrik-elektronik ve inşaat sektörlerinde faaliyet gösteren KOBİ’lere göre daha yüksek olduğu görülmektedir. Çalışan sayısı 51-250 olan firmaların yeşil örgüt kültürü ölçeği, sürdürülebilir iş modeli inovasyonu ölçeği ve işletme performansı ölçeği puanlarının 10’dan az ve 10-50 arası olan KOBİ’lere göre daha yüksek olduğu görülmektedir.

Regresyon analizi sonuçlarına göre, yeşil örgüt kültürünün sürdürülebilir iş modeli inovasyonu üzerinde istatistiksel olarak anlamlı düzeyde pozitif bir etkisi olduğu görülmüştür ($\beta=0,877$; $p<0,05$). Bu bulguya göre çalışmanın ilk hipotezi olan **H₁**: Yeşil örgüt kültürünün sürdürülebilir iş modeli inovasyonları üzerinde pozitif etkisi bulunmaktadır tezi kabul edilmiştir. Bu bulgu, yeşil örgüt kültürünün KOBİ’lerde sürdürülebilir iş modeli inovasyonlarının hayata geçirilmesi için önemli bir itici güç olduğunu göstermektedir. Çevresel değerlere önem veren, sürdürülebilirlik hedeflerini benimseyen ve bu yönde iletişim ve katılım ortamı sağlayan örgütlerde, çalışanların sürdürülebilir çözümler üretme ve uygulama konusunda daha istekli ve yetenekli oldukları görülmektedir. Bu durum, inovasyon süreçlerinin daha çevreci ve sürdürülebilir odaklı

olmasına katkı sağlamaktadır. Elde edilen bu sonuç Bhatti vd. (2024)’nin araştırma sonuçlarıyla benzerlik göstermektedir.

Regresyon analizi sonuçlarına göre yeşil örgüt kültürünün işletme performansı üzerinde pozitif yönlü ve istatistiksel olarak anlamlı bir etkisi saptanmıştır ($\beta=0,845$, $p<0,05$). İkinci hipotez olan **H₂**: Yeşil örgüt kültürünün işletme performansı üzerinde pozitif etkisi bulunmaktadır hipotezi de desteklenmiştir. Çalışma sonuçları, yeşil örgüt kültürüne sahip KOBİ’lerin daha iyi bir işletme performansı sergilediğini ortaya koymaktadır. Bu durum, çevresel sorumluluk bilincine sahip çalışanların daha motive, yenilikçi ve verimli olmaları ile işletmenin dış paydaşlar nezdindeki imajının güçlenmesiyle açıklanabilir. Bu sonuç, yeşil örgüt kültürü ile işletme performansı arasındaki ilişkiyi inceleyen çalışmalarla da paralellik göstermektedir (Wang, 2019; García-Machado & Martínez-Ávila, 2019; Chandra et al., 2021; Karakuş & Erdirençelebi, 2018).

Regresyon analizi sonuçlarına göre sürdürülebilir iş modeli inovasyonunun işletme performansı üzerinde istatistiksel olarak anlamlı düzeyde pozitif bir etkisi olduğu görülmektedir ($\beta=0,917$; $p<0,05$). Çalışmanın üçüncü hipotezi olan **H₃**: Sürdürülebilir iş modeli inovasyonlarının işletme performansı üzerinde pozitif etkisi bulunmaktadır hipotezi kabul edilmiştir. Bu sonuç, sürdürülebilirlik odaklı yeni iş yapış biçimlerinin benimsenmesinin KOBİ’lerin gelişimini ve finansal performansını olumlu yönde etkilediğini göstermektedir. Bu sonuç, literatürdeki benzer çalışmalarla da örtüşmektedir. (Bashir et al., 2022; Caldera et al., 2019; Schneider & Spieth, 2013). Kaynak verimliliğini artıran, atık miktarını azaltan, döngüsel ekonomi prensiplerini benimseyen veya paydaş beklentilerini sürdürülebilirlik çerçevesinde karşılayan iş modeli inovasyonları, KOBİ’lerin hem maliyetlerini düşürmelerine hem de piyasa itibarını güçlendirmelerine yardımcı olabilecektir.

Yeşil örgüt kültürünün işletme performansı üzerinde anlamlı bir etkisinin olduğu tespit edildikten sonra, bu etkide sürdürülebilir iş modeli inovasyonlarının aracı rolü olup olmadığına bakılmıştır. Yapılan analiz sonucunda, sürdürülebilir iş modeli inovasyonlarının aracı rolü olduğu belirlenmiştir. Böylece, dördüncü hipotez olan **H₄**: Yeşil örgüt kültürünün işletme performansı üzerindeki etkisinde sürdürülebilir iş modeli inovasyonlarının aracı etkisi bulunmaktadır hipotezi de desteklenmiştir. Bu sonuç, yeşil örgüt kültürünün işletme performansı üzerindeki pozitif etkisinin yalnızca doğrudan değil, aynı zamanda sürdürülebilir iş modeli inovasyonları aracılığıyla da gerçekleştiği anlamına gelmektedir. Başka bir deyişle, yeşil örgüt kültürü KOBİ’leri sürdürülebilir iş modeli inovasyonları geliştirmeye teşvik etmekte ve bu inovasyonlar da işletme performansını artırabilmektedir. Bu bulgu, sürdürülebilirlik ile performans arasındaki ilişkileri bütüncül bir bakış açısıyla ele almak gerektiğini vurgulamaktadır. Yeşil örgüt kültürü, sürdürülebilir iş modeli inovasyonları için uygun bir zemin hazırlayarak işletmelerin uzun vadeli başarısına katkıda bulunabilir.

Çalışmanın Teorik Katkıları

Çalışma, sürdürülebilir iş modeli inovasyonlarının işletme performansı üzerindeki doğrudan pozitif etkisini ampirik olarak ortaya koyarak, bu alandaki mevcut literatüre katkıda bulunmaktadır. Özellikle KOBİ’ler bağlamında bu ilişkinin incelenmesi, gelişmekte olan ülke ekonomilerinde sürdürülebilir iş modeli inovasyonları ile performans arasındaki dinamiklere dair yeni bilgiler sunmaktadır. Yapılan çalışma ile yeşil örgüt kültürünün hem işletme performansı üzerindeki etkisi hem de sürdürülebilir iş modeli inovasyonlarının bu ilişkideki aracı rolü ampirik olarak kanıtlanmıştır. Bu, yeşil örgüt kültürü literatürüne sürdürülebilirlik odaklı yeni bir boyut kazandırmakta ve yeşil örgüt kültürünün örgütsel çıktılar üzerindeki önemini vurgulamaktadır. Çalışmada incelenen aracı model, sürdürülebilirlik, yeşil örgüt kültürü ve performans arasındaki karmaşık etkileşimleri daha bütüncül bir şekilde ele almak için teorik bir çerçeve sunmaktadır. Çalışmanın sürdürülebilirlik temalı araştırmaların genellikle büyük işletmelere odaklı olduğu literatürde, KOBİ’lerin sürdürülebilirlik uygulamalarını ve bunların performans üzerindeki etkilerini incelediği için literatüre katkı sağlayacağı düşünülmektedir.

Çalışmanın Pratik Katkıları

Çalışma sonuçları, KOBİ yöneticilerine sürdürülebilir iş modeli inovasyonlarının ve yeşil bir örgüt kültürünün işletme performansı üzerindeki etkilerini göstermektedir. Bu bulgular, KOBİ’leri sürdürülebilirlik odaklı stratejiler geliştirmeye ve uygulamaya teşvik edebilir. Sürdürülebilir iş modeli inovasyonlarının sadece çevresel bir zorunluluk değil, aynı zamanda performans artışı için bir fırsat olduğu gerçeği, KOBİ’lerde bu konuda farkındalık yaratılmasına katkıda bulunabilir. Çalışma, yeşil örgüt kültürünün önemini vurguladığından, KOBİ’lerin bu tür bir kültürü inşa etmelerine katkı sağlayabilir. Çalışanların katılımını teşvik eden, sürdürülebilirlik değerlerini benimseyen ve bu doğrultuda iletişim kuran uygulamaların hayata geçirilmesine yönelik pratik öneriler geliştirilebilir. Çalışma sonuçları, politika yapıcılar için KOBİ’lerin sürdürülebilirlik uygulamalarını teşvik etmeye yönelik politika ve destek mekanizmaları geliştirme konusunda yol gösterici olabilir. Yeşil örgüt kültürünü ve sürdürülebilir iş modeli inovasyonlarını destekleyen teşvikler ve eğitim programları tasarlanabilir. İlgili faaliyetlerin hayata geçirilmesi için finansal destek sağlanabilir. KOBİ’ler arası iş birliklerinin geliştirilmesiyle, özellikle imalat sanayii gibi çevresel etkileri yüksek sektörler için yol haritaları ve iş modeli inovasyon örnekleri oluşturulabilir.

Bu çalışmanın sonuçları, KOBİ’ler bağlamında değerlendirildiğinde, sürdürülebilir iş modellerinin aynı zamanda performans artışı için önemli bir fırsat olarak görülmesi gerektiğini ortaya koymaktadır. Özellikle yeşil bir örgüt kültürünün oluşturulması, KOBİ’lerin hem çevresel sorumluluklarını yerine getirmelerine hem de daha yenilikçi ve başarılı olmalarına yardımcı olabilir.

Bu çalışmanın bazı sınırlılıkları bulunmaktadır. Öncelikle, araştırma KOBİ’ler üzerinde gerçekleştirilmiş olup, sonuçların diğer ülkelere veya sektörlerle genellenebilirliği

sınırlı olabilir. İkinci olarak, çalışmada kullanılan nicel araştırma yöntemi değişkenler arasındaki ilişkilerin derinlemesine anlaşılması için nitel araştırmalarla desteklenebilir. İlerleyen zamanlarda yapılacak araştırmalar, farklı sektörlerde ve farklı ülke örneklemelerinde bu ilişkileri inceleyerek genellenebilirlik düzeyini artırabilir.

Sonuç olarak, bu çalışma KOBİ’ler için sürdürülebilir iş modeli inovasyonlarının ve yeşil örgüt kültürünün işletme performansı üzerindeki olumlu etkilerini açıkça ortaya koymaktadır. Yeşil örgüt kültürünün sürdürülebilir iş modeli inovasyonlarını teşvik ederek işletme performansını artırmadaki kritik rolü, KOBİ’lerin sürdürülebilirlik stratejilerini şekillendirirken dikkate almaları gereken önemli bir sonuçtur. Özetle, bu çalışma literatüre kavramsal ve ampirik katkılar sunarken KOBİ yöneticileri, politika yapımcılar ve finansal kurumlar için sürdürülebilirlik odaklı stratejiler geliştirme ve uygulama konusunda pratik yol gösterici bilgiler sağlayabilecektir.

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Faiz ve Enflasyon Dinamiklerinde Yapısal Dönüşüm: Türkiye Örneğinde 2021 Sonrası Rejim Değişimi

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Structural Transformation in Interest Rate and Inflation Dynamics: The Case of Türkiye's Post-2021 Policy Regime Shift

Abstract

This study examines the relationship between inflation and interest rates in Türkiye during the 2015-2024 period, with a specific focus on the monetary policy shift implemented in September 2021. Using the ARDL model, Toda-Yamamoto causality test, and structural break analysis, the findings reveal a reversal in the inflation-interest rate relationship after the policy change. The results suggest that the observed dynamics may reflect not a temporary anomaly but a structural transformation aligned with the Neo-Fisher effect, offering critical insights into the effectiveness of monetary policy under changing regimes.

Keywords : Inflation, Interest Rate, Monetary Policy, Structural Break, ARDL, Neo-Fisher Effect.

JEL Classification Codes : E31, E43, E52.

Öz

Bu çalışma, Türkiye’de 2015-2024 döneminde enflasyon ve faiz oranı arasındaki ilişkiyi incelemekte; özellikle 2021 Eylül ayında uygulamaya konulan para politikası değişikliğinin etkilerine odaklanmaktadır. Autoregressive Distributed Lag (ARDL) modeli, Toda-Yamamoto nedensellik testi ve yapısal kırılma analizleri ile elde edilen bulgular, 2021 sonrası dönemde faiz-enflasyon ilişkisinde yön değişikliği yaşandığını ortaya koymaktadır. Çalışma, Neo-Fisher etkisinin Türkiye ekonomisinde geçici olmadığını; bunun yapısal bir dönüşümle ilişkili olabileceğini öne sürmekte ve para politikasının etkinliğine ilişkin önemli politika önerileri sunmaktadır.

Anahtar Sözcükler : Enflasyon, Faiz Oranı, Para Politikası, Yapısal Kırılma, ARDL, Neo-Fisher Etkisi.

1. Giriş

Enflasyon ile faiz oranı arasındaki ilişki, makroekonomik yapıların anlaşılması ve etkili ekonomi politikalarının oluşturulması açısından temel öneme sahiptir. Bu iki değişkenin birbirini hangi yönde etkilediği, yani nedenselliğin yönü, iktisat literatüründe uzun süredir tartışılmaktadır. Politika yapıcılar açısından ise bu ilişkinin doğru biçimde tespit edilmesi, alınacak kararların ekonomik etkilerini öngörme açısından kritik bir gerekliliktir (Dua, 2010).

Enflasyon, fiyatlar genel düzeyinde sürekli artış anlamına gelir ve küresel ölçekte ekonomik istikrarı tehdit eden bir unsur olarak öne çıkmaktadır. Kalıcı fiyat artışları ekonomik durgunlukları derinleştirmekte ve belirsizlik düzeyini artırarak piyasa işleyişini zayıflatmaktadır. Bu durum sadece üretim ve yatırım kararlarını değil, hane halkının tasarruf ve harcama tercihlerini de olumsuz etkileyerek kaynakların verimsiz alanlara yönelmesine neden olabilir. Bu bağlamda, enflasyonun faiz oranları üzerinde mi etkili olduğu, yoksa faiz oranlarının enflasyonu mu şekillendirdiği sorusu, iktisat teorisinde uzun süredir süregelen bir nedensellik tartışmasının merkezinde yer almaktadır.

Faiz oranı ise temelde paranın kullanım maliyetini ifade eder; yatırım veya borçlanma gibi finansal işlemlerde kaynak tahsisini yönlendiren bir göstergedir. Ekonomik sistem içinde sermayenin fiyatı olarak kabul edilen faiz oranları, hem üretim hem de tüketim kararları üzerinde belirleyici bir rol oynar. Faizlerin düşük olduğu ortamlarda borçlanma eğilimi artarken, bu durum harcamaları teşvik edebilir; yüksek faiz oranları ise finansman maliyetini artırarak yatırımları kısıtlayabilir. Bu çerçevede, enflasyon ve faiz oranı arasındaki ilişkinin zaman içinde nasıl evrildiği ve hangi koşullarda farklılaştığı, ekonomi politikalarının etkililiği açısından özel bir önem taşımaktadır.

Literatürde enflasyon-faiz ilişkisine dair farklı yaklaşımlar bulunmaktadır. Klasik iktisat okulu, enflasyonu temelde parasal bir olgu olarak değerlendirmekte ve para arzı ile enflasyon arasında doğrusal bir ilişki olduğunu savunmaktadır. Klasik yaklaşımda reel ve parasal sektörlerin ayrı olduğu, enflasyonun yalnızca fiyatları artıran bir olgu olduğu ve çıktı miktarını etkilemediği kabul edilmektedir (Ercan, 1997). Keynesyen yaklaşımda ise ekonominin genellikle tam istihdamda değil, eksik istihdamda olduğu kabul edilmekte ve enflasyon açığı modeli ön plana çıkmaktadır (Büyükakın, 2007). Monetarist yaklaşım ise para arzındaki artışın nominal gelirleri ve fiyatları etkileme sürecine odaklanmakta, para arzındaki artış ile enflasyon arasında bir gecikme olduğunu savunmaktadır (Macesich, 1984).

Gelişmekte olan ülkeler için enflasyon-faiz ilişkisinin anlaşılması, yapısal sorunların çözümü ve ekonomik istikrarın sağlanması açısından giderek daha da önem kazanmaktadır. Yapısalcı yaklaşım, bu ekonomilerde enflasyonun kontrol altına alınması için üretim faktörlerinin arz esnekliğinin artırılması ve verimlilik odaklı bir ekonomi politikası izlenmesi gerektiğini savunmaktadır (Şahinoğlu vd., 2010). Türkiye gibi enflasyon sorununu

sıklıkla deneyimleyen ekonomilerde, enflasyon-faiz ilişkisinin doğru anlaşılması, etkin para politikası stratejilerinin geliştirilmesi açısından hayati önem taşımaktadır.

Ekonomik gelişmeler karşısında merkez bankalarının uyguladığı para politikaları, yalnızca faiz oranları üzerinde değil, aynı zamanda genel ekonomik denge üzerinde de belirleyici etkilere yol açabilmektedir. Bu bağlamda, enflasyon ile faiz oranları arasındaki nedensellik ilişkisinin yönünün ve niteliğinin belirlenmesi, para politikası uygulamalarının etkinliği açısından kritik öneme sahiptir. Literatürde, enflasyondaki artışın ekonomik aktörlerin para talebini artırarak dolaylı yoldan faiz oranları üzerinde yukarı yönlü bir baskı oluşturduğuna dair bulgulara sıkça rastlanmaktadır (Dua, 2010).

Bu çalışma, Türkiye ekonomisinde 2021 Eylül sonrası dönemde yaşanan para politikası rejimi değişikliğini yapısal bir kırılma olarak ele alarak, enflasyon ile faiz oranı arasındaki ilişkinin yönünü ve dinamiklerini yeniden değerlendirmeyi amaçlamaktadır. Literatürde Türkiye üzerine yapılan birçok çalışma (örneğin Doğan vd., 2016; Evren & Mucuk, 2019) genellikle 1980 sonrası dönemi kapsamakta ve yapısal rejim değişikliklerini yeterince dikkate almamaktadır. Bu çalışmanın özgün katkısı, 2021 sonrası dönemi ayrı bir analiz birimi olarak ele alması; bu kapsamda Chow testi, kukla değişkenler ve ARDL modelleriyle politika değişikliğinin enflasyon-faiz ilişkisindeki yapısal etkilerini ortaya koymasındır. Ayrıca, klasik Fisher etkisinin aksine, bu dönemde ters yönlü bir ilişki gözlemlenmesi, mevcut literatüre neo-Fisher etkisi bağlamında yeni bir perspektif sunmaktadır.

Mevcut literatürde Türkiye ekonomisi özelinde enflasyon-faiz ilişkisini inceleyen çalışmalar bulunmakla birlikte, bu çalışmaların birçoğu ya kısa dönemli analizlere odaklanmakta ya da tek yönlü bir nedensellik ilişkisi varsayımıyla hareket etmektedir. Bu çalışma, daha uzun bir zaman dilimine yayılan 2015m1-2024-m12 dönemi aylık verilerini kullanarak, hem doğrudan hem de dolaylı etkileri içeren kapsamlı bir analiz sunması bakımından literatüre önemli bir katkı sağlamayı hedeflemektedir. Ayrıca, makroekonomik değişkenler arasındaki kompleks ilişkileri dikkate alan bir metodoloji kullanarak, merkez bankası politikaları, döviz kurları ve uluslararası ekonomik ilişkiler gibi faktörlerin etkisini de analiz kapsamına dahil etmektedir.

Araştırmanın temel varsayımı, enflasyon ile faiz oranı arasında bir ilişkinin var olması ve bu ilişkinin yönünün ve niteliğinin ekonomik koşullara göre değişebileceğidir. Çalışmanın bu varsayım üzerine inşa edilmesi, farklı ekonomik rejimlerde ve koşullarda enflasyon-faiz ilişkisinin nasıl şekillendiğinin anlaşılmasına katkı sağlayacaktır. Bu çalışmanın Türkiye ekonomisindeki enflasyon-faiz ilişkisine dair kapsamlı ve güncel bir analiz sunarak hem akademik literatüre hem de politika yapıcılara değerli içgörüler sağlaması hedeflenmektedir. Elde edilecek bulgular, makroekonomik istikrarın sağlanması ve sürdürülebilir ekonomik büyümenin desteklenmesi için uygulanacak para ve maliye politikalarının tasarlanmasında önemli bir referans kaynağı olacaktır.

Bu çalışma beş ana bölümden oluşmaktadır. Giriş bölümünde, enflasyon ile faiz oranı arasındaki ilişkiye dair teorik tartışmalar çerçevesinde çalışmanın amacı ve önemi ortaya konmaktadır. İkinci bölümde, enflasyon-faiz etkileşimini inceleyen ulusal ve uluslararası literatür değerlendirilmektedir. Üçüncü bölümde, kullanılan veri seti, değişken tanımları ve ekonometrik yöntemler ayrıntılandırılmaktadır. Dördüncü bölümde, 2015-2024 dönemine ilişkin ampirik analiz bulgularına yer verilmekte ve 2021 sonrası politika rejimi değişiminin etkileri incelenmektedir. Son bölümde ise bulgular ışığında sonuçlar özetlenmekte ve para politikası açısından öneriler sunulmaktadır.

2. Literatür

Enflasyon ve faiz oranı arasındaki ilişki, hem teorik hem de ampirik çalışmalarda uzun süredir tartışma konusu olmuştur. Bu tartışmaların odağında genellikle Fisher Hipotezi yer alır. Hipotez, beklenen enflasyondaki artışın nominal faiz oranlarını aynı ölçüde etkilemesi gerektiğini savunur. Ancak farklı ülke örnekleri ve yönetsel yaklaşımlar bu ilişkinin tutarlılığına dair çelişkili bulgular sunmuştur.

Uluslararası çalışmalarda, Siklos (1999) gibi bazı araştırmalar Fisher etkisinin geçerliliğini savunurken, Beechey vd. (2011) ve King (1997) gibi diğerleri, bu etkinin hem ABD hem de Almanya gibi gelişmiş ekonomilerde geçerli olmadığını ortaya koymuştur. 2000'li yıllarda yapılan daha gelişmiş panel analizleri ise (örneğin Boot & Ciner, 2001; Westerlund & Edgerton, 2005) uzun dönemli ilişkileri doğrulayan bulgular sunmuştur.

Gelişmekte olan ülkeler için yapılan analizler, yapısal farklılıkların ve ekonomik kırılmalıkların bu ilişki üzerinde belirleyici olduğunu göstermektedir. Türkiye özelinde yapılan çalışmalar da bu açıdan oldukça çeşitlidir. Bazı araştırmalar (Yılancı, 2009; Onur, 2014; Doğan vd., 2016) faiz ve enflasyon arasında tek yönlü ya da zayıf ilişkiler tespit ederken, diğerleri (Korkmaz, 2017; Afsal vd., 2018) bu ilişkinin hem çift yönlü olabileceğini hem de döviz kuru, para arzı ve beklentiler gibi faktörlere duyarlı bir yapıya sahip olduğunu göstermiştir.

Son yıllarda yapılan çalışmalarda, enflasyon-faiz ilişkisinin doğrusal olmayan, asimetrik ve rejim bağımlı dinamikler taşıdığına dair bulgular da öne çıkmaktadır (Evren & Mucuk, 2019; Çevik & Teksöz, 2013; Aytekin vd., 2023). Bu bulgular, Türkiye gibi enflasyon şoklarına açık ve para politikası rejimleri zaman içinde değişkenlik gösteren ekonomilerde, tek tip bir ilişki modeli kurmanın yeterli olmadığını ortaya koymaktadır. Ayrıca, döviz kuru geçişkenliği, para arzı dinamikleri ve maliye politikaları da bu ilişkinin doğasını şekillendiren unsurlardan bazılarıdır.

Son dönem ampirik çalışmalar, faiz oranları ile enflasyon arasındaki karmaşık dinamikleri farklı ekonomik bağlamlarda incelemeye devam etmekte olup, elde edilen çeşitli sonuçlar ülkeye özgü faktörlerin ve kullanılan metodolojik yaklaşımların önemini vurgulamaktadır. Goonatilake ve Reyes (2019), ekonomik büyümenin sürdürülebilirliğinin enflasyon ve faiz politikaları arasındaki dengenin sağlanmasına kritik düzeyde bağlı

olduğunu ortaya koymakta; ayrıca pratikte Fisher etkisinden önemli sapmaların sıklıkla gözlemlendiğini belirtmektedir. Bu bakış açısını destekleyen Dinh (2020), Vietnam ve Çin'e yönelik karşılaştırmalı analizinde, gelişmekte olan ekonomilerin özellikle ekonomik geçiş dönemlerinde para politikası araçları ile enflasyon sonuçları arasında doğrusal olmayan ilişkiler sergilediğini göstermektedir. Benzer şekilde, Aji vd. (2021) VAR yöntemi kullanarak faiz oranları ile enflasyon arasında çift yönlü nedensellik ilişkileri tespit etmektedir ve bu ilişkilerin analizinde dinamik modelleme yaklaşımlarının önemine vurgu yapmaktadır. Türkiye özelinde ise Çiğdem (2019) faiz-enflasyon paradoksuna işaret etmekte ve yüksek enflasyon, oynaklık ile dış finansal baskıların yoğun olduğu gelişmekte olan ekonomilerde geleneksel para politikası aktarım mekanizmalarının farklı işleyebileceğini öne sürmektedir. Bu güncel bulgular bir arada değerlendirildiğinde, yapısal özelliklerin ve politika rejimi değişikliklerinin dikkate alındığı ülkeye özgü ampirik araştırmaların gerekliliği, özellikle geleneksel para politikası kanallarının kurumsal ve dışsal faktörler tarafından kısıtlandığı gelişen piyasa ekonomilerinde açıkça ortaya çıkmaktadır. Altunöz (2018) Çin ekonomisinde Fisher etkisini test etse de, yöntemsel olarak Türkiye'de yapılacak benzer ARDL uygulamaları için önemli teknik örnekler sunmaktadır. Bu çalışmalar, hem metodolojik hem de veri dönemi açısından makalemize doğrudan katkı sağlamakta ve literatürün genişletilmesi için değerli kanıtlar sunmaktadır.

Genel olarak değerlendirildiğinde, literatürdeki bulgular enflasyon ile faiz oranı arasındaki ilişkinin ekonomik dönemlere, yapısal kırılmalara ve ülkelerin politika çerçevelerine göre değişebileceğini ortaya koymaktadır. Bu nedenle, Türkiye gibi makroekonomik belirsizliklerin yoğun yaşandığı ülkelerde, zamanla değişen nedensellik yönlerinin ve rejim farklılıklarının dikkate alındığı ampirik analizlere duyulan ihtiyaç artmaktadır.

3. Veri ve Yöntem

Bu bölümde, çalışmada kullanılan veri kaynakları, değişkenler ve ekonometrik metodoloji ayrıntılı olarak açıklanmaktadır.

3.1. Veri Seti ve Kaynaklar

Çalışmada kullanılan veri seti, 2015 Ocak - 2024 Aralık dönemini kapsayan aylık frekansta makroekonomik zaman serilerinden oluşmaktadır. Temel veri kaynağı Türkiye Cumhuriyet Merkez Bankası (TCMB) Elektronik Veri Dağıtım Sistemi'dir (EVDS). Tablo 1'de çalışmada kullanılan değişkenlerin tanımları, kaynakları ve özellikleri özetlenmektedir.

Tablo: 1
Değişken Tanımları

Değişken	Tanım	Kaynak	Dönüşüm
Enflasyon (%)	Tüketici Fiyat Endeksi'nin yıllık bazda yüzde değişimi	TCMB-EVDS	-
Politika Faiz Oranı (%)	TCMB tarafından belirlenen bir haftalık repo ihale faizi oranı	TCMB -EVDS	-
USD/TRY	ABD Doları ile Türk Lirası arasındaki döviz kuru (aylık ortalama)	TCMB -EVDS	Logaritmik
Sanayi Üretim Endeksi	Toplam sanayi üretim endeksi (2015=100, mevsimsellikten arındırılmış)	TCMB -EVDS	-
M2 Para Arzı	Geniş para arzı (milyar TL cinsinden)	TCMB -EVDS	Logaritmik
Enflasyon Beklentisi (%)	TCMB Beklenti Anketi'nden elde edilen 12 ay sonrası enflasyon tahmini	TCMB -EVDS	-
D_Crisis_2008	2008 Küresel Finansal Krizi için oluşturulan kukla değişken	Yazar tarafından hesaplanmıştır	0-1 Kukla
D_Pandemic_2020	COVID-19 pandemisi dönemi için oluşturulan kukla değişken	Yazar tarafından hesaplanmıştır	0-1 Kukla
D_Post2021Policy	2021 Eylül sonrası para politikası değişimi için oluşturulan kukla değişken	Yazar tarafından hesaplanmıştır	0-1 Kukla

Not: TCMB-EVDS, Türkiye Cumhuriyet Merkez Bankası Elektronik Veri Dağıtım Sistemi'ni ifade eder.

Çalışmada kullanılan değişkenlerden USD/TRY döviz kuru ve M2 para arzı için logaritmik dönüşüm uygulanmıştır. Bu dönüşüm, ilgili değişkenlerdeki yüzde değişimlerin doğrudan yorumlanabilmesine olanak sağlamakta ve değişen varyans sorununu azaltmaktadır. Kukla değişkenlerden D_Crisis_2008, 2008 Ekim - 2009 Haziran döneminde 1, diğer dönemlerde 0 değerini; D_Pandemic_2020, 2020 Mart - 2021 Haziran döneminde 1, diğer dönemlerde 0 değerini; D_Post2021Policy ise 2021 Eylül ve sonrasında 1, öncesinde 0 değerini almaktadır.

3.2. Ekonometrik Yöntem

Bu çalışma, Türkiye'de enflasyon ile faiz oranları arasındaki ilişkiyi analiz etmek amacıyla çeşitli zaman serisi ekonometri tekniklerinden yararlanmaktadır. Uygulanan metodolojik çerçeve aşağıdaki adımlardan oluşmaktadır.

3.2.1. Durağanlık Analizi

Zaman serisi analizlerinde sahte regresyon sorunlarını önlemek amacıyla, tüm değişkenlerin durağanlık özellikleri Genişletilmiş Dickey-Fuller (ADF) testi ile incelenmiştir. ADF regresyon denklemi aşağıda verilmiştir:

$$\Delta y_t = \alpha + \beta_t + \gamma y_{t-1} + \sum_{i=1}^p \delta_i \Delta y_{t-1} + \varepsilon_t \quad (1)$$

Burada Δy_t , y değişkeninin birinci farkını; α , sabit terimi; β_t , zaman trendini; γ , durağanlığı test eden katsayıyı; δ_i , gecikmeli fark terimlerinin katsayılarını ve ε_t , hata terimini ifade etmektedir. $H_0: \gamma = 0$ şeklindeki boş hipotez, serinin durağan olmadığını, $H_1: \gamma < 0$ şeklindeki alternatif hipotez ise serinin durağan olduğunu göstermektedir (Dickey & Fuller, 1979).

3.2.2. ARDL Modeli ve Sınır Testi

Değişkenlerin farklı seviyelerde bütünleşme derecelerine sahip olabileceği göz önüne alındığında, Pesaran vd. (2001) tarafından önerilen Otoregresif Dağıtılmış Gecikmeler (ARDL) modeli kullanılmıştır. ARDL modeli, değişkenlerin $I(0)$ ya da $I(1)$ olmasından

bağımsız olarak hem kısa hem de uzun dönem dinamiklerini tahmin etme yeteneğine sahiptir. Bu çalışmada kullanılan ARDL modeli aşağıdaki şekilde ifade edilmektedir:

$$\Delta CPI_t = \alpha_0 + \sum_{i=1}^p \beta_i \Delta CPI_{t-i} + \sum_{i=0}^{q1} \gamma_i \Delta PR_{t-i} + \sum_{i=0}^{q2} \delta_i \Delta X_{t-i} + \theta_1 CPI_{t-1} + \theta_2 PR_{t-1} + \theta_3 X_{t-1} + \varepsilon_t \quad (2)$$

Burada CPI_t , Tüketici Fiyat Endeksi'nin yıllık değişimini; PR_t , politika faiz oranını; X_t ise döviz kuru, sanayi üretim endeksi, para arzı, enflasyon beklentisi ve kukla değişkenler gibi diğer açıklayıcı değişkenleri temsil etmektedir. $\alpha_0, \beta_i, \gamma_i$ ve δ_i parametreleri kısa dönem dinamiklerini; θ_1, θ_2 ve θ_3 ise uzun dönem katsayılarını göstermektedir.

Değişkenler arasında eşbütünlüşme ilişkisinin varlığını test etmek amacıyla sınır testi yöntemi uygulanmıştır. $H_0: \theta_1 = \theta_2 = \theta_3 = 0$ şeklindeki boş hipotez, Pesaran vd. (2001) tarafından sunulan kritik değerlerle karşılaştırılan F-istatistiği kullanılarak test edilmiştir.

ARDL modelinde uygun gecikme uzunluklarının seçimi, faiz oranları ile enflasyon arasındaki dinamik ilişkilerin doğru şekilde yakalanması ve aşırı parametrelendirmeden kaçınılması açısından kritik öneme sahiptir. Bu kapsamda, gecikme uzunlukları Akaike Bilgi Kriteri (AIC) ve Schwarz Bilgi Kriteri (SIC) dikkate alınarak belirlenmiştir. Zaman serisi ekonometrisinde yaygın olarak uygulanan bu yaklaşım doğrultusunda çeşitli ARDL(p,q) modelleri tahmin edilmiş; burada p bağımlı değişken olan enflasyon oranının gecikmesini, q ise bağımsız değişken olan politika faiz oranının gecikmesini temsil etmektedir.

AIC kriteri ARDL(3,2) modelini (AIC değeri: 4.832) tercih ederken, SIC kriteri daha yalın olan ARDL(2,1) modelini (SIC değeri: 4.891) önermiştir. SIC kriterinin parametre sayısını daha güçlü şekilde cezalandırması ve daha parsimoniyen modelleri tercih etmesi dikkate alınarak, nihai model olarak ARDL(2,1) seçilmiştir. Bu tercih, model uyumunu korurken küçük örneklem yapısına sahip zaman serilerinde karşılaşılan aşırı uyum (overfitting) riskini en aza indirmeyi amaçlamaktadır.

3.2.3. Toda-Yamamoto Nedensellik Testi

Nedensellik yönünü analiz etmek amacıyla Toda-Yamamoto (1995) yöntemi uygulanmıştır. Bu yöntem, değişkenlerin durağanlık özelliklerinden bağımsız olarak nedensellik analizinin yapılmasını mümkün kılmaktadır. Yöntem, değişkenlerin maksimum bütünlüşme derecesi (dmax) kadar gecikme eklenmiş artırılmış bir VAR modelinin tahmin edilmesini ve ilk p gecikmeye ait katsayıların Wald testi ile anlamlılıklarının sınanmasını içermektedir:

$$Y_t = \alpha + \sum_{i=1}^p \beta_i Y_{t-i} + \sum_{j=p+1}^{p+d} \beta_j Y_{t-j} + \varepsilon_t \quad (3)$$

Burada Y_t , analiz edilen değişkenlerin vektörünü; α , sabit terim vektörünü; β_i ve β_j , katsayı matrislerini; ε_t ise hata terimi vektörünü ifade etmektedir. Nedensellik ilişkisini

belirlemek amacıyla, ilk başlatma denkleminde p gecikmeye ait katsayılar üzerinde Wald testleri uygulanmaktadır.

3.2.4. Yapısal Kırılma Testi

Para politikasındaki değişikliklerin etkisini değerlendirmek amacıyla, Chow (1960) tarafından geliştirilen yapısal kırılma testi uygulanmıştır. Bu test, belirli bir kırılma tarihinde (2021 Eylül) model parametrelerinde istatistiksel olarak anlamlı bir değişiklik olup olmadığını belirlemeyi amaçlamaktadır. Bu kapsamda kullanılan F-istatistiği aşağıdaki şekilde hesaplanmaktadır:

$$F = \left\{ \frac{(RSS_C - (RSS_1 + RSS_2))}{k} \right\} / \left\{ \frac{(RSS_1 + RSS_2)}{(n_1 + n_2 - 2k)} \right\} \quad (4)$$

Burada RSS_C , tüm dönem için hata kareler toplamını; RSS_1 ve RSS_2 , alt dönemler için hata kareler toplamlarını; k , modeldeki parametre sayısını; n_1 ve n_2 ise her bir alt döneme ait gözlem sayılarını ifade etmektedir.

3.2.5. Model Spesifikasyonu

Enflasyon ve faiz oranları arasındaki ilişkiyi analiz etmek amacıyla iki temel model spesifikasyonu kullanılmıştır:

Model 1: Bağımlı değişken olarak enflasyon kullanılmıştır.

$$CPI_t = \alpha^0 + \alpha^1 PR_t + \alpha^2 \log(USD/TRY)_t + \alpha^3 IPI_t + \alpha^4 \log(M2)_t + \alpha^5 Exp_t + \alpha^6 D_{\{Crisis_{2008,t}\}} + \alpha^7 D_{\{Pandemic_{2020,t}\}} + \alpha^8 D_{\{Post2021Policy,t\}} + \varepsilon_t \quad (5)$$

Model 2: Bağımlı değişken olarak politika faiz oranı kullanılmıştır.

$$PR_t = \beta^0 + \beta^1 CPI_t + \beta^2 \log(USD/TRY)_t + \beta^3 IPI_t + \beta^4 \log(M2)_t + \beta^5 Exp_t + \beta^6 D_{\{Crisis_{2008,t}\}} + \beta^7 D_{\{Pandemic_{2020,t}\}} + \beta^8 D_{\{Post2021Policy,t\}} + \mu_t \quad (6)$$

Burada CPI_t , Tüketici Fiyat Endeksi'nin yıllık değişimini; PR_t , politika faiz oranını; $\log(USD/TRY)_t$, döviz kurunun logaritmasını; IPI_t , sanayi üretim endeksini; $\log(M2)_t$, para arzının logaritmasını; Exp_t , enflasyon beklentisini ifade etmektedir. $D_{Crisis_{2008,t}}$, $D_{Pandemic_{2020,t}}$ ve $D_{Post2021Policy,t}$ şeklindeki kukla değişkenler ise dışsal şokları temsil etmektedir. Modeller, 2015-2024 dönemi için tüm örneklem üzerinde ve ayrıca 2021 Eylül öncesi ve sonrası alt dönemler için ayrı ayrı tahmin edilmiştir. Bu yaklaşım, para politikasındaki değişimlerin karşılaştırmalı olarak analiz edilmesine olanak tanır.

4. Bulgular

Bu bölümde, Türkiye'de 2015-2024 döneminde enflasyon ve faiz oranları arasındaki ilişkinin ekonometrik analiz sonuçları sunulmaktadır. İncelenen verilerin temel istatistiksel

özelliklerinden başlayarak, durağanlık analizleri, nedensellik testleri, eşbütünleşme ilişkileri, regresyon modelleri ve dönemsel karşılaştırmalara kadar kapsamlı bir analiz yapılmıştır.

Tablo 2, Ocak 2015 - Aralık 2024 dönemine ilişkin Türkiye'ye ait temel makroekonomik değişkenlerin tanımlayıcı istatistiklerini sunmaktadır. Toplam 120 aylık gözlemi kapsayan bu tabloda, yıllık bazda Tüketici Fiyat Endeksi (TÜFE), Merkez Bankası tarafından belirlenen politika faiz oranı, USD/TRY döviz kuru, sanayi üretim endeksi (2015=100), geniş para arzı (M2, milyar TL cinsinden) ve 12 ay sonrası enflasyon beklentisi değişkenleri yer almaktadır. Her bir seriye ilişkin ortalama, minimum, maksimum, standart sapma, çarpıklık ve basıklık değerleri rapor edilmiştir.

Tablo: 2
Tanımlayıcı İstatistikler

İstatistik	Enflasyon (%)	Politika Faiz Oranı (%)	USD/TRY	Sanayi Üretim Endeksi	M2 Para Arzı (Milyar TL)	Enflasyon Beklentisi (%)
Ortalama	2.03	18.21	10.91	90.22	816.42	17.37
Minimum	-1.44	6.95	2.34	58.57	369.97	6.69
Maksimum	13.58	56.18	35.02	112.45	1,966.60	45.28
Std. Sapma	2.28	13.01	9.90	12.84	446.97	11.63
Skewness	2.15	1.82	1.03	-0.29	1.17	0.92
Kurtosis	9.02	5.74	2.76	2.11	3.05	2.59

Not: Tabloda 2015 Ocak - 2024 Aralık dönemini kapsayan 120 aylık gözleme ilişkin tanımlayıcı istatistikler sunulmuştur.

Tanımlayıcı istatistikler incelendiğinde, TÜFE'nin yıllık değişim oranının ortalama %2.03 olduğu, minimum %-1.44 ve maksimum %13.58 değerlerini aldığı görülmektedir. Politika faiz oranının ise ortalama %18.21 olduğu, minimum %6.95 ve maksimum %56.18 değerlerini aldığı görülmektedir. Bu durum, incelenen dönemde hem enflasyon hem de faiz oranlarında önemli dalgalanmalar olduğunu göstermektedir. Değişkenlerin standart sapma değerleri incelendiğinde, politika faiz oranının (13.01) enflasyon oranından (2.28) daha yüksek bir volatiliteye sahip olduğu anlaşılmaktadır. Çarpıklık ve basıklık değerleri, özellikle enflasyon ve faiz oranlarının normal dağılıma sahip olmadığını, sağa çarpık ve kalın kuyruklu bir dağılım gösterdiğini ortaya koymaktadır. Değişkenler arasındaki korelasyon ilişkileri Tablo 3'te gösterilmektedir.

Tablo: 3
Değişkenler Arası Korelasyon Matrisi

Değişken	Enflasyon (%)	Politika Faiz Oranı (%)	USD/TRY	Sanayi Üretim Endeksi	M2 Para Arzı (Milyar TL)	Enflasyon Beklentisi (%)
Enflasyon (%)	1.000	0.287	0.346	0.189	0.327	0.491
Politika Faiz Oranı (%)	0.287	1.000	0.902	0.415	0.887	0.931
USD/TRY	0.346	0.902	1.000	0.585	0.976	0.961
Sanayi Üretim Endeksi	0.189	0.415	0.585	1.000	0.512	0.493
M2 Para Arzı (Milyar TL)	0.327	0.887	0.976	0.512	1.000	0.957
Enflasyon Beklentisi (%)	0.491	0.931	0.961	0.493	0.957	1.000

Not: Tablo Pearson korelasyon katsayılarını göstermektedir.

Modelde kullanılan bazı açıklayıcı değişkenler arasında yüksek korelasyon gözlemlenmiş ve bu durum Varyans Şişirme Faktörü (VIF) değerlerine de yansımıştır. Özellikle log(USD/TRY) ve log(M2 Para Arzı) değişkenlerinin VIF değerleri sırasıyla 15.37

ve 14.26 olarak hesaplanmıştır. Bu durum, söz konusu değişkenlerin birbirine yüksek derecede bağlı olduğunu, ancak aynı zamanda modelde teorik olarak önemli bir yer tuttuğunu göstermektedir. Literatürde, benzer şekilde, yüksek VIF değerlerine rağmen bu değişkenler modele dâhil edilmeye devam edilmiştir (örn. Kılavuz & Altınöz, 2020; Beechey vd., 2011). Bu bağlamda, bu değişkenlerin çıkarılması modelin anlamlılık düzeyini düşürmüştür; çıkarıldıklarında ise önemli değişkenlerin etkisi eksik yansıtılmıştır. Bu nedenle, bu çalışmada yüksek VIF değerlerine rağmen modelin teorik tutarlılığını korumak amacıyla tüm değişkenler korunmuştur.

Tablo 4 analizde yer alan değişkenlere uygulanan Genişletilmiş Dickey-Fuller (ADF) birim kök testinin sonuçlarını özetlemektedir. Bu test, her bir zaman serisinin seviyede durağan olup olmadığını ya da birinci fark alındıktan sonra durağan hale geldiğini belirlemektedir. ADF testinin boş hipotezi, serinin birim kök içerdiğini, yani durağan olmadığını varsaymaktadır.

Tablo: 4
ADF Birim Kök Testi Sonuçları

Değişken	ADF İstatistiği	p-değeri	Durağanlık
Enflasyon (%)	-3.649	0.005**	Durağan I(0)
Politika Faiz Oranı (%)	-1.867	0.348	Durağan Değil
Δ Politika Faiz Oranı (%)	-5.921	0.000***	Durağan I(1)
log(USD/TRY)	-0.584	0.871	Durağan Değil
Δ log(USD/TRY)	-8.336	0.000***	Durağan I(1)
Sanayi Üretim Endeksi	-2.975	0.038*	Durağan I(0)
log(M2 Para Arzı)	1.242	0.998	Durağan Değil
Δ log(M2 Para Arzı)	-10.743	0.000***	Durağan I(1)
Enflasyon Beklentisi (%)	-2.215	0.201	Durağan Değil
Δ Enflasyon Beklentisi (%)	-6.753	0.000***	Durağan I(1)

Not: Δ sembolü ilgili değişkenin birinci farkını ifade eder. %1, %5 ve %10 anlamlılık düzeyleri için kritik değerler sırasıyla -3.48, -2.88 ve -2.57'dir. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Tablo 4'te görüldüğü üzere, TÜFE ve Sanayi Üretim Endeksi düzeyde durağan [I(0)] iken, Politika Faizi, log(USD/TRY), log(M2 Para Arzı) ve Enflasyon Beklentisi birinci farklarında durağan [I(1)] hale gelmektedir. Değişkenlerin farklı durağanlık derecelerine sahip olması, eşbütünlüşme, nedensellik ve etki-tepki analizlerinde kullanılacak metodolojinin seçilmesini etkilemektedir. Bu sonuçlar, değişkenlerin farklı durağanlık özelliklerine uygun ekonometrik yöntemlerin kullanılması gerektiğini göstermektedir.

Değişkenlerin farklı durağanlık derecelerine sahip olması nedeniyle, bu çalışmada ARDL (Autoregressive Distributed Lag) modeli kullanılmıştır. ARDL modeli, değişkenlerin I(0) veya I(1) olmasından bağımsız olarak uygulanabilmesi ve hem kısa hem de uzun dönem dinamiklerini aynı anda analiz edebilmesi nedeniyle tercih edilmiştir.

Tablo 5, Tüketici Fiyat Endeksi'nin (TÜFE) yıllık yüzde değişimi bağımlı değişken olarak tahmin edilen Ototregresif Dağıtılmış Gecikmeler (ARDL) modelinin tüm dönem, 2021 öncesi ve 2021 sonrası alt dönemler için elde edilen sonuçlarını sunmaktadır. Katsayı tahminlerinin ardından parantez içinde standart hatalar verilmiştir. Her bir alt dönem için tanı testleri ve ARDL sınır testi sonuçları da tabloda sunulmuştur.

Tablo 5. ARDL Modeli Tahmin Sonuçları (Bağımlı Değişken: Enflasyon Oranı %)

Değişken	Tüm Dönem	2015-2021 (Eylül Öncesi)	2021(Eylül)-2024
Sabit Terim	-5.463** (2.201)	-3.872* (1.984)	-11.746*** (3.487)
CPI(-1)	0.581*** (0.066)	0.429*** (0.089)	0.682*** (0.104)
CPI(-2)	0.215*** (0.068)	0.238** (0.094)	-
Politika Oranı	0.031** (0.012)	0.019* (0.010)	-0.112*** (0.032)
log(USD/TRY)	0.972** (0.386)	0.744** (0.345)	2.578*** (0.842)
Sanayi Üretim Endeksi	-0.029* (0.015)	-0.015 (0.012)	-0.043 (0.036)
log(M2 Para Arzı)	1.872*** (0.578)	1.345** (0.526)	3.274** (1.325)
Enflasyon Beklentisi	0.089*** (0.022)	0.052** (0.025)	0.142*** (0.048)
R ²	0.782	0.659	0.824
Adj. R ²	0.762	0.624	0.785
F-statistic	52.86***	22.73***	34.15***
LM Test (Otokorelasyon)	1.842 [0.178]	1.526 [0.224]	2.035 [0.163]
RESET Test	1.423 [0.237]	1.211 [0.275]	1.875 [0.182]
ARDL Bounds F-stat.	4.86**	3.92*	5.74**

Not: Standart hatalar parantez içinde, p-değerleri ise köşeli parantez içinde verilmiştir. *p<0.1, **p<0.05, ***p<0.01. ARDL sınır testi için %5 anlamlılık düzeyindeki kritik değerler, alt sınır için 3.79 ve üst sınır için 4.85'tir.

Tablo 5'teki ARDL model sonuçları incelendiğinde, tüm dönemler için modelin açıklama gücünün oldukça yüksek olduğu ($R^2 = 0.782$) görülmektedir. Bağımlı değişken üzerinde gecikmeli enflasyon değerleri, politika faizi, döviz kuru, para arzı ve enflasyon beklentilerinin istatistiksel olarak anlamlı etkilere sahip olduğu tespit edilmiştir.

Dönemler arası karşılaştırma yapıldığında, en dikkat çekici bulgu politika faizinin enflasyon üzerindeki etkisindeki değişimdir. 2021 öncesi dönemde politika faizi enflasyonu pozitif yönde etkilerken (katsayı = 0.019, $p < 0.1$), 2021 sonrası dönemde bu etki negatife dönmüştür (katsayı = -0.112, $p < 0.01$). Bu bulgu, 2021 sonrası dönemde faiz artışlarının enflasyonu düşürme yönünde etki gösterdiğini, ancak 2021 öncesi dönemde bu etkinin tersi yönde olduğunu göstermektedir.

Her üç model için de gerçekleştirilen ARDL sınır testi sonuçları, değişkenler arasında eşbütünleşme ilişkisinin varlığını doğrulamaktadır. Tüm dönem ($F = 4.86$) ve 2021 sonrası dönem ($F = 5.74$) için F-istatistik değerleri %5 anlamlılık düzeyindeki üst sınır değerinden büyük olup, 2021 öncesi dönem ($F = 3.92$) için F-istatistik değeri alt ve üst sınırlar arasında yer almaktadır. Bu sonuçlar, özellikle 2021 sonrası dönemde değişkenler arasında daha güçlü bir uzun dönem ilişkisinin varlığına işaret etmektedir.

ARDL modeline ait parametre kararlılığı, Brown vd. (1975) tarafından önerilen CUSUM ve CUSUMSQ testleri kullanılarak değerlendirilmiştir. Şekil 1 ve Şekil 2'de sunulan bu testler, model katsayılarının zaman içinde yapısal olarak istikrarlı olup olmadığını sınamaktadır. Her iki test grafiğinde de istatistiksel anlamlılık sınırları içerisinde kaldığı görülmekte olup, model parametrelerinin %5 güven düzeyinde kararlı olduğu sonucuna ulaşılmıştır. Bu bulgu, modelin geçerliliğini desteklemekte ve yapısal kırılmaların ARDL tahmin sonuçlarını etkilemediğini göstermektedir.

Şekil: 1
CUSUM Kararlılık Testi Grafiği



Şekil: 2
CUSUMSQ Kararlılık Testi Grafiği



ARDL modelinin güvenilirliği, tahmin sonuçlarının geçerliliğini sağlamak amacıyla kapsamlı tanı (diagnostik) testleriyle değerlendirilmiştir. Otokorelasyon, Ljung-Box testi ile sınanmış ve 8.743 test istatistiği ile p-değeri 0.189 bulunmuştur; bu da %5 anlamlılık düzeyinde artıklarda otokorelasyon olmadığını göstermektedir. Değişen varyans (heteroskedastisite) için Breusch-Pagan testi uygulanmış ve 2.456 test istatistiği ile p-değeri 0.117 elde edilmiştir; bu sonuç artıkların sabit varyansa (homoskedastisite) sahip olduğunu teyit etmektedir. Artıkların normalliği Jarque-Bera testi ile değerlendirilmiş ve 4.821 test istatistiği (p-değeri = 0.090) elde edilmiştir. Bu sonuç, artıkların geleneksel anlamlılık düzeylerinde normal dağıldığını göstermektedir. Elde edilen bulgular, ARDL modelinin temel varsayımlarını sağladığını ve güvenilir çıkarımlar yapılabileceğini ortaya koymaktadır (Test sonuçları için bkz. Ek 1).

Değişkenlerin farklı durağanlık seviyelerine sahip olması nedeniyle, standart Granger nedensellik testi yerine durağanlık gerektirmeyen Toda-Yamamoto nedensellik yaklaşımı kullanılmıştır. Bu test, değişkenlerin entegrasyon derecelerini göz önünde bulundurarak nedensellik ilişkilerini daha güvenilir bir şekilde analiz etmektedir.

Tablo 6, enflasyon (TÜFE) ile politika faiz oranı arasındaki yönlü ilişkileri değerlendirmek amacıyla, tüm örneklem ve 2021 Eylül ayındaki yapısal değişim öncesi ve sonrası alt dönemler için uygulanan Toda-Yamamoto nedensellik testinin sonuçlarını sunmaktadır.

Tablo: 6
Toda-Yamamoto Nedensellik Testi Sonuçları

Nedensellik Yönü	Tüm Dönem	2015-2021 (Eylül Öncesi)	2021(Eylül)-2024
TÜFE → Politika Oranı			
Wald İstatistiği	11.869	9.754	3.251
p-değeri	0.008***	0.021**	0.354
Nedensellik	Var	Var	Yok
Politika Oranı → TÜFE			
Wald İstatistiği	8.426	4.372	10.563
p-değeri	0.038**	0.224	0.014**
Nedensellik	Var	Yok	Var

Not: Tablo, Toda-Yamamoto nedensellik testine ait Wald istatistiklerini ve bunlara karşılık gelen p-değerlerini raporlamaktadır. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Nedensellik, nedensellik olmadığına ilişkin sıfır hipotezinin reddedilip reddedilmediğini göstermektedir.

Tablo 6’daki nedensellik testi sonuçları, tüm dönem boyunca enflasyon ile politika faizi arasında çift yönlü nedensellik ilişkisinin varlığını göstermektedir. Ancak bu ilişki alt dönemlerde önemli ölçüde farklılaşmaktadır. 2021 öncesi dönemde, enflasyondan politika faizine doğru tek yönlü bir nedensellik ilişkisi bulunurken ($p = 0.021$), 2021 sonrası dönemde bu ilişki tersine dönmekte ve politika faizinden enflasyona doğru tek yönlü bir nedensellik ilişkisi ortaya çıkmaktadır ($p = 0.014$).

Bu bulgular, 2021 öncesi dönemde Türkiye Cumhuriyet Merkez Bankası’nın (TCMB) politika faizi kararlarında enflasyondaki değişimleri dikkate aldığını, ancak politika faizi değişikliklerinin enflasyon üzerinde anlamlı bir nedensel etkisinin olmadığını göstermektedir. Öte yandan, 2021 sonrası dönemde TCMB’nin politika faizi kararlarının enflasyon üzerinde anlamlı bir nedensel etkisi bulunurken, enflasyondaki değişimlerin politika faizi kararları üzerindeki nedensel etkisinin ortadan kalktığı görülmektedir. Bu sonuçlar, 2021 sonrası dönemde para politikası stratejisinde önemli bir değişiklik olduğuna işaret etmektedir.

2021 yılı Eylül ayında Türkiye’nin para politikasında meydana gelen değişikliğin istatistiksel olarak anlamlı bir yapısal kırılma oluşturup oluşturmadığını test etmek amacıyla Chow testi uygulanmıştır. Tablo 6, hem enflasyonu hem de politika faizini bağımlı değişken olarak kullanan modeller için yapısal kırılma testi sonuçlarını göstermektedir.

Tablo 7, enflasyon ve politika faizi modellerinde yapısal kırılma olup olmadığını tespit etmek amacıyla uygulanan Chow testinin sonuçlarını sunmaktadır. Test 2021 yılı Eylül ayında bir yapısal değişim meydana gelip gelmediğini incelemektedir. İki regresyon

modeli test edilmiştir: Model 1’de bağımlı değişken enflasyon, Model 2’de ise politika faizi kullanılmıştır.

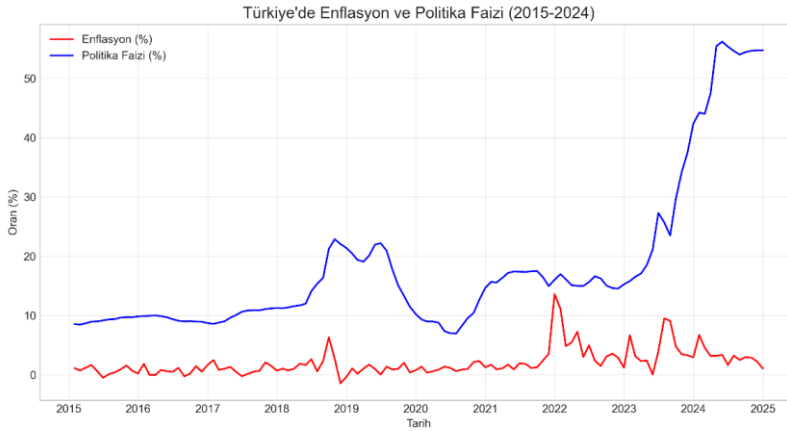
Tablo: 7
Yapısal Kırılma Testi Sonuçları

Model	F-istatistiği	p-değeri	Yapısal Kırılma
Model 1: $TÜFE = f(\text{Politika oranı, log(USD/TRY), Sanayi Üretim Endeksi, log(M2), Enflasyon Beklentisi})$	14.736	0.000***	Var
Model 2: $\text{Politika Oranı} = f(TÜFE, \text{log(USD/TRY), Sanayi Üretim Endeksi, log(M2), Enflasyon Beklentisi})$	21.893	0.000***	Var

Not: Chow testi, 2021 yılı Eylül ayı yapısal kırılma tarihi olarak alınarak uygulanmıştır. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Tablo 7’de sunulan Chow testi sonuçları, hem enflasyon modelinde ($F = 14.736$, $p < 0.01$) hem de politika faizi modelinde ($F = 21.893$, $p < 0.01$) 2021 yılı Eylül ayında istatistiksel olarak anlamlı bir yapısal kırılmanın varlığını güçlü bir şekilde desteklemektedir. Bu bulgu, 2021 sonrası dönemde Türkiye’nin para politikasında ve makroekonomik değişkenler arasındaki ilişkilerde önemli bir rejim değişikliğinin yaşandığını doğrulamaktadır. Bu kırılmanın zaman içindeki etkisini daha açık biçimde ortaya koymak amacıyla, 2015-2024 döneminde enflasyon ve politika faizi oranlarının seyri Şekil 1’de grafiksel olarak gösterilmiştir.

Şekil: 3
Türkiye’de Enflasyon ve Politika Faizi Aylık Zaman Serisi



Not: 2021 yılındaki politika değişikliğinin ardından faiz oranları düşerken enflasyon hızla artmış; bu durum, para politikası aktarım mekanizmasının zayıfladığına işaret etmiştir.

Yapısal kırılma testinin yanı sıra, alt dönem regresyon katsayılarının karşılaştırılması da değişkenler arasındaki ilişkilerdeki değişimi açıkça göstermektedir. Özellikle enflasyon ile politika faizi arasındaki ilişkinin yönü ve büyüklüğü, iki dönem arasında önemli farklılıklar göstermiştir. 2021 öncesi dönemde enflasyonun politika faizi üzerindeki etkisi

pozitif ve anlamlıyken (katsayı = 1.241, $p < 0.01$), 2021 sonrası dönemde bu etki negatife dönmüştür (katsayı = -3.857, $p < 0.01$).

Çalışmada, Türkiye ekonomisinde son on yılda yaşanan üç önemli olayı modele dahil etmek amacıyla kukla değişkenler seçilmiştir: (1) 2008 finansal krizi, makroekonomik değişkenler üzerinde kalıcı etkiler bırakabilecek küresel bir şok olması; (2) COVID-19 pandemisi, ekonomik aktivite ve tüketici davranışlarında önemli değişimlere yol açan benzeri görülmemiş bir sağlık krizi olması; ve (3) 2021 Eylül'ündeki para politikası değişimi, TCMB'nin enflasyon-faiz ilişkisine yönelik yaklaşımında belirgin bir dönüşüm olması nedeniyle seçilmiştir. Literatürde, Mishkin (2009), finansal krizlerin para politikası aktarım mekanizmasını etkileyebileceğini; Caggiano vd. (2020) COVID-19 pandemisinin para politikası etkinliğini değiştirebileceğini ve Davig ve Doh (2014) para politikasındaki rejim değişikliklerinin makroekonomik değişkenler arasındaki ilişkileri yeniden şekillendirebileceğini vurgulamıştır. Bu bağlamda, kukla değişkenler aracılığıyla, enflasyon ve faiz ilişkisinin belirli koşullar altında nasıl değişebileceğini analiz etmek ve bu değişimlerin normal ekonomik dinamiklerden mi yoksa dışsal şoklardan mı kaynaklandığını ayırt etmek mümkün olabilmektedir.

Tablo: 8
Regresyon Modellerinde Kukla Değişkenlerin Etkileri

Kukla Değişken	Model	Tüm Dönem	2015-2021 (Eylül Öncesi)	2021(Eylül)-2024
D_Crisis_2008	Enflasyon Modeli	-0.284 (0.612)	-0.346 (0.537)	-
D_Crisis_2008	Faiz Oranı Modeli	-1.842 (3.974)	-2.217 (3.548)	-
D_Pandemic_2020	Enflasyon Modeli	-0.316 (0.482)	-0.294 (0.446)	-0.387 (0.521)
D_Pandemic_2020	Faiz Oranı Modeli	-2.568 (3.118)	-2.153 (2.986)	-2.741 (4.289)
D_Post2021Policy	Enflasyon Modeli	0.963** (0.481)	-	-
D_Post2021Policy	Faiz Oranı Modeli	20.713*** (2.848)	-	-

Note: Standart hatalar parantez içinde verilmiştir. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Tablo 8'deki sonuçlar incelendiğinde, 2008 finansal krizi ve COVID-19 pandemisini temsil eden kukla değişkenlerin hem enflasyon hem de politika faizi üzerindeki etkilerinin istatistiksel olarak anlamlı olmadığı görülmektedir. Bu bulgu, bu iki önemli kriz döneminin Türkiye'de enflasyon ve faiz dinamikleri üzerinde döviz kuru, para arzı ve enflasyon beklentileri gibi temel makroekonomik değişkenler üzerinden bağımsız olarak anlamlı bir etki yaratmadığını göstermektedir.

Buna karşılık, 2021 sonrası para politikası değişimini temsil eden D_Post2021Policy kukla değişkeninin hem enflasyon hem de faiz modelleri üzerinde istatistiksel olarak anlamlı etkilere sahip olduğu tespit edilmiştir. Bu kukla değişken, diğer faktörler sabit tutulduğunda, enflasyon üzerinde pozitif bir etki (katsayı = 0.963, $p < 0.05$) gösterirken, politika faizi üzerinde çok daha güçlü bir pozitif etki (katsayı = 20.713, $p < 0.01$) göstermektedir. Bu bulgu, 2021 Eylül ayı sonrasında uygulanan para politikasının hem enflasyon hem de faiz düzeylerinde yapısal bir artışa yol açtığını doğrulamaktadır.

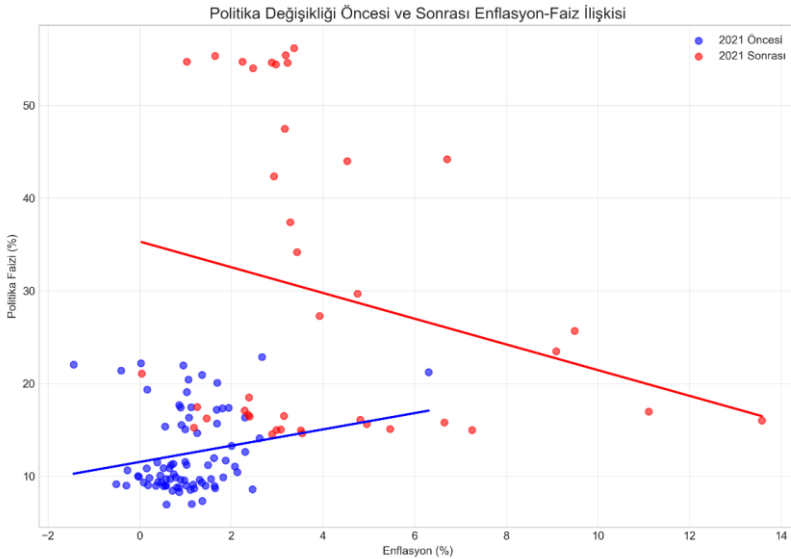
Dönemler arası analizde, kukla değişkenlerin etkilerinde de farklılıklar gözlemlenmiştir. D_Pandemic_2020 değişkeninin 2021 öncesi ve sonrası dönemlerdeki etkisi incelendiğinde, her iki dönemde de istatistiksel olarak anlamlı olmadığı, ancak katsayı

büyükliğünün 2021 sonrası dönemde nispeten arttığı görülmektedir. Bu durum, pandemi etkilerinin 2021 sonrası dönemde daha belirgin hâle geldiğini, ancak hâlâ istatistiksel olarak anlamlı düzeyde olmadığını göstermektedir.

ARDL modelinde, $D\_Post2021Policy$ kukla değişkeninin uzun dönem katsayısı (1.853, $p < 0.01$), bu değişkenin kısa dönem katsayısından (0.963, $p < 0.05$) daha yüksektir; bu durum, politika değişikliğinin enflasyon üzerindeki etkisinin uzun vadede daha güçlü olduğunu göstermektedir. Bu bulgu, 2021 sonrası para politikası değişikliğinin geçici bir etki yerine kalıcı bir yapısal değişime işaret ettiğini doğrulamaktadır.

Türkiye ekonomisinde enflasyon ve faiz oranları arasındaki ilişkinin incelendiği bu çalışmada, 2015-2024 dönemini kapsayan analizlerimiz sonucunda önemli bulgular elde edilmiştir. Analizler iki değişken arasındaki ilişkinin zaman içinde önemli değişimler gösterdiğini ortaya koymaktadır. Özellikle 2021 yılı Eylül ayında gerçekleşen para politikası değişikliği, bu ilişkide belirgin bir yapısal kırılmaya yol açmıştır. Bu yapısal dönüşümün görsel olarak daha net anlaşılabilmesi adına, politika değişikliği öncesi ve sonrası dönemlerde enflasyon ile politika faizi arasındaki ilişki, regresyon çizgileriyle birlikte karşılaştırmalı olarak aşağıdaki Şekil 2’de sunulmuştur.

Şekil: 4
Politika Değişimi Öncesi ve Sonrasında Enflasyon-Faiz Oranı İlişkisi



Not: Regresyon eğimleri, 2021 sonrası dönemde ilişki yönünde bir tersine dönüş olduğunu göstermekte olup bu durum, olası bir neo-Fisher dinamiğine işaret etmektedir.

En çarpıcı bulgu, 2021 öncesi ve sonrası dönemlerde enflasyon-faiz ilişkisindeki paradigma değişimidir. 2021 öncesinde politika faizi ile enflasyon arasında pozitif bir ilişki varken, 2021 sonrasında bu ilişki negatife dönmüştür. Bu bulgu, TCMB'nin 2021 öncesinde enflasyona tepki veren bir politika izlediğini, 2021 sonrasında ise enflasyonu aktif şekilde etkilemeye yönelik bir strateji benimsediğini göstermektedir. Nedensellik analizleri de bu değişimi desteklemekte; 2021 öncesinde enflasyondan faize doğru olan tek yönlü nedenselliğin 2021 sonrasında faizden enflasyona doğru değiştiğini göstermektedir. Döviz kuru ve para arzı gibi diğer makroekonomik değişkenlerin enflasyon üzerindeki etkisi de 2021 sonrası dönemde belirgin şekilde artmıştır. Bu durum, Türkiye ekonomisinin bu faktörlere karşı daha duyarlı hale geldiğini göstermektedir. Kukla değişken analizlerimiz, ilginç bir şekilde, 2008 finansal krizi ve COVID-19 pandemisinin enflasyon ve faiz dinamikleri üzerinde istatistiksel olarak anlamlı bir etki yaratmadığını, ancak 2021 politika değişikliğinin önemli bir yapısal değişime işaret ettiğini ortaya koymuştur. Bu bulgu, Türkiye'de makroekonomik değişkenlerin dış şoklardan ziyade içsel politika tercihlerinden daha fazla etkilendiğini düşündürmektedir.

5. Sonuç ve Politika Önerileri

Bu çalışma, Türkiye'de 2015-2024 dönemi boyunca enflasyon ile faiz oranları arasındaki değişen ilişkiyi incelemekte ve özellikle Eylül 2021'de başlatılan para politikası değişiminin etkisine odaklanmaktadır. ARDL modelleri, nedensellik testleri ve yapısal kırılma analizinden elde edilen ampirik bulgular, söz konusu politika değişiminin ardından bu ilişkinin belirgin bir dönüşüm yaşadığını ortaya koymaktadır.

Çalışmada elde edilen bulgular, faiz oranı ile enflasyon arasında hem kısa hem de uzun dönemde istatistiksel olarak anlamlı ilişkiler olduğunu göstermektedir. ARDL modeli kapsamında tahmin edilen uzun dönem katsayısı, politika faiz oranındaki 1 birimlik artışın enflasyonu yaklaşık 0.39 birim artırdığını ve bu ilişkinin %5 anlamlılık düzeyinde istatistiksel olarak anlamlı olduğunu göstermektedir. Kısa dönem katsayıları incelendiğinde, faiz oranının bir dönem gecikmeli farkı 0.28 katsayısıyla %10 düzeyinde anlamlı bulunmuştur. Ayrıca, hata düzeltme katsayısı ECM_{t-1} değeri -0.46 olup, negatif işaretli ve %1 anlamlılık düzeyinde anlamlıdır. Bu sonuç, modelin kısa dönem dengesizliklerini her dönem %46 oranında düzelttiğini ve sistemin uzun dönem dengeye doğru istikrarlı biçimde yöneldiğini göstermektedir.

2021 öncesi dönemde elde edilen sonuçlar, politika faizindeki değişimlerin ya etkisiz kaldığını ya da enflasyonla pozitif yönde ilişkili olduğunu ortaya koymaktadır; bu durum Neo-Fisher hipoteziyle uyumludur. Buna karşın, 2021 sonrası alt dönemde bu ilişki tersine dönmüş; geleneksel para politikası aktarım mekanizmalarının yeniden işlerlik kazandığı ve faiz artışlarının dezenflasyonist etkiler doğurduğu görülmüştür.

Elde edilen bulgular, enflasyonist baskıların şekillenmesinde döviz kuru dinamikleri, para arzı büyümesi ve enflasyon beklentileri gibi ilave makroekonomik değişkenlerin de kritik bir rol oynadığını göstermektedir. Kukla değişkenlerin dahil edildiği regresyon

analizleri, COVID-19 pandemisi ve 2008 küresel finansal krizi gibi yapısal şokların istatistiksel olarak anlamlı etkiler yarattığını; aynı zamanda 2021'deki politika rejimi değişiminin enflasyon-faiz ilişkisi açısından belirleyici bir dönüm noktası olduğunu ortaya koymuştur.

Politika açısından değerlendirildiğinde, elde edilen sonuçlar para politikasının güvenilirliği ve tutarlılığına vurgu yapmaktadır. Merkez bankaları, özellikle belirsizlik dönemlerinde, şeffaf ve geleceğe dönük iletişim stratejileriyle enflasyon beklentilerini sabitlemelidir. 2021 sonrası döneme ilişkin bulgular, geleneksel politika çerçevesinin faiz aracı üzerindeki etkinliğini yeniden tesis edebileceğini göstermektedir.

Gelecekte yapılacak çalışmalar, analize ek makro-f finansal değişkenlerin dahil edilmesiyle kapsamını genişletebilir; ayrıca, potansiyel asimetrleri ve eşik etkilerini incelemek amacıyla doğrusal olmayan ekonometrik modellerden yararlanılabilir. Ayrıca, yükselen piyasa ekonomileri arasında yapılacak karşılaştırmalı analizler, Türkiye'ye özgü bir durumun mu söz konusu olduğunu yoksa daha geniş bir yapısal dönüşümün parçası mı olduğunu ortaya koyabilir.

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EK Tablo: 1

Test	Test İstatistiği	P-değeri	Sonuç
Ljung-Box (Otokorelasyon)	8.743	0.189	Otokorelasyon Yok
Breusch-Pagan (Heteroskedastisite)	2.456	0.117	Varyans Sabit (Homoskedastisite)
Jarque-Bera (Normallik)	4.821	0.090	Normal Dağılım
Ljung-Box (Otokorelasyon)	8.743	0.189	Otokorelasyon Yok

Not: Tüm testler %5 anlamlılık düzeyinde değerlendirilmiştir.

Türkiye’de Finansal Piyasalar Arasında Volatilite Yayılımı: TVP- VAR Modeli Uygulaması

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Volatility Spillover Among Financial Markets in Türkiye: An Application of the TVP-VAR Model

Abstract

In this study, the volatility spillovers among the BIST 100 index, the USD/TL exchange rate, gold prices, the TL overnight reference rate, the 5-year bond yield, and the 5-year CDS premium in Türkiye are examined using daily data for the period 02.01.2018-31.12.2024. The TVP-VAR method, which captures the dynamic characteristics of time-varying parameters, is employed. The findings show that the USD/TL exchange rate is the primary source of volatility, strongly affecting the CDS premium, the BIST 100 index, and the 5-year bond yield, while gold and the overnight rate exhibit relatively limited spillovers.

Keywords : TVP-VAR, Financial Markets, Volatility Spillover.

JEL Classification Codes : C32, C50, G10.

Öz

Bu çalışmada, Türkiye’de BIST 100 endeksi, USD/TL kuru, altın fiyatları, TL gecelik referans faiz oranı, 5 yıllık tahvil faizi ve 5 yıllık CDS primi arasındaki volatilite yayılımı 02.01.2018-31.12.2024 dönemine ait günlük frekanslı verilerle incelenmiştir. Analizde, zamanla değişen parametrelerin dinamik özelliklerini ortaya koyabilen TVP-VAR yöntemi kullanılmıştır. Bulgular, USD/TL kurunun finansal sistemde en güçlü volatilite kaynağı olduğunu ve özellikle CDS primini, BIST 100 endeksini ve 5 yıllık tahvil faizini belirgin biçimde etkilediğini göstermektedir. Buna karşılık, gram altın fiyatları ve TL gecelik referans faiz oranı, görece daha sınırlı bir volatilite yayılımı sergilemekte ve diğer değişkenlere daha düşük düzeyde oynaklık aktarmaktadır.

Anahtar Sözcükler : TVP-VAR, Finansal Piyasalar, Volatilite Yayılımı.

1. Giriş

Finansal piyasalarda volatilité, varlıkların beklenen gelecekteki değerlerinden sapmalarla kendini gösteren önemli bir oynaklık göstergesidir. Bir varlığın gelecekteki fiyatına ilişkin belirsizliği temsil eden bu kavram, genellikle varyans veya standart sapma ile ifade edilmektedir (Bhowmik & Wang, 2020: 2). Volatilité, yalnızca finansal piyasalardaki belirsizliği ve risk algısını değil, aynı zamanda finansal istikrarı ve piyasa dinamiklerini de yansıtan kritik bir göstergedir. Risk-getiri ilişkisi üzerinde doğrudan etkili olması nedeniyle, varlık fiyatlaması, portföy yönetimi, riskten korunma stratejileri ve yatırım kararları açısından da merkezi bir rol oynamaktadır. Bu yönüyle volatilité, finansal piyasaların en belirgin ve karakteristik özelliklerinden biri olarak değerlendirilmektedir.

Volatilitenin bir piyasadan diğerine geçmesi, yani bir finansal varlık ya da piyasada meydana gelen oynaklığın başka bir varlık ya da piyasayı etkilemesi "volatilité yayılımı" olarak tanımlanmaktadır (Korkusuz et al., 2023: 1518). Küresel düzeyde finansal liberalleşme, deregülasyon, teknolojik gelişmeler ve piyasa entegrasyonu gibi unsurlar piyasalar arası bu yayılım etkisini güçlendirmektedir. Özellikle 2008 küresel finansal krizi gibi, belirli bir ülke veya bölgede ortaya çıkan ekonomik şokların diğer ülkelerin finansal piyasaları, döviz kurları ve borsa endeksleri üzerinde etkili olması, volatilité yayılımını daha da önemli bir olgu hâline getirmiştir. Bu durum, sistemik riskin azaltılması, finansal istikrarın korunması ve etkin portföy yönetiminin sağlanması amacıyla politika yapıcılar, finans yöneticileri, yatırımcılar ve akademisyenleri volatilité yayılımını daha yakından incelemeye yönlendirmektedir.

Finansal piyasalarda korunma isteği ve korunma maliyetini temsil eden risk primleri de volatilitenin düzeyine bağlı olarak oluşmaktadır. Yüksek volatilité, yatırımcılara potansiyel kazanç fırsatları sunsa da, aynı zamanda ciddi zarar riskleri de doğurur. Bu bağlamda, özellikle türev ürünlerin fiyatlamasında gelecekteki volatilitenin doğru tahmini büyük önem taşımaktadır (De Silva et al., 2017: 365). Bu nedenle, volatilitenin karmaşık doğası karşısında etkin risk yönetimi modellerinin geliştirilmesi, yatırım kararlarının başarısı açısından kritik bir unsur hâline gelmiştir. Türkiye'de geçmişte döviz ve altın gibi geleneksel yatırım araçları öne çıkarken, son yıllarda Merkezi Kayıt Kuruluşu (MKK) verilerine göre Borsa İstanbul'daki yatırımcı sayısındaki artış, yatırım davranışlarında belirgin bir değişimi ortaya koymaktadır. Devlet iç borçlanma senetleri, özel sektör tahvilleri ve BIST endekslerinin güçlü performansı, hisse senetlerini ön plana çıkarırken, Aralık 2021'den itibaren USD/TL kurundaki artış da döviz piyasasına olan ilgiyi yeniden artırmıştır.

Volatilité, genel olarak üç temel şekilde sınıflandırılmaktadır: varsayımsal, beklenen ve ani (gerçekleşen) volatilité. Varsayımsal volatilité, benzer finansal ürünlerin getirilerindeki değişkenliğe dayalı olarak tahmin edilen volatilité düzeyini ifade ederken, beklenen volatilité, geçmiş fiyat verilerinden hareketle gelecekteki fiyat değişimlerinin öngörüsüdür. Ani volatilité ise belirli bir anda ekonomik, siyasi veya sosyal gelişmelerin yarattığı olumlu ya da olumsuz şoklar sonucunda ortaya çıkan fiyat oynaklığıdır (De Silva

et al., 2017: 367). Volatilitenin bir piyasadan diğetine geçmesi, yani bir finansal varlık ya da piyasada meydana gelen oynaklığın başka bir varlık ya da piyasayı etkilemesi, "volatilité yayılımı" olarak tanımlanır. Küreselleşen piyasalarda finansal liberalleşme, deregölasyon, teknolojik gelişmeler ve piyasa entegrasyonu gibi dinamikler bu yayılım etkisini artırmaktadır. Bu çerçevede, sistemik riskin azaltılması, finansal istikrarın korunması ve etkin portföy yönetimi açısından volatilité yayılımının analizi, akademik ve pratik açıdan önemli bir araştırma konusu hâline gelmiştir.

Finansal piyasalarda farklı yatırım araçları arasındaki ilişki, bu araçların birbirleri üzerindeki olası etkileri ve yatırımcının risk-getiri tercihi doğrultusunda menkul kıymet seçimi, volatilité yayılımını anlamayı gerekli kılmaktadır. Literatürde, hisse senedi, döviz, tahvil ve emtia piyasaları arasındaki oynaklık ilişkilerini analiz eden birçok çalışma bulunmaktadır. Bu analizlerde ARCH ve GARCH modelleri (Engle et al., 1990: 526), DCC-GARCH (Engle, 2002: 340) ve stokastik volatilité modelleri (Diebold & Yilmaz, 2009: 159) yaygın olarak kullanılmaktadır. Bu çalışmada ise finansal piyasalar arasındaki volatilité yayılımı, zamanla değişen parametreli vektör otoregresyon (TVP-VAR) modeli ile analiz edilmekte olup, Türkiye bağlamında sınırlı sayıda araştırma tarafından ele alınmış olması bakımından literatüre katkı sağlaması beklenmektedir. Borsa endeksi, döviz kuru (USD/TL), gram altın fiyatları, TL gecelik referans faiz oranı, 5 yıllık tahvil faiz oranı ve 5 yıllık CDS primi gibi farklı finansal göstergeler arasındaki volatilité aktarımının incelenmesi hem yatırımcılar hem de politika yapıcılar açısından önemli bilgiler sunmaktadır.

Piyasa entegrasyonunun artması ve bilgi iletimindeki hızlanma, bir piyasada yaşanan dalgalanmaların diğ piyasalara kısa sürede yansımaya neden olmaktadır. Özellikle döviz piyasası, yüksek likiditesi ve kesintisiz işlem yapısı nedeniyle bu yayılımın merkezinde yer almaktadır. Para ve sermaye piyasalarında işlem gören menkul kıymetler döviz piyasasında gerçekleşen hareketlerden önemli ölçüde etkilenmektedir. Bunun yanı sıra, hisse senedi ve tahvil piyasaları arasında da oynaklık geçişleri yaygın olarak gözlemlenmektedir (Dean et al., 2010: 288). Ekonomik ve finansal kriz dönemlerinde bu etkileşim daha da güçlenmektedir. Küreselleşen finansal sistemin karmaşık ve karşılıklı bağımlılık içeren yapısı, volatilité yayılımının ölçülmesini ve izlenmesini daha da önemli hâle getirmiştir. Zira bu dalgalanmalar belirsizliği ve riski artırarak finansal sistemin işleyişini olumsuz yönde etkileyebilmektedir (Bhowmik & Wang, 2020: 1).

Bu çalışma, 02.01.2018-31.12.2024 dönemini kapsamaktadır. Söz konusu dönem, Türkiye'de 2018 Kur Krizi ile başlayan ve takip eden yıllarda TCMB'nin faiz politikalarında önemli değişimlerin yaşandığı, enflasyonla mücadele sürecinin ön plana çıktığı bir dönem olması nedeniyle seçilmiştir. Bu süreçte, finansal piyasalarda artan oynaklık, döviz kuru dalgalanmaları ve risk primindeki değişimler piyasalar arasındaki dinamik bağlantılılığın incelenmesini gerekli kılmaktadır. Bu amaç doğrultusunda, 2018-2024 dönemi Türkiye finansal piyasalarının belirli makroekonomik olaylara ve politika değişimlerine yüksek derecede duyarlı olduğu bir dönem olarak değerlendirilmektedir. Literatürde yapılan çalışmalardan bazıları (Akyıldırım vd., 2022; Erdoğan, 2023; Özdemir-Höl, 2023) pandeminin finansal piyasalar üzerindeki etkilerine odaklanmaktadır. Ancak bu çalışma

yalnızca COVID-19 sürecini ele almakla kalmayıp, 2018 Kur Krizi ile başlayan, takip eden yıllarda TCMB'nin faiz politikalarında önemli değişimlerin yaşandığı, enflasyonla mücadele sürecinin belirginleştiği ve 2023 genel seçimleri gibi politika belirsizliklerinin finansal piyasalar üzerindeki etkilerinin hissedildiği volatilitenin yüksek olduğu bir dönemi kapsamaktadır. Bu nedenle, volatilitenin yoğun olduğu bir dönemin incelenmesi, kullanılan veri setinin güncel olması ve zamanla değişen parametrelerin dinamik yapısını yakalayabilen Zamanla Değişen Parametrelili Vektör Otoregresyon (TVP-VAR) yöntemi gibi güncel ekonometrik tekniklerin kullanılmış olması yönüyle çalışmanın literatüre önemli bir katkı sağlaması beklenmektedir. Çalışma, giriş bölümü; konuya ilişkin teorik ve ampirik literatürün incelendiği literatür taramasını takiben, veri seti ve analiz sürecini kapsayan ekonometrik metodolojinin açıklanmasıyla başlar; ampirik bulgulara ve bulguların kapsamlı bir şekilde yorumlanmasına yer verilerek genel değerlendirmelerin sunulduğu sonuç bölümüyle sonlandırılır.

2. Literatür

Finansal piyasalar arasındaki volatilité yayılımına yönelik literatür, volatilitenin ve volatilité yayılımının belirleyicilerini, yönünü ve etkilerini inceleyen akademik çalışmalardan elde edilen teorik ve ampirik bulguları sentezlemektedir. Finansal piyasalar arasındaki bağlantı ya da volatilité yayılımına ilişkin bu çalışmalar özellikle 1980'lerden sonra, finansal liberalizasyon ve küreselleşme sonrasında piyasalar arasındaki etkileşimin gelişmesiyle birlikte artmıştır. Hisse senedi, tahvil, döviz ve emtia piyasaları arasında volatilité aktarımını inceleyen çok sayıda araştırma, piyasa oynaklığının yalnızca yerel değil, aynı zamanda uluslararası düzeyde de sistematik biçimde yayıldığını ortaya koymaktadır.

Volatilité yayılımı üzerine literatürde bazı teorik temellere de yer verilmiştir. Bu konudaki ilk araştırmalar 20. Yüzyılın ortalarında hisse senedi getirisi, volatilitesi ve diğer piyasalar arasındaki dağılımının araştırılmasıyla başlamıştır. Markowitz (1952) portföy teorisinde riski veya volatilitéyi matematiksel bir kavram olarak kullanan ilk kişi olmuştur. Piyasa fiyatlarının mevcut tüm bilgileri tam olarak yansıttığını varsayan Etkin Piyasalar Hipotezi (The Efficient Market Hypothesis), yeni bilgilerin varlık fiyatlarına hızla dahil edildiğini ve piyasalar arasında volatilité yayılımına katkıda bulunduğunu ileri sürmektedir (Fama, 1970: 414). İkinci önemli teori, finansal bulaşma teorisidir. Finansal bulaşma, başlangıçta birkaç finansal kurumu etkileyen ve finansal sistemin geri kalanına yayılan, genellikle diğer ülkelerin ekonomilerini etkileyen bir şok olarak tanımlanmakta olup, bulaşmalar genellikle krizlerin bir piyasa, varlık sınıfı veya coğrafi bölge genelinde yayılmasıyla ilişkilidir. Bu bağlamda, finansal bulaşma teorisini, bir piyasadaki oynaklık şoklarının yatırımcı duygusu, piyasa bağlantıları ve küresel riskten kaçınma nedeniyle diğerlerine yayılabileceğini öne sürmektedir (Forbes & Rigobon, 2002: 2223). Başka bir teorik bakış açısı da Kyle'ın (1985) likidite kısıtlamalarının ve emir akışı dinamiklerinin oynaklık iletimini nasıl etkilediğini inceleyen mikro yapı yaklaşımıdır (Microstructure Approach). Piyasa mikro yapısı, hem teorik hem de ampirik olarak, bir menkul kıymet piyasasındaki minimum fiyat adımları (tick) bazında fiyat oluşumunun incelenmesidir. Kyle (1985), piyasa etki maliyeti, değişken maliyet ve sabit maliyet dahil olmak üzere örtük işlem

maliyetlerinin farklı bileşenlerinin dinamiklerini on yıl boyunca tik-tik alım satım verilerini kullanarak incelemiş, piyasa etki maliyetinin zaman içinde sabit kaldığını, sabit maliyet ve değişken maliyetin ise zaman içinde önemli ölçüde azaldığını tespit etmiştir.

Finansal piyasalar arasında volatilité yayılımına ilişkin ilk çalışmalar tek bir ülkenin finansal piyasalarında, özellikle de menkul kıymetler borsası endeksindeki oynaklık faktörünü anlamak amacıyla yapılmıştır (Harvey, 1995: 773; Eun & Shim, 1989: 241).

Günümüzde volatilité yayılımına ilişkin ampirik araştırmaların büyük bölümü gelişmiş ülke finans piyasalarına odaklanmaktadır. Kanas (2000), ABD, İngiltere, Japonya, Almanya, Fransa ve Kanada'yı kapsayan çalışmada; Yang & Dong (2004), G7 ülkelerini ele aldıkları analizlerinde; Alaganar & Bhar (2007) ise ABD özelinde gerçekleştirdikleri araştırmada, volatilité yayılımının genellikle hisse senedi piyasalarından döviz piyasalarına doğru olduğunu, buna karşın döviz piyasalarından hisse senedi piyasalarına yönelik etkinin daha zayıf kaldığını ortaya koymuşlardır.

Döviz kuru volatilitesi, makroekonomik değişkenler, para politikası değişiklikleri ve sermaye akışlarıyla yakından ilişkilidir. Bu nedenle, döviz kurlarındaki oynaklık ile diğer finansal piyasalar arasındaki ilişki literatürde önemli bir yer tutmaktadır. Xiong & Han (2015), döviz ve hisse senedi piyasaları arasındaki volatilité aktarımını incelemiş; ülkede döviz kuru ve hisse senedi fiyatları arasında negatif bir korelasyon olduğunu ve ulusal ekonominin kendi makroekonomik değişkenlerindeki dalgalanmaların ekonomik denge üzerinde daha hızlı etkili olacağını belirtmişlerdir. Dornbusch & Fischer (1980); Branson (1983). Pan, Fok & Liu (2007) ve Chkili & Nguyen (2014) döviz kurlarındaki dalgalanmaların şirket kazançlarını ve yatırımcı algısını olumsuz etkilediğini ve özellikle gelişmekte olan piyasalarda menkul kıymet piyasaları üzerinde etkili olduğunu bulmuşlardır. Ayrıca, bu ilişki döviz kuru rejimleri, dış ticaret hacminin büyüklüğü, sermaye kontrolleri ve hisse senedi piyasasının büyüklüğü açısından ekonomiler arasında farklılık gösterebilir. Özellikle merkez bankaları tarafından belirlenen para politikası, faiz oranı değişiklikleri ve makroekonomik haberler döviz kurlarında önemli dalgalanmalara yol açabilir (Ehrmann & Fratzscher, 2005). Fama'nın (1984) açıklanmamış faiz oranı (uncovered interest parity) teorisine göre, döviz kurlarında beklenen değişikliklerin faiz oranı farklarını telafi etmesi gerekirken, bazı çalışmalarda (Valente et al., 2006) faiz oranı ve döviz kuru değişimlerinde sapmalar olduğu ve faiz oranı değişikliklerine karşı döviz kurlarının artan bir duyarlılığa sahip olduğu belirlenmiştir (Rey, 2013). Longstaff vd. (2011) tarafından yapılan çalışmada da, yüksek yabancı para cinsinden borcu olan ülkelerde ulusal paranın aşırı değer kaybetmesi durumunda, kredi riski algısını yansıtan CDS spreadlerinin artmasına neden olacağı vurgulanmıştır.

Menkul kıymetler borsaları sistematik riskleri çok iyi yansıttığından, borsa endeksleri ile diğer piyasalar arasında volatilité etkileşimi de oldukça güçlüdür. Finansal krizler ve makroekonomik şoklar döviz kuru ile hisse senedi piyasası arasındaki volatilité aktarımına yönelik bağlantıyı güçlendirmektedir (Forbes & Rigobon, 2002). Para politikası değişiklikleri, faiz oranlarındaki dalgalanmalar, iskonto oranları ve borçlanma maliyetlerini

etkileyerek hisse senedi piyasalarında volatilitenin artmasına neden olabilir (Bernanke & Kuttner, 2005). Acharya & Johnson (2007) menkul kıymet piyasaları ile CDS primleri arasında güçlü bir negatif korelasyon bulunduğunu ortaya koymuştur. Bai & Collin-Dufresne (2013) ise borsalarda meydana gelen bir dalgalanmanın CDS primlerini artırdığını belirlemiştir.

Merkez bankalarının politika faiz oranları, gösterge niteliğindeki referans faiz oranları ile LIBOR gibi uluslararası gösterge niteliğindeki faiz oranları da diğer finansal piyasalar üzerinde etkili olabilmektedir. Faiz oranlarındaki değişimler, kredi ve mevduat faizleri ile fonlama maliyetleri üzerinden menkul kıymet, döviz ve CDS piyasalarına yansımaktadır (Gilchrist & Zakrajšek, 2012). Bu etkileşimler, özellikle finansal kriz dönemlerinde daha da belirgin hâle gelmektedir (Augustin et al., 2014). Faiz oranları üzerindeki en önemli belirleyici para politikası olduğundan, para politikası rejimlerinin tüm finansal piyasalar üzerinde volatilité aktarma gücüne sahip olduğu görülmektedir. Genişletici para politikaları, borsa endeksleri, döviz kurları veya CDS primlerini olumlu yönde etkilerken, daraltıcı para politikaları söz konusu değişkenler üzerinde negatif bir etkiye sahip olacaktır. Nitekim, Campbell vd. (2001) parasal sıkılaştırmanın piyasa volatilitésini artırdığını, genişlemeci politikaların ise azalttığını göstermektedir.

Volatilitenin yönüne odaklanan çalışmalarda, genellikle gelişmiş ülkelerden gelişmekte olan ülkelere doğru bir etki iletiminin olduğu tespit edilmiştir (Bekaert & Harvey, 1997). Diebold & Yılmaz (2009) ise büyük finansal piyasalar arasındaki yönlü volatilité etkileşimini varyans ayrıştırma teknikleriyle analiz etmiş ve finansal kriz dönemlerinde bu etkileşimin daha belirgin hâle geldiğini ortaya koymuştur.

Faiz oranları, enflasyon ve para politikası gibi makroekonomik faktörler finansal piyasalardaki volatilité yayılımını etkilemede önemli bir rol oynamaktadır. Bernanke & Kuttner (2005), para politikasındaki beklenmedik değişikliklerin hisse senedi piyasası oynaklığını; Bekaert vd. (2013), riskten kaçınma ve para politikası kararlarındaki değişikliklerin; Chen vd. (1986), enflasyon ve endüstriyel üretim büyüme oranlarının volatilité yayılmalarını önemli ölçüde etkilediğini öne sürmüşlerdir.

Finansal piyasalar arasında volatilité yayılımında piyasa entegrasyonu, likidite koşulları, makroekonomik şoklar ve yatırımcı davranışları önemli belirleyicilerdir. Baele (2005) daha yüksek finansal entegrasyonun daha güçlü oynaklık iletimine yol açabileceğini; Adrian & Shin (2010) düşük likiditenin volatilité yayılımını artırdığını; Bloom (2009) faiz oranları, enflasyon ve ekonomi politikalarındaki değişim, dalgalanma veya belirsizliklerin piyasa genelinde volatilité yayılımını desteklediğini; Barberis vd. (1998) ve Barberis & Thaler (2003) yatırımcı davranışının, özellikle de yatırımcıdaki sürü psikolojisinin, volatilité yayılımına katkı sağladığını belirlemişlerdir. Engle & Sokalska (2012) tarafından yapılan araştırmada, makroekonomik faktörlere ilişkin açıklamaların ve jeopolitik olayların volatilité yayılmalarını önemli ölçüde etkilediği belirlenmiştir. Finansal davranışların volatilité yayılımını ele alan bir diğer çalışmada ise boğa piyasalarının ayı piyasalarına kıyasla daha yüksek volatilité yayılımını desteklediği ileri sürülmüştür (Quyyum & Kemal,

2006). Volatilité yayılımı farklı piyasa veya varlık türlerinin yanı sıra farklı sektörler üzerinde de etkili olabilmektedir. Nitekim, Adrian & Shin (2010) oynaklığı ekonomik temellerle ilişkilendirmiş ve finans sektörünün volatilitéyi veya ekonomik şokları ekonominin diğer sektörlerine iletmede merkezi bir konuma sahip olduğunu bulmuşlardır.

Dünyada 1980'lerden itibaren etkili olmaya başlayan küreselleşme ve finansal liberalizasyonun yanı sıra Türkiye'de 24 Ocak 1980 kararları ve sonrasında ihracata dayalı dışa açık büyüme politikasının belirlenmesi, kur politikasının değiştirilerek dalgalı kur sisteminin benimsenmesi, sermaye akımları serbestleştirilerek, Türk Lirasına konvertibilite tanınması, sermaye piyasalarının gelişimini destekleyecek kurumların düzenlemelerin yapılması ve borsanın kurulması ve finans sektöründeki reformlar Türk finansal piyasalarının gelişimini, küresel ekonomik sisteme entegrasyonunu hızlandırmıştır. Bu durum, Türkiye'ye yönelik portföy yatırımlarını artırırken, Türkiye'de döviz, faiz ve hisse senedi gibi finansal piyasaların diğer gelişmiş ve gelişmekte olan ülke piyasalarından etkilenmesine de neden olmuş; volatilité yayılımı artmıştır. 2008-2009 yıllarında yaşanan küresel ekonomik ve finansal krizin Türk ekonomisinde büyümenin 2008 yılında yalnızca %0,8 oranında gerçekleşmesine, 2009 yılında ise %4,7'lik gerilemesine neden olması, finansal piyasalar arasındaki volatilité aktarımı ve bu volatilité aktarımının nasıl gerçekleştiğine yönelik çalışmaları artırmıştır.

Türkiye'de finansal piyasalar arasında volatilité aktarımının incelenmesine yönelik fazla sayıda çalışma bulunmamaktadır. Özdemir (2024) BIST-100 endeksi, TR 10 yıllık tahviller, USD-TL döviz kuru, altın vadeli işlemleri ve Brent petrolü arasındaki volatilité aktarımını Kantil Vektör Otoregresyon (QVAR) modeli ile incelemiş, normal dönemlerde hisse senedi, tahvil ve döviz piyasalarında düşük ve orta düzeyde volatilité aktarımının olduğunu, altın ve petrolün net risk alıcıları USD/TL döviz kurunun ise tek risk aktarıcısı olduğunu belirlerken, Gencer & Musoğlu'nun (2014) araştırmasında altın fiyatları ile borsa endeksi arasında iki yönlü, altından tahvil faizlerine yönelik tek yönlü bir ilişki bulunmuştur.

Alkan & Çiçek (2020), küresel piyasaların Türk finans piyasaları üzerindeki etkisini; Karabıyık (2020), Türkiye'deki emtia, tahvil, döviz kuru ve hisse senedi piyasaları arasındaki volatilité yayılımını; Kartal vd. (2024) para politikasının finansal varlıkların getirisi üzerindeki etkisini; Gök (2020), hisse senedi piyasası ile makroekonomik değişkenler arasındaki ilişkiyi; Kara vd. (2022), BİST 30 Futures piyasası ile spot piyasa arasındaki etkileşimi; Karakaya & Kutlu (2023), hisse senedi ve bono piyasaları arasındaki volatilité yayılımını; Ustaoglu (2022), kripto para birimleri ile hisse senedi getirileri arasındaki volatilité etkisini; Nazlıoğlu vd. (2015); Erdoğan vd. (2020); Yarovaya vd. (2021) ile Bossman vd. (2022) İslami ve konvansiyonel hisse senedi piyasalarında volatilité geçişkenliğini incelemiş ve finansal piyasalar arasında volatilité aktarımına ilişkin bulgular elde etmişlerdir.

Yapılan çalışmaların bulguları, volatilité yayılımının finansal piyasalarda yaygın bir olgu olduğunu göstermektedir. Literatür, küresel finansal piyasaların birbirine bağılılığını ve

yatırımcılar, politika yapıcılar ve düzenleyiciler için volatilité iletim mekanizmalarını anlamının önemini vurgulamaktadır.

3. Uygulama

3.1. Veri Seti

Bu çalışmada, Türkiye’de BIST 100 endeksi, dolar/TL kuru, gram altın fiyatları, TL gecelik referans faiz oranı, 5 yıllık tahvil faiz oranı ve 5 yıllık CDS primi arasındaki dinamik bağılantılılık, Antonakakis ve arkadaşları (2019a) tarafından önerilen Zamanla Değişen Parametrelî Vektör Otoregresyon (TVP-VAR) modeli aracılığıyla analiz edilmiştir. Türkiye’de finansal piyasalar arasındaki bu dinamik etkileşim, 02.01.2018-31.12.2024 dönemine ait günlük frekanslı veriler kullanılarak analiz edilmiştir. Çalışmada incelenen 02.01.2018-31.12.2024 dönemi, Türkiye’de 2018 Kur Krizi ile başlayan ve takip eden yıllarda TCMB’nin faiz politikalarında önemli değişimlerin yaşandığı, enflasyonla mücadele sürecinin ön plana çıktığı bir dönem olması nedeniyle seçilmiştir. Çalışmada kullanılan değişkenler ve bu değişkenlere ilişkin açıklayıcı bilgiler Tablo 1’de sunulmuştur.

Tablo: 1
Değişken Listesi ve Tanımlayıcı Bilgiler

Değişken	Tanım	Veri Kaynağı	Frekans	Dönem
XU100	BİST100 Endeksi	TCMB-EVDS	Günlük	02.01.2018-31.12.2024
USD/TL	Dolar TL Kuru	TCMB-EVDS	Günlük	02.01.2018-31.12.2024
GAU/TRY	Gram Altın Fiyatı	Bloomberg	Günlük	02.01.2018-31.12.2024
TLREF	TL Gecelik Referans Faiz Oranı	Borsa İstanbul	Günlük	02.01.2018-31.12.2024
TR5Y	Türkiye’nin 5 Yıllık Tahvil Faiz Oranı	Bloomberg	Günlük	02.01.2018-31.12.2024
CDS	Türkiye’nin 5 Yıllık CDS Primi	Bloomberg	Günlük	02.01.2018-31.12.2024

Tablo: 2
Volatilité Serilerine İlişkin Tanımlayıcı İstatistikler

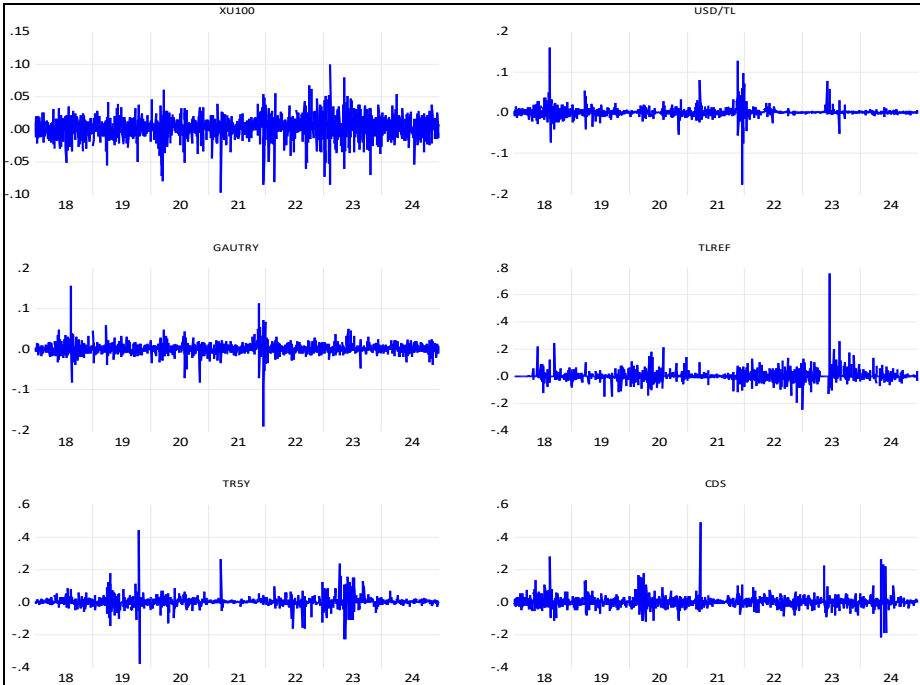
Panel A1: Tanımlayıcı İstatistikler						
	XU100	USD/TL	GAU/TRY	TLREF	TR5Y	CDS
Ortalama	0,001368	0,001337	0,001516	0,001440	0,000685	0,000858
Medyan	0,001811	0,000797	0,001173	0,000000	0,000000	0,000000
Maksimum	0,098801	0,159746	0,155323	0,757511	0,439726	0,491081
Minimum	-0,097934	-0,177202	-0,189679	-0,247563	-0,380114	-0,220922
Std. Sapma	0,016928	0,012439	0,014342	0,038410	0,033618	0,034634
Çarpıklık	-0,504229	0,443761	-0,726668	4,908257	0,529452	2,640837
Basıklık	7,174319	56,41945	34,45584	94,60210	38,50861	36,39809
Jarque-Bera	1349,261 (0,000)	208373,1 (0,000)	72385,49 (0,000)	619573,5 (0,000)	92124,75 (0,000)	83462,97 (0,000)
Panel A2: Otokorelasyon ve Değişen Varyans Testleri						
Q(20)	37,376 (0,000)	79,066 (0,000)	56,844 (0,000)	72,743 (0,000)	52,700 (0,000)	44,422 (0,000)
Q ² (20)	219,55 (0,000)	544,54 (0,000)	341,01 (0,000)	81,391 (0,000)	394,67 (0,000)	56,255 (0,000)
ARCH(20)	146,12 (0,000)	313,74 (0,000)	214,305 (0,000)	247,510 (0,000)	389,921 (0,000)	40,893 (0,000)
Panel A3: Birim Kök Testleri ve Durağanlık						
ADF	-40,797 (0,000)	-35,956 (0,000)	-38,011 (0,000)	-29,900 (0,000)	-42,628 (0,000)	-39,484 (0,000)
PP	-40,968 (0,000)	-35,778 (0,000)	-37,914 (0,000)	-45,226 (0,000)	-42,717 (0,000)	-39,439 (0,000)

Not: Parantez içindeki değerler p-değerlerini temsil etmektedir.

Çalışmada değişkenlere ait volatilite serileri $y_t = \ln(x_t) - \ln(x_{t-1})$ formülü kullanılarak hesaplanmıştır. Volatilite serilerine ilişkin tanımlayıcı istatistikler Tablo 2'de sunulmuştur.

Tablo 1'de raporlanan tanımlayıcı istatistikler incelendiğinde, serilerin standart sapma değerleri açısından en yüksek değişkenliğe ve dolayısıyla en yüksek riske sahip serilerin sırasıyla TLREF, CDS ve TR5Y olduğu görülmektedir. Öte yandan, en düşük standart sapma değerlerine sahip seriler sırasıyla USD/TL, GAU/TRY ve XU100 olarak belirlenmiştir. Çarpıklık değerleri incelendiğinde, XU100 ve GAU/TRY değişkenlerinin negatif, diğer değişkenlerin ise pozitif değerlere sahip olduğu görülmektedir. Ayrıca, değişkenlerin normal dağılıma uymadığı Jarque-Bera test istatistikleri ile de doğrulanmaktadır. Serilerin durağanlık düzeylerini belirlemek amacıyla Dickey & Fuller (ADF, 1981) ile Phillips & Perron (PP, 1988) birim kök testleri uygulanmış olup, elde edilen sonuçlar serilerin durağan olduğunu ve birim kök içermediğini göstermektedir. Ljung-Box Q ve Q^2 test istatistikleri, analiz edilen volatilite serilerinin kendi geçmiş değerleriyle anlamlı bir ilişki taşıdığını ve dolayısıyla otokorelasyon içerdiğini göstermektedir. ARCH test istatistikleri, serilerde heteroskedastisitenin varlığını göstermektedir.

Şekil: 1
Volatilite Serilerin Zaman Yolu Grafikleri



Şekil 1'de, hesaplanan volatilité serilerine ilişkin getiri serilerinin grafiksel gösterimi yer almaktadır. Volatilité serileri incelendiğinde, Türkiye finansal piyasalarının incelenen dönemde (2018-2024) iç siyasi ve ekonomik gelişmeler ile küresel krizlerin etkisiyle önemli şoklara maruz kaldığı ortaya çıkmaktadır.

Bu dönemde, dünyada olduğu gibi Türkiye'de de ekonomiyi ve finansal piyasaları en fazla etkileyen unsur COVID-19 pandemisi olmuştur. Hükümetler, sağlıklı bir nüfusa sahip olmak ile sağlıklı bir ekonomiye sahip olmak arasında seçim yapmak gibi zor bir ikileme karşı karşıya kalmışlar; mümkün olduğu kadar çok yaşamı koruma önceliği, üretim tesislerinin üretim ve hizmetlerinin kısıtlanması, ekonomiyle ilgili olarak kaçınılmaz olarak resesyona ve arz problemlerine neden olmuştur.

Türkiye'nin para politikasında önemli değişiklikler yaşanmıştır. Merkez Bankası'nın 2021 yılında faiz oranlarını %19'dan %14'e düşürmesi ve uygulanan heterodoks politikalar bu süreçte Türk lirasının %44 değer kaybetmesine yol açmıştır. Diğer yandan, 2023 yılı ilk çeyreğinden itibaren Ortodoks politikalara geri dönülmesiyle birlikte faiz oranları hızla artırılmış; merkez bankasının politika faiz oranı Mart 2024'e kadar %50'ye ulaşmıştır. Para politikasındaki bu değişiklikler enflasyonu ve parasal istikrarı olumsuz etkilediğinden, bu dönemde finansal piyasalarda önemli dalgalanmalar yaşanmıştır.

Bu dönemde, özellikle Amerika Birleşik Devletleri ile yaşanan jeopolitik gerginlikler ve özel kesimin kısa vadeli döviz borcunun yüksek olması, Türkiye'nin 2018 yılında Türk lirasının keskin bir şekilde devalüe edilmesine, artan enflasyon ve artan borçlanma maliyetleri ile karakterize edilen ciddi bir döviz kuru kriziyle karşı karşıya kalmasına neden olmuştur. Merkez Bankası verilerine göre 1.1.2018 tarihinde USD/TL kuru 3,78 iken, 20.12.2021 tarihinde rekor bir yükselişe 18,36 lira seviyesine ulaşmıştır. Merkez Bankası'nın piyasaya müdahalelerinin yeterince etkili olmaması üzerine vadeli mevduat hesaplarında tutulan Türk Lirası'nın vade sonunda dolar, euro veya sterlin karşısında faiz oranından daha fazla artması durumunda aradaki farkın ödenmesini gerektiren ve "kur korumalı mevduat sistemi" adıyla bilinen uygulama başlatılmıştır. Kur Korumalı Mevduat uygulamasıyla USD/TL kuru önce 11,86 lira seviyesine gerilemiş; Mayıs 2022'de 16, 2024'ün ilk aylarında 30, 2024 yıl sonunda ise 35 lirayı aşmıştır.

Bu dönemde küresel ekonomik büyümedeki, faiz oranlarındaki ve enflasyon oranlarındaki dalgalanmalar, dünyanın çeşitli bölgelerindeki gerginlikler ve politik belirsizlikler, yatırımcıların güvenli liman olarak değerlendirdiği altına olan talebini etkilemiştir. Türkiye'de ise altın fiyatları hem küresel altın fiyatları hem de Türk lirasının ABD dolarına karşı döviz kuru değişiminden etkilendiğinden, Türk lirasında yaşanan değer kaybı yerel altın fiyatlarında önemli dalgalanmalara ve yükselişlere neden olmuştur.

2014-2018 döneminde Türkiye'nin CDS primleri de yine küresel para politikaları, iç ekonomik gelişmeler, siyasi istikrar ve döviz kuru oynaklığına bağlı olarak dalgalanmalar göstermiştir.

Bu dönemde COVID-19 salgını, Rusya'nın Ukrayna'ya, İsrail'in Gazze'yi işgali gibi çeşitli ekonomik ve jeopolitik faktörlerin etkisiyle hem küresel olarak hem de Türkiye'de önemli dalgalanmalar yaşamıştır.

Yukarıda belirtilen ve araştırma kapsamına alınan dönemde yaşanan siyasi ve jeopolitik gelişmeler, ekonomi politikalarındaki değişiklikler, enflasyon ve döviz kurlarındaki istikrarsızlıklar, finansal piyasalarda ve finansal varlık fiyatlarında oynaklığın artmasına ve bulaşmasına neden olmuştur.

Öncelikle, BİST100 (XU100) endeksine ait volatilité serisi incelendiğinde, özellikle 2020 COVID-19 krizi ve 2023 seçim sürecinde belirgin bir volatilité artışı olduğu görülmektedir. Araştırma kapsamında 2018-2024 dönemi boyunca endeks getirilerinde oluşan ani sıçramalar ve dalgalanmalar, finansal piyasaların makroekonomik gelişmelere oldukça duyarlı olduğunu göstermektedir.

USD/TL kuru için hesaplanan volatilité serisi, 2018, 2021 ve 2023 yıllarında yaşanan kur atakları, 2020 COVID-19 süreci ve 2021'de uygulamaya konulan Kur Korumalı Mevduat (KKM) sistemi sonrası dalgalanmaların belirgin şekilde arttığını göstermektedir. USD/TRY oynaklığı 2023 seçim süreci sonrasında da artmakla birlikte, 2023 ortalarından itibaren nispeten azaldığı görülmektedir. Gram altın (GAUTRY) fiyatlarındaki bulgu özellikle 2018 ve 2020 yıllarında belirgin oynaklık artışları göstermektedir. Altın fiyatlarındaki volatilitenin döviz kuru dalgalanmalarıyla eşzamanlı olarak hareket ettiği görülmektedir. TL gecelik referans faiz oranı (TLREF) serisi, özellikle 2018 kur krizinin ardından belirgin bir volatilité artışı göstermiştir. 2020 COVID-19 sürecinde repo faizlerinde artan oynaklık dikkat çekmektedir. 2021 KKM sonrası repo faizlerinde volatilitenin görece azaldığı, ancak 2023 seçim sürecinin ardından faiz politikalarındaki değişimle birlikte dalgalanmaların yeniden arttığı gözlemlenmiştir. Türkiye'nin 5 yıllık tahvil faiz oranı (TRSY) serisinde de benzer bir dinamik gözlenmektedir. Son olarak, CDS primi serisinde, özellikle 2018, 2020 ve 2021 yıllarında keskin oynaklık artışları gözlenmiştir. Türkiye'nin risk primini yansıtan CDS seviyeleri, COVID-19 sürecinde ve 2021 KKM uygulaması sonrasında yüksek dalgalanmalar göstermiştir. 2023 seçim süreci ve sonrasında CDS seviyelerinde belirli dönemlerde dalgalanmalar gözlemlenmiş; ancak genel olarak risk priminin düşüş eğilimi gösterdiği söylenebilir.

Yukarıdaki bulgular ve volatilité serileri incelendiğinde, 2018 yılında başlayan kur şokundan borsa ve diğer varlıklara doğru bir yayılma veya bulaşma etkisi olduğu görülmektedir. Döviz piyasasındaki ani fiyat dalgalanmaları, diğer piyasalarda (hisse senedi fiyatları, TRYREF faiz oranları, tahvil ve altın fiyatları ile CDS primleri) belirli bir zaman gecikmesi olsa da, bu dalgalanmaları tetiklemektedir. Volatilité yayılımının etkisinin tüm piyasalarda oldukça yoğun, sert ve eşzamanlı yaşandığı durumlar ise ekonomik ve finansal kriz dönemleri olarak açıklanmaktadır.

3.2. Ekonometrik Metodoloji ve Ampirik Bulgular

Bu çalışmada, değişkenler arasındaki karşılıklı etkileşimi belirlemek amacıyla Antonakakis vd. (2019a) tarafından literatüre kazandırılan Zamanla Değişen Parametrelî Vektör Otoregresyon (TVP-VAR) yöntemi kullanılmıştır. Antonakakis vd. (2020b) tarafından geliştirilen TVP-VAR yöntemi, zaman içinde değişen dinamikleri analiz etmek için kullanılan bir yöntemdir. Geleneksel VAR modelleri sabit parametreler varsayar; ancak TVP-VAR modeli, zamanla değişen parametreleri kullanarak daha esnek bir yapı sunar. Önerilen TVP-VAR yönteminde, Koop & Korobilis (2014) tarafından geliştirilen Zamanla Değişen Parametrelî Vektör Otoregresyon (TVP-VAR) metodolojisi, Diebold & Yılmaz'ın (2014) bağlantılılık yaklaşımıyla birleştirilmektedir. Bu yöntem, Kalman Filtresi tahmini aracılığıyla varyansların zaman içinde dinamik olarak değişmesine olanak tanımakta ve böylece değişkenler arasındaki ilişkilerin zamana bağlı olarak nasıl evrildiğini analiz etmeye imkân vermektedir (Antonakakis et al., 2019b: 2).

TVP-VAR(p) modeli aşağıdaki gibi tanımlanır (Antonakakis et al., 2020a: 4):

$$y_t = A_t z_{t-1} \varepsilon_t \quad \varepsilon_t = |\Omega_{t-1} \sim N(0, \Sigma_t) \quad (1)$$

$$vec(A_t) = vec(A_{t-1}) + \zeta_t \quad \zeta_t = |\Omega_{t-1} \sim N(0, \Xi_t) \quad (2)$$

$$z_{t-1} = \begin{pmatrix} y_{t-1} \\ y_{t-2} \\ \vdots \\ \cdot \\ \cdot \\ y_{t-p} \end{pmatrix} \quad A_t' = \begin{pmatrix} A_{1t} \\ A_{2t} \\ \dots \\ A_{pt} \end{pmatrix}$$

Eşitlik (1) ve (2)'de, Ω_{t-1} t-1 zamanına kadar mevcut olan tüm bilgiyi temsil etmektedir. y_t ve z_{t-1} , sırasıyla $m \times 1$ ve $mp \times 1$ boyutlarında vektörlerdir. A_t ve A_{it} , sırasıyla $m \times mp$ ve $m \times m$ boyutlarında matrislerdir. e_t , $m \times 1$ boyutunda bir vektör iken, ζ_t , $m^2 p \times 1$ boyutunda bir vektördür. Zamanla değişen varyans-kovaryans matrisleri olan Σ_t ve Ξ_t , sırasıyla $m \times m$ ve $m^2 p \times m^2 p$ boyutlarına sahiptir. Ayrıca, $vec(A_t)$, A_t matrisinin vektörleştirilmiş hali olup, $m^2 p \times 1$ boyutunda bir vektördür.

Zamanla değişen parametreler tahmin edildikten sonra, TVP-VAR modelinin, Wold temsili $y_t = \sum_{i=1}^p A_{it} y_{t-i} + \varepsilon_t = \sum_{j=1}^{\infty} X_{jt} \varepsilon_{t-j} + \varepsilon_t$ şeklindedir. Zamanla değişen katsayılar ve zamanla değişen varyans-kovaryans matrisleri, Diebold & Yılmaz'ın (2014) genelleştirilmiş bağlantılılık prosedürünü tahmin etmek için kullanılmaktadır. Bahsedilen prosedür, Koop, Pesaran & Potter (1996) ile Pesaran & Shin (1998) tarafından geliştirilen genelleştirilmiş etki-tepki fonksiyonları (GIRF) ve genelleştirilmiş tahmin hatası varyans ayrıştırımlarına (GFEVD) dayanmaktadır. GIRF ve GFEVD hesaplamalarını gerçekleştirebilmek için Wold temsili teoremi temel alınarak TVP-VAR modeli Vektör Hareketli Ortalama (VMA) gösterimine dönüştürülmektedir. VMA modeline ait zamanla değişen katsayılar ise, yinelemeli yerine koyma yöntemiyle elde edilebilir (Antonakakis et al., 2020a: 5):

$$y_t = J'(M_t(z_{t-2} + \eta_{t-1}) + \eta_t) \quad (3)$$

$$= J'(M_t(M_t(z_{t-3} + \eta_{t-2}) + \eta_{t-1}) + \eta_t) \quad (4)$$

$$\vdots \quad (5)$$

$$= J'(M_t^{k-1}z_{t-k-1} + \sum_{j=0}^k M_t^j \eta_{t-j}) \quad (6)$$

$$M_t = \begin{pmatrix} A_t & \\ I_{m(p-1)} & 0_{m(p-1) \times m} \end{pmatrix} \eta_t = \begin{pmatrix} \epsilon_t \\ 0 \\ \vdots \\ 0 \end{pmatrix} = J \epsilon_t J = \begin{pmatrix} I \\ 0 \\ \vdots \\ 0 \end{pmatrix} \quad (7)$$

Burada; M_t , $mp \times mp$ boyutundaki matrisi, η_t , $mp \times I$ boyutundaki vektörü ve J ise $mp \times m$ boyutundaki seçim matrisini göstermektedir. k sonsuza yaklaştığında limit şu şekilde elde edilir:

$$y_t = \lim_{k \rightarrow \infty} J'(M_t^{k-1}z_{t-k-1} + \sum_{j=0}^k M_t^j \eta_{t-j}) = \sum_{j=0}^{\infty} J' M_t^j \eta_{t-j}, \quad (8)$$

$$y_t = \sum_{j=0}^{\infty} J' M_t^j J \epsilon_{t-j} \quad (9)$$

Burada, $B_{j,t}$ şu şekilde tanımlanabilir:

$$B_{j,t} = J' M_t^j J, j = 0, 1, \dots \quad (10)$$

Genelleştirilmiş Etki-Tepki Fonksiyonları (GIRF, $\Psi_{ij,t}(H)$), i değişkeni üzerinde meydana gelen bir şok sonrasında tüm değişkenlerin (J) tepkilerini göstermektedir. Yapısal bir model bulunmadığından, bu tepkiler, değişken i şoka maruz kaldığında ve maruz kalmadığında yapılan H adım ilerisine yönelik tahminler arasındaki fark üzerinden hesaplanmıştır. GIRF aşağıdaki gibi hesaplanır (Antonakakis et al., 2020a: 6-7):

$$GIRF_t(H, \delta_{j,t}, \Omega_{t-1}) = E(y_t + H | e_j = \delta_{j,t}, \Omega_{t-1}) - E(y_{t+j} | \Omega_{t-1}) \quad (11)$$

$$\Psi_{j,t}(H) = \frac{B_{H,t} \sum_t e_j}{\sqrt{\sum_{jj,t}}} \frac{\delta_{j,t}}{\sqrt{\sum_{jj,t}}} \delta_{j,t} = \sqrt{\sum_{jj,t}} \quad (12)$$

$$\Psi_{j,t}(H) = \sum_{jj,t}^{-1/2} B_{H,t} \sum_t e_j \quad (13)$$

Burada; e_j , $m \times I$ boyutundaki seçim vektörünü temsil ederken, $\Psi_{j,t}(H)$ ise değişkenlerin H adım sonraki tepkisini göstermektedir.

Benzer şekilde Genelleştirilmiş Varyans Ayırıştırması (GFEVD) hesaplaması aşağıdaki gibidir:

$$\hat{\phi}_{ij,t}(H) = \frac{\sum_{t=1}^{H-1} \Psi_{ij,t}^2}{\sum_{j=1}^m \sum_{t=1}^{H-1} \Psi_{ij,t}^2} \quad (14)$$

Burada $\sum_{j=1}^m \hat{\phi}_{ij,t}(H) = 1$ ve $\sum_{i,j=1}^m \hat{\phi}_{ij,t}(H) = m$ eşitlikleri sağlanmaktadır. Eşitlik (14)'te payda, tüm şokların kümülatif etkisini temsil ederken, pay ise değişken i üzerindeki bir şokun kümülatif etkisini göstermektedir.

Toplam Bağlantılılık Endeksi (TCI), Genelleştirilmiş Varyans Ayırıştırma (GFEVD) yaklaşımı temel alınarak aşağıdaki şekilde hesaplanmaktadır:

$$C_t(H) = \frac{\sum_{i,j=1,i \neq j}^m \hat{\phi}_{ij,t}(H)}{\sum_{i,j=1}^m \hat{\phi}_{ij,t}(H)} * 100 = \frac{\sum_{i,j=1,i \neq j}^m \hat{\phi}_{ij,t}(H)}{m} * 100 \quad (15)$$

Bu bağlantılılık yaklaşımı, bir değişkende ortaya çıkan bir şokun diğer değişkenler üzerinde nasıl bir etki yarattığını analiz etmeyi amaçlamaktadır. İlk aşamada, toplam yönlü bağlantılılık, yani i değişkeninden kaynaklanan bir şokun tüm j değişkenlerine olan yayılma etkisini ifade eden *başka değişkenlere şok yayma etkisi*, aşağıdaki şekilde hesaplanmaktadır:

$$C_{i \rightarrow j,t}(H) = \frac{\sum_{j=1,i \neq j}^m \tilde{\phi}_{ji,t}(H)}{\sum_{j=1}^m \tilde{\phi}_{ji,t}(H)} * 100 \quad (16)$$

Başkalarından alınan şoklar olarak adlandırılan, i değişkeninin j değişkenlerinden aldığı yönlü bağlantılılık aşağıdaki şekilde hesaplanmaktadır:

$$C_{i \leftarrow j,t}(H) = \frac{\sum_{j=1,i \neq j}^m \tilde{\phi}_{ji,t}(H)}{\sum_{i=1}^m \tilde{\phi}_{ji,t}(H)} * 100 \quad (17)$$

Son olarak, net toplam yönlü bağlantılılığı elde etmek amacıyla Eşitlik (16), Eşitlik (17)'den çıkarılmıştır. Bu değer, i değişkeninin analiz edilen ağ üzerindeki etkisini göstermekte olup, aşağıdaki şekilde hesaplanmaktadır (Antonakakis et al., 2020b: 5):

$$C_{i,t} = C_{i \rightarrow j,t}(H) - C_{i \leftarrow j,t}(H) \quad (18)$$

Eğer $C_{i,t} > 0$ ise, değişken i ağına ana belirleyicilerinden biridir. $C_{i,t} < 0$ ise, değişken i , şokları daha çok alan bir değişkendir.

Son olarak, net toplam yönlü bağlantılılık daha ayrıntılı bir şekilde ayrıştırılarak, çift yönlü ilişkilerin daha derinlemesine incelenmesi amacıyla *net çift yönlü bağlantılılık* hesaplanmıştır:

$$NPDC_{ij}(H) = (\hat{\phi}_{jit}(H) - \hat{\phi}_{ijt}(H)) * 100 \quad (19)$$

Hesaplanan NPDC değeri pozitif ise, i değişkeni j değişkeni üzerinde daha fazla etkiye sahiptir. Buna karşın, NPDC değeri negatif ise, i değişkeni j değişkeninden daha fazla etkilenmektedir (Antonakakis et al., 2020a: 7).

Çalışmada, değişkenler arasındaki dinamik ilişkilerin analizinde Antonakakis vd. (2019a) tarafından ortaya konulan TVP-VAR yöntemi kullanılmıştır. TVP-VAR modeline dayalı olarak, değişkenler arası volatilitenin hangi oranının kendi içsel dinamiklerinden,

hangi kısmının ise sistemdeki diğer değişkenlerle olan etkileşimlerden kaynaklandığını yansıtan Ortalama Dinamik Bağlantılılık sonuçları Tablo 3'te sunulmuştur.

Tablo: 3
Değişkenlere Ait Ortalama Dinamik Bağlantılılık Tablosu

	XU100	USD/TL	GAU/TRY	TLREF	TR5Y	CDS	Diğerlerinden
XU100	72,14	5,85	2,61	2,31	5,23	11,85	27,86
USD/TL	4,70	58,91	23,19	1,61	4,54	7,04	41,09
GAU/TRY	1,99	24,52	63,79	2,25	2,90	4,55	36,21
TLREF	0,99	2,30	2,06	93,26	0,82	0,56	6,74
TR5Y	5,38	5,98	3,27	1,16	78,73	5,48	21,27
CDS	10,59	10,01	6,22	1,05	5,90	66,23	33,77
Diğerlerine	23,66	48,65	37,35	8,39	19,41	29,48	166,94
Kendi Etkisi Dahil	95,81	107,57	101,14	101,64	98,14	95,71	TCI
Net	-4,19	7,57	1,14	1,64	-1,86	-4,29	33,39

Tablo 3'te yer alan ortalama dinamik bağlantılılık sonuçlarına göre, XU100 endeksinin varyansındaki değişimlerin %72,14'lük kısmı kendisinden kaynaklanırken, %27,86'lık kısmı diğer değişkenlerden kaynaklanmaktadır. XU100 endeksinde meydana gelen değişimlerin %5,85'lik kısmı dolar kuru (USD/TL), %2,61'lik kısmı gram altın fiyatları (GAU/TRY), %2,31'lik kısmı TL gecelik referans faiz oranı (TLREF), %5,23'lük kısmı 5 yıllık tahvil faiz oranı (TR5Y) ve %11,85'i CDS primleri tarafından açıklanmaktadır. USD/TL kurunda meydana gelen varyans değişimlerinin %58,91'i kendi iç dinamiklerinden kaynaklanırken, kalan %41,09'luk kısım diğer değişkenler tarafından açıklanmaktadır. USD/TL'deki değişimlerin %4,70'i XU100 endeksi, %23,19'u gram altın fiyatları (GAU/TRY), %1,61'i TL gecelik referans faiz oranı (TLREF), %4,54'ü 5 yıllık tahvil faiz oranı (TR5Y) ve %7,04'ü CDS primleri ile ilişkilendirilmektedir. Benzer şekilde, gram altın fiyatlarında (GAU/TRY) gözlenen varyans değişimlerinin %63,79'u kendi kaynaklı olup, %36,21'i diğer değişkenlerden kaynaklanmaktadır. GAU/TRY'deki değişimlerin %1,99'u XU100, %24,52'si USD/TL, %2,25'i TLREF, %2,90'ı TR5Y ve %4,55'i CDS primleri tarafından açıklanmaktadır. TL gecelik referans faiz oranında (TLREF) meydana gelen değişimlerin büyük bir kısmı, %93,26 oranında, kendi iç dinamiklerinden kaynaklanırken, %6,74'ü diğer değişkenlerin etkisiyle oluşmaktadır. TLREF değişimlerinin %0,99'u XU100, %2,30'u USD/TL, %2,06'sı GAU/TRY, %0,82'si TR5Y ve %0,56'sı CDS primleri tarafından açıklanmaktadır. 5 yıllık tahvil faiz oranında (TR5Y) meydana gelen varyans değişimlerinin %78,73'ü kendi iç dinamiklerinden kaynaklanırken, %21,27'si diğer değişkenlerin etkisiyle oluşmaktadır. TR5Y'deki değişimlerin %5,38'i XU100, %5,98'i USD/TL, %3,27'si GAU/TRY, %1,16'sı TLREF ve %5,48'i CDS primleri tarafından açıklanmaktadır. Son olarak, CDS primlerinde gözlenen varyans değişimlerinin %66,23'ü kendi iç dinamiklerinden kaynaklanmakta, %33,77'si ise diğer değişkenlerin etkisiyle oluşmaktadır. CDS değişimlerinin %10,59'u XU100, %10,01'i USD/TL, %6,22'si GAU/TRY, %1,05'i TLREF ve %5,90'ı TR5Y tarafından açıklanmaktadır.

Diğer değişkenlerden en fazla etkilenen değişkenler sırasıyla %41,09 ile USD/TL kuru, %36,21 ile gram altın fiyatı (GAU/TRY), %33,77 ile CDS primleri ve %27,86 ile XU100 endeksi olmuştur. Öte yandan, diğer değişkenlerden en az etkilenen değişkenler

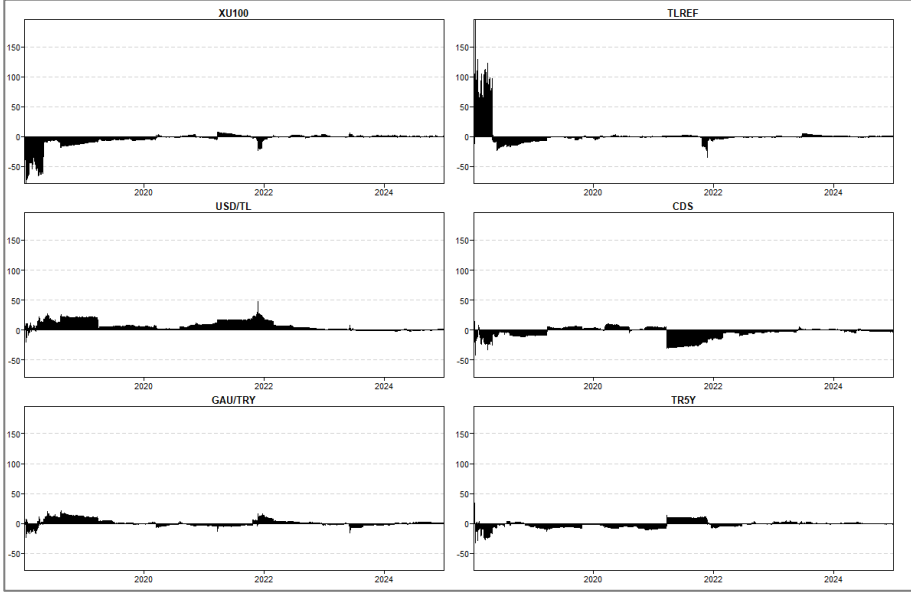
%21,27 ile 5 yıllık tahvil faiz oranı (TR5Y) ve %6,74 ile TL gecelik referans faiz oranı (TLREF) olarak belirlenmiştir. Diğer değişkenler üzerinde en fazla etkiye sahip olan değişkenler sırasıyla %48,65 ile USD/TL kuru, %37,35 ile gram altın fiyatları (GAU/TRY), %29,48 ile CDS primleri, %23,66 ile XU100 endeksi ve %19,41 ile 5 yıllık tahvil faiz oranı (TR5Y) olmuştur. Öte yandan, diğer değişkenler üzerinde en az etkiye sahip olan değişken %8,39 ile TL gecelik referans faiz oranı (TLREF) olarak belirlenmiştir. Volatilité yayılımı açısından değerlendirildiğinde, %7,57 ile USD/TL kurunun, %1,64 ile TL gecelik referans faiz oranının (TLREF) ve %1,14 ile gram altın fiyatlarının (GAU/TRY) volatilitéyi yaydığı; buna karşılık, %4,29 ile CDS primlerinin, %4,19 ile XU100 endeksinin ve %1,86 ile 5 yıllık tahvil faiz oranının (TR5Y) volatilitéyi aldığı görülmektedir. Analizde kullanılan değişkenler arasındaki toplam dinamik bağılantılılık seviyesi %33,92 olarak hesaplanmıştır. Değişkenler arasındaki dinamik bağılantılılık ilişkisi Şekil 2'de sunulmaktadır.

Şekil: 2
Değişkenlere Ait Dinamik Toplam Bağılantılılık Grafiği



Şekil 2'de paylaşılan dinamik toplam bağılantılılık grafiği, değişkenler arasındaki toplam yönlü bağılantılılığın zaman içindeki değişimini göstermektedir. 2018-2020 döneminde bağılantılılık yüksek seviyelerde seyretniş, ancak 2020'ye doğru düşüş eğilimine girmiştir. 2018'de yaşanan kur krizi ve 2020'de COVID-19 pandemisinin patlak vermesiyle birlikte bağılantılılık seviyesinde belirgin artışlar gözlemlenmiştir. 2021 yılında ise Kur Korumalı Mevduat (KKM) uygulamasının hayata geçirilmesi ve faiz politikalarında yaşanan değişiklikler bağılantılılık düzeylerinde geçici nitelikte dalgalanmalara yol açmıştır. 2023 seçim sürecinde kısa vadeli bir artış görülmekle birlikte, takip eden dönemde bağılantılılık belirgin bir düşüş eğilimi göstermiştir. Çalışmada, değişkenler arasındaki volatilité yayılım dinamiklerini daha açık bir şekilde ortaya koymak amacıyla, Şekil 3'te Net Toplam Yönsel Bağılantılılık grafiği sunulmuştur.

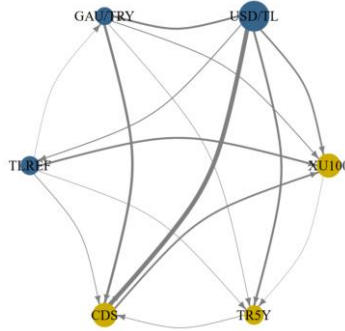
Şekil: 3
Değişkenlerin Net Toplam Yönel Bağlantılılık Grafiği



Net Toplam Yönel Bağlantılılık grafiği incelendiğinde, yatay eksen üzerindeki alanın ilgili piyasanın net şok yayıcısı olarak konumlandığı dönemleri; buna karşılık eksenin alt kısmının ise piyasanın dışsal şoklara maruz kaldığı dönemleri yansıttığı görülmektedir. Şekil 3'te raporlanan değişkenlere ait grafikler incelendiğinde, XU100 endeksinin ilk dönemlerde net şok alıcı konumunda olduğu, ancak ilerleyen yıllarda zaman zaman şok yayıcı konumuna geçtiği gözlemlenmektedir. TL gecelik referans faiz oranı (TLREF), özellikle 2018 kur krizi sırasında şok yayıcı bir rol üstlenirken, takip eden yıllarda genel olarak nötr ya da şok alıcı bir yapıya bürünmüştür. USD/TL kuru, analiz döneminin başlarında net şok yayıcı konumunda bulunurken zamanla daha dengeli bir yapıya geçmiş; ancak belirli dönemlerde tekrar şok yayıcı rolünü üstlenmiştir. CDS primi, analiz edilen dönemin başlarında şok alıcı olarak hareket etmiş, ancak özellikle 2020 sonrası belirli dönemlerde şok yayıcı konumuna geçmiştir. Gram altın fiyatları (GAU/TRY), ilk dönemlerde net bir şok alıcı rolü üstlenirken, ilerleyen süreçte şok yayıcı konumuna geçtiği gözlemlenmektedir. Türkiye'nin 5 yıllık tahvil faiz oranı (TR5Y) ise belirli dönemlerde şok alıcı ve yayıcı roller arasında dalgalanarak piyasa koşullarına bağlı olarak değişkenlik göstermiştir.

Şekil 4'te, değişkenler arasındaki volatilité yayılımının yönü ve şiddetini daha net bir şekilde gösteren volatilité yayılım grafiği sunulmuştur.

Şekil: 4
Değişkenlere Ait Volatilite Yayılım Grafiği



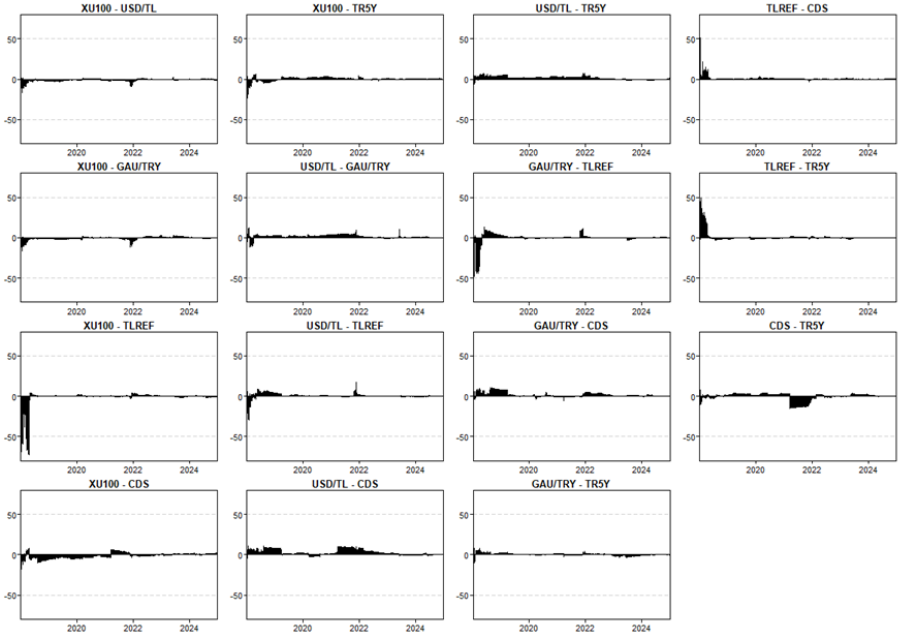
Şekil 4’te görselleştirilen ağ yapısında yer alan gri renkli oklar, değişkenler arasındaki volatilité yayılımının hem yönünü hem de şiddetini temsil etmektedir. Okların kalınlığı, yüksek düzeyde bir yayılım ilişkisini; inceliği ise görece olarak zayıf etkileşimleri göstermektedir. Ağ yapısı üzerinde sarı renk ile gösterilen değişkenler, volatilitéyi alan (alıcı konumundaki) değişkenlerdir; mavi renk ile gösterilenler ise volatilitenin kaynağı olan (yayımcı konumundaki) değişkenlerdir. Dairelerin boyutu ise her bir değişkenin sistem içindeki yayılım gücünü (yayımcı ya da alıcı konumundaki etkisini) yansıtmaktadır.

Volatilite yayılım grafiğine göre, USD/TL kuru sistemindeki en güçlü şok yayıcısı olarak öne çıkmakta ve özellikle CDS primi, BIST 100 endeksi (XU100) ve 5 yıllık devlet tahvili faiz oranı (TR5Y) üzerinde belirgin düzeyde oynaklık yaratmaktadır. USD/TL’den bu değişkenlere yönelen kalın oklar, döviz piyasasındaki şokların doğrudan sermaye piyasalarına ve ülke riskine yansıdığını göstermektedir. Bu durum, Türkiye’de döviz kurunun sistemik oynaklık açısından merkezi bir rol üstlendiğini ve makro-finance kırılma noktalarının öncü göstergesi olabileceğini göstermektedir. Öte yandan, CDS primi ve XU100 endeksi, en yüksek düzeyde şok alan değişkenler arasında yer almakta; bu da söz konusu piyasaların dışsal şoklara karşı daha duyarlı olduğunu göstermektedir. Ayrıca, sistemin diğer bileşenleri olan TLREF ve gram altın fiyatları (GAU/TRY) da önceki yapılarla kıyaslandığında daha yoğun etkileşim göstermekte ve volatilité aktarım ağı içinde daha merkezi bir konuma kaymaktadır. Bu durum, finansal sistemindeki oynaklık yapısının zaman içinde daha karşılıklı bağımlı ve yoğun bir hâle geldiğini ortaya koymaktadır.

Çalışmada, değişkenler arasındaki volatilité yayılımının yönü incelendikten sonra, zamanla değişen net ikili yönlü bağlantısallık düzeyleri değerlendirilmiştir. Bu analiz, değişken çiftleri arasındaki şok iletili ve alıcı konumların dönemsel olarak nasıl değiştiğini ortaya koymaktadır. Şekil 5’te değişkenler arasındaki çift yönlü bağlantısallık sonuçları verilmiştir. Şekil 5’in sol üst köşesinde yer alan XU100-USD/TL başlıklı ilk panelde, bu iki değişken arasında zaman içerisinde hangisinin net şok alıcı, hangisinin net şok yayıcı konumunda olduğu gözlemlenebilmektedir. XU100 ilk sırada yer almakta ve grafik üzerindeki

değerler sıfırın altında (siyah gölgeli alan) yer almaktadır. Analiz bulguları, özellikle USD/TL kurunun sistemde baskın bir şok yayıcı olarak öne çıktığını ve birçok değişkenle olan ikili ilişkilerinde ağırlıklı olarak pozitif net bağlantısallık sergilediğini göstermektedir. Bu durum, döviz kurundaki dalgalanmaların finansal sistem genelinde belirleyici bir oynaklık kaynağı olduğunu göstermektedir. Buna karşılık, XU100 endeksi ve CDS primi birçok ikili ilişkide net şok alıcı konumunda yer almakta; bu durum, söz konusu değişkenlerin dışsal şoklara karşı daha duyarlı olduğunu göstermektedir. Özellikle XU100 endeksinin hem USD/TL hem de CDS ile olan ilişkilerinde istikrarlı şekilde negatif bağlantısallık sergilemesi, endeksin sistemik şoklardan etkilenen bir yapıya sahip olduğu şeklinde yorumlanabilir. TLREF, TR5Y ve GAU/TRY gibi diğer değişkenler ise bazı ilişkilerde şok yayıcı, bazı dönemlerde ise şok alıcı konumunda yer almakta; bu durum, finansal sistemin zamanla değişen karşılıklı bağımlılık yapısına işaret etmektedir.

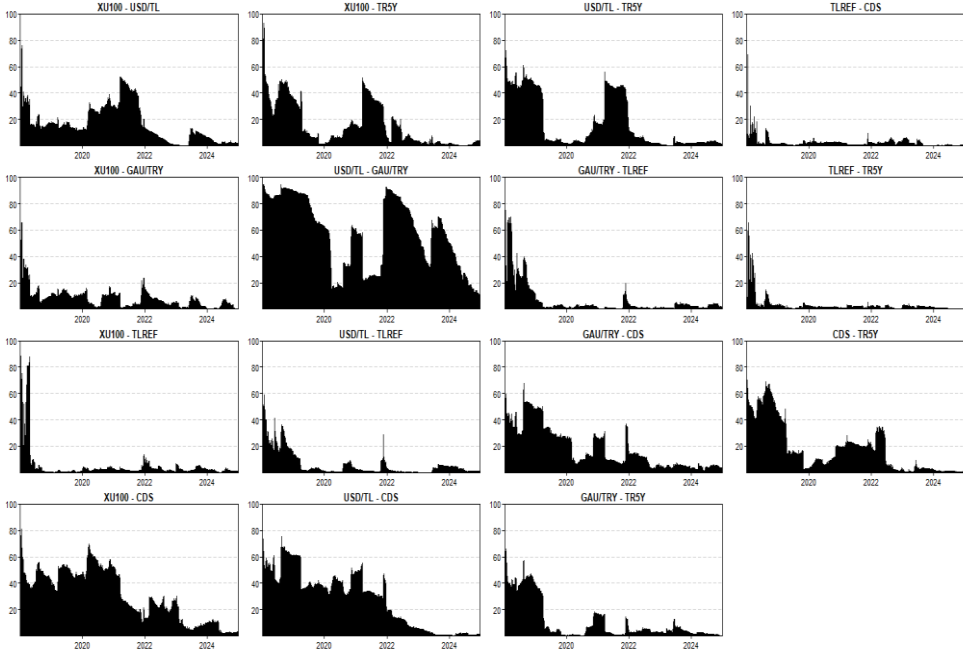
Şekil: 5
Değişkenlere Ait Net Çift Yönlü Bağlantısallık Grafiği



Çalışmada, zamanla değişen net ikili yönlü bağlantısallık düzeyleri incelendikten sonra değişkenler arasındaki zamanla oluşan karşılıklı (çift yönlü) bağlantısallık düzeyleri de incelenmiştir. Bu analiz, iki değişken arasındaki yönlü etkilerden bağımsız olarak, karşılıklı volatilité eşgüdümünün derecesini değerlendirmeyi amaçlamaktadır. Çalışmada hangi değişken çiftlerinin daha yoğun karşılıklı etkileşim sergilediği ve bu ilişkilerin zaman içinde nasıl evrildiği Şekil 6'da sunulmuştur.

Şekil 6'da sunulan karşılıklı bağıntısallık düzeyleri genel olarak değerlendirildiğinde, etkileşim düzeylerinin dönemsel olarak önemli farklılıklar gösterdiği ve bazı değişken çiftlerinde oldukça yüksek düzeyde eşzamanlı oynaklık hareketlerinin olduğu görülmektedir. Özellikle USD/TL'nin diğer değişkenlerle olan çift yönlü ilişkilerinde 2020 sonrası dönemde belirgin bir ortak hareketlilik dikkat çekmektedir. USD/TL-GAU/TRY, USD/TL-TR5Y ve USD/TL-CDS panellerinde yüksek seviyelerde karşılıklı bağıntısallık gözlenmiş; bu durum döviz kuru ile hem risk primi hem de faiz dinamikleri arasında güçlü bir eşzamanlı oynaklık aktarımını ortaya koymaktadır. Buna ek olarak, XU100-USD/TL ve XU100-CDS panellerinde zaman zaman %60'ın üzerinde karşılıklı etkileşim düzeylerinin gözlenmesi dikkat çekicidir. Bu bulgu, BIST 100 endeksinin hem döviz kuru hem de ülke risk primi ile yüksek düzeyde eşzamanlı volatilité hareketleri sergilediği dönemlerin varlığına işaret etmektedir. Öte yandan, TLREF, TR5Y ve GAU/TRY gibi daha stabil değişkenler arasında karşılıklı etkileşim düzeyi genellikle düşük seyretmiştir. Ancak özellikle COVID-19 pandemisi ve 2021 sonrası politika değişimleri gibi dönemlerde kısa süreli artışlar gözlenmiştir. Genel olarak elde edilen bulgular, finansal sistemdeki karşılıklı volatilité etkileşimlerinin zamanla belirgin şekilde dalgalandığını ve özellikle makrofinansal şok dönemlerinde ortak oynaklık seviyelerinde ciddi artışlar olduğunu ortaya koymaktadır.

Şekil: 6
Değişkenlere Ait Çift Yönlü Bağlantılılık Grafiği



4. Sonuç

Finansal piyasalarda varlıklar arasındaki ilişkiler, birbirlerini etkileme dereceleri ve volatilité yayılımı yatırımcılar, politika yapımcılar ve diğér piyasa katılımcıları açısından büyük önem taşımaktadır. Finansal varlıklar arasındaki bu etkileşim, piyasa dinamiklerini anlamak, etkin risk yönetimi stratejileri geliştirmek ve sağlıklı yatırım kararları almak açısından kritik öneme sahiptir. Bu ilişkiler, genellikle makroekonomik koşullar, küresel piyasa dalgalanmaları ve politika değışiklikleri gibi çeşitli faktörlerden etkilenmekte olup, piyasalardaki belirsizlik ve risk düzeyinin belirlenmesinde önemli bir gösterge niteliğı taşımaktadır.

Bu bağlamda, finansal varlıklar arasındaki dinamik etkileşimlerin daha iyi anlaşılabilmesi için volatilitenin yoğun olduğı belirli dönemlerin incelenmesi büyük önem taşımaktadır. Bu kapsamda, çalışmada ele alınan 2018-2024 dönemi, Türkiye'de 2018 Kur Krizi ile başlayan, takip eden yıllarda TCMB'nin faiz politikalarında önemli değışimlerin yaşandığı ve enflasyonla mücadele sürecinin ön plana çıktığı bir dönem olması nedeniyle seçilmiştir. Ayrıca, bu süreçte COVID-19 pandemisinin küresel finansal piyasalarda yol açtığı dalgalanmalar, Türkiye ekonomisinde de ciddi etkiler yaratmış ve finansal piyasalardaki volatilité dinamiklerini önemli ölçüde şekillendirmiştir.

Bu çalışmada, Türkiye'de BIST 100 endeksi, USD/TL kuru, gram altın fiyatları, TL Gecelik Referans Faiz Oranı, 5 yıllık tahvil faiz oranı ve 5 yıllık CDS primi arasındaki volatilité yayılımı, 02.01.2018-31.12.2024 dönemini kapsayan günlük frekanstaki veriler kullanılarak analiz edilmiştir. Volatilité yayılımının incelenmesinde, zamanla değışen parametrelerin dinamik yapısını yakalayabilen Zamanla Değışen Parametrelili Vektör Otoregresyon (TVP-VAR) yöntemi tercih edilmiştir. Ekonometrik analizlerin ilk aşamasında, incelenen finansal değışkenlere ait volatilité serileri oluşturulmuş ve bu serilere TVP-VAR analizi uygulanmıştır. Bu analiz sonucunda, hangi değışkenlerin volatilitéyi yaydığını (volatilité kaynağı) ve hangilerinin volatilitéyi aldığını (volatilité alıcısı) net bir şekilde ortaya koyan ortalama dinamik bağlantılılık tablosu elde edilmiştir.

Ortalama dinamik bağlantılılık analizine göre, diğér değışkenlerden en fazla etkilenen değışkenler USD/TL kuru, gram altın fiyatları (GAU/TRY), CDS primleri ve XU100 endeksi olarak belirlenmiştir. Öte yandan, 5 yıllık tahvil faiz oranı (TR5Y) ve TL gecelik referans faiz oranı (TLREF) diğér değışkenlerden en az etkilenenler arasında yer almıştır. Diğér değışkenler üzerinde en fazla etkiye sahip olan değışkenlerin başında USD/TL kuru gelirken, bunu gram altın fiyatları (GAU/TRY), CDS primleri, XU100 endeksi ve 5 yıllık tahvil faiz oranı (TR5Y) takip etmektedir. En az etkiye sahip değışken, TL gecelik referans faiz oranı (TLREF) olarak tespit edilmiştir. Volatilité yayılımı açısından değerlendirildiğinde, en güçlü volatilité kaynağının USD/TL kuru olduğu görülmektedir. Buna karşılık, CDS primleri, XU100 endeksi ve 5 yıllık tahvil faiz oranı (TR5Y) volatilitéyi en çok etkileyen değışkenlerdir. Analiz kapsamında incelenen değışkenler arasındaki toplam dinamik bağlantılılık seviyesinin %33,39 olarak tespit edilmesi, bu değışkenlerin portföy çeşitlendirme stratejilerinde kullanılabileceğine işaret etmektedir.

Bu bulgular, makroekonomik temeller, para politikası ve sermaye akışlarından önemli ölçüde etkilenen USD/TL kurunun finansal sistemde belirleyici bir volatilité kaynağı olduğunu ve özellikle CDS primi ile hisse senedi piyasası (XU100) üzerinde baskın bir etkiye sahip olduğunu göstermektedir. Özellikle, USD/TL'de meydana gelen dalgalanmaların piyasa risk algısını yansıtan CDS primleri ile sermaye piyasaları arasında güçlü bir bağlantı kurması, döviz kuru oynaklığının Türkiye finansal sistemi üzerindeki sistemik etkilerine işaret etmektedir. Bununla birlikte, CDS primlerinin ve hisse senedi piyasasının volatilitéyi en fazla etkileyen değişkenler olması, küresel ve yerel ekonomik belirsizlikler karşısında yatırımcı davranışlarının bu varlıklar üzerinde belirgin bir etkisinin olabileceğini düşündürmektedir. Elde edilen sonuçlar, döviz kuru oynaklığının finansal piyasalardaki risk ve belirsizlik algısını doğrudan şekillendirebileceğini ve bu durumun yatırım kararları ile makroekonomik politika yapım süreçlerine etki edebileceğini göstermektedir.

Yine TVP-VAR modelinin çıktılarından biri olan volatilité yayılım grafiği, piyasaların zaman içinde net şok alıcısı ya da net şok yayıcısı olarak nasıl konumlandığını ortaya koymaktadır. Volatilité yayılım grafiğine dayalı analiz sonuçları, USD/TL kurunun finansal piyasalarda en güçlü volatilité kaynağı olarak öne çıktığını ve özellikle CDS primi, XU100 endeksi ve 5 yıllık tahvil faiz oranı (TR5Y) üzerinde belirgin bir oynaklık aktarımı yarattığını göstermektedir. Bu alandaki literatür USD/TL kurunun en güçlü volatilité aktarım kaynağı olduğunu açıkça göstermektedir.

Öte yandan, CDS primi ve XU100 endeksi volatilitéyi en çok etkileyen değişkenler olarak belirlenmiştir. Değer kaybeden para birimleri, özellikle gelişmekte olan ülkeler için temerrüt riski algısını artırdığından, CDS primleri USD/TL'den gelen oynaklıktan en çok etkilenen değişkenler arasındadır (Longstaff et al., 2011). Döviz kurlarındaki değişimler, hisse senedi piyasalarında da beklentileri olumsuz etkileyerek hisse senedi fiyatlarının düşmesine neden olmaktadır. Hisse senedi fiyatları düşen firmalar genellikle artan temerrüt riskine işaret ettiğinden, XU100 borsa endeksi ile CDS primleri arasında güçlü bir negatif korelasyon ortaya çıkmaktadır. Bu bulgu, CDS primleri ile hisse senedi piyasasının döviz kuru şoklarına karşı duyarlılığının yüksek olduğunu göstermektedir. Finansal krizler sırasında bu etkileşimler daha belirgin hale gelir (Augustin et al., 2014). Buna karşılık, gram altın fiyatları (GAU/TRY) ve TL gecelik referans faiz oranı (TLREF) görece daha sınırlı bir volatilité yayılımı göstermekte ve diğer değişkenlere daha düşük düzeyde oynaklık aktarmaktadır.

2018-2024 dönemini kapsayan ve TVP-VAR modelini kullanan bu çalışma, Türkiye'deki finansal piyasalar arasındaki bağlantılılık yapısını ortaya koymaktadır. Bu yapı sayesinde, piyasaların toplam risk seviyelerindeki değişimlerin belirlenmesinin yanı sıra, şokları yayan ve alan piyasaların zaman içindeki dinamiklerinin incelenmesi mümkün olmuştur. Özellikle, volatilité yayan değişkenlerin tespit edilmesi, risk faktörlerinin daha etkin yönetilmesine olanak sağlarken, volatilité alan değişkenler ise portföy dengelenmesi açısından kritik bir rol oynamaktadır.

Elde edilen bulgular, finansal piyasalar arasındaki bağlantılılık dinamiklerinin farklı paydaşlar için önemli sonuçlar doğurduğunu göstermektedir. Bu doğrultuda, politika yapıcılar, yatırımcılar ve araştırmacılar için çeşitli çıkarımlar ve öneriler sunulmaktadır. Volatilite yayılımı finansal istikrar açısından önemli olduğundan, politika yapıcılar ve para otoritesi olan merkez bankaları tarafından sistemik krizleri önlemek ve finansal istikrarı korumak amacıyla volatilite yayılımı, nedenleri ve yönü yakından takip edilmektedir.

Piyasa istikrarının sağlanması ve sistemik risklerin minimize edilmesi amacıyla, özellikle USD/TL kurunun belirleyici bir volatilite kaynağı olduğu göz önünde bulundurularak, politika yapıcıların döviz kuru dalgalanmalarını hafifletici veya önleyici tedbirler geliştirmeleri önem arz etmektedir. Finansal aktörler, USD/TL kurunun finansal sistemde belirleyici bir volatilite kaynağı olduğunu ve özellikle CDS primi ile hisse senedi piyasası (XU100) üzerinde baskın bir etkiye sahip olduğunu göz ardı etmemelidir. Portföy çeşitlendirmesi stratejilerinde, USD/TL kuru ve bu kurdan kaynaklanan risklerin dikkate alınması gerekmektedir. Özellikle CDS primi ve hisse senedi piyasası gibi yüksek oynaklık gösteren alanlarda, etkin risk yönetimi stratejilerinin titizlikle uygulanması ve daha istikrarlı alternatif varlıkların değerlendirilmesi, yatırımcıların risklerini azaltmada önemli bir rol oynayabilir.

Volatilite yayılımı, finansal piyasalar arasındaki risk iletimini ve potansiyel kayıp kaynaklarını anlamak açısından politika yapıcılar, finansal kurumlar ve yatırımcılar için kritik bir konudur. Günümüzde politika yapıcılar, finansal piyasalarda aşırı oynaklıkları sınırlamak amacıyla sermaye kontrolleri, devre kesiciler, döviz ve faiz piyasalarına doğrudan müdahale ile makro ihtiyati para politikası araçları gibi çeşitli düzenleyici önlemler uygulamaktadır (Claessens et al., 2011). Öte yandan, finansal aracı kurumlar, portföy yöneticileri ve yatırımcılar, piyasalar genelinde ortaya çıkan volatilite riskini yönetmek amacıyla başta opsiyonlar olmak üzere çeşitli türev ürünler aracılığıyla korunma stratejileri geliştirmektedir (Hull, 2017; Andersen et al., 2007).

Bu çalışmada, Türkiye'de 2018-2024 dönemine odaklanılmış olup, gelecekteki araştırmalarda farklı frekanslardaki veriler (örneğin, haftalık veya aylık) ve alternatif veri setleri esas alınarak literatüre katkı sağlanabilir. Ayrıca, ekonometri literatüründeki gelişmeler dikkate alındığında, ekonometrik modelleme, tahmin ve makine öğrenimi tekniklerinin daha geniş veri setlerine ve farklı ülke gruplarına uygulanması, volatilite dinamiklerinin daha kapsamlı bir şekilde ortaya konmasına olanak tanıyabilecektir.

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NOTES FOR CONTRIBUTORS

1. Articles not published or submitted for publication elsewhere, accepted in either *Turkish* or *British English*.

2. Manuscripts should be, at most, single-spaced and 24 A4 pages with Times New Roman 11-point font. Article submissions are welcome only on the DergiPark platform.

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4. Tables, figures, and graphs should be numbered consecutively and contain full references. The titles of the tables, figures, and charts should be placed at their headings; the references for tables, figures, and graphs should be listed at the bottom. A comma should separate decimals. Equations should be numbered consecutively. Equation numbers should appear in parentheses at the right margin. The complete derivation of the formulas (if abbreviated in the text) should be provided on a separate sheet for the referee's use.

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6. All references should be cited in the text (not in footnotes) and conform to the following examples:

It has been argued (Alkin, 1982: 210-215) ...

Griffin (1970a: 15-20) states ...

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(Rivera-Batiz & Rivera-Batiz, 1989: 247-249; Dornbusch, 1980: 19-23).

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Books: Kenen, P.B. (1989), *The International Economy*, Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Periodicals: Kapıcıoğlu, R. & H. Ekelik (2026), “Hofstede's Cultural Dimensions and Tax Compliance: Analysis Using the CART Algorithm at the Country Level”, *Sosyoekonomi*, 34(68), 59-80. DOI: 10.17233/sosyoekonomi.2026.02.03

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Chang, R. (1998), “The Asian Crisis”, *NBER Discussion Paper*, 4470, National Bureau of Economic Research, Cambridge, MA.

8. Cited web pages should exist in the References with their complete address and cited date as follows:

....., <<http://www.sosyoekonomijournal.org>>, 18.12.2025.

YAZARLARA DUYURU

1. Sosyoekonomi Dergisi'nde *Türkçe* ve *İngilizce* makaleler yayımlanmaktadır. Dergiye gönderilen makaleler başka bir yerde yayımlanmamış veya yayımlanmak üzere gönderilmemiş olmalıdır.

2. Yazılar A4 boyutunda kâğıda, tek aralıkla, *Times New Roman* karakterinde, 11 puntoyla ve 24 sayfayı geçmeyecek şekilde yazılmalıdır. DergiPark platformu dışından yapılan gönderiler kabul edilmemektedir.

3. Gönderilecek Word dosyasının ilk sayfasında Türkçe ve İngilizce olarak şu bilgiler yer almalıdır: (i) yazının başlığı; (ii) en çok 100 kelimelik özet; (iii) anahtar sözcükler; (iv) çalışmanın JEL kodları; ayrı bir Word dosyasında ise (i) yazar(lar)ın adı; (ii) ORCID ID numaraları; (iii) yazar(lar)ın bağlı bulunduğu kurumun açık adı; (iv) yazar(lar)ın e-mail adresi ve telefon numarası belirtilmelidir. Etik onayı gerektiren ve ankete dayalı çalışmalarda ilgili kurumdan alınan “Etik Kurul İzin Belgesi” başvuru anında sisteme yüklenmelidir.

4. Tablo, şekil ve grafiklere başlık ve numara verilmeli; başlıklar tablo, şekil ve grafiklerin üzerinde yer almalı; kaynaklar ise tablo, şekil ve grafiklerin altına yazılmalıdır. Rakamlarda ondalık kesirler virgül ile ayrılmalıdır. Denklemlere verilecek sıra numarası, parantez içinde sayfanın sağ eninde yer almalıdır. Denklemlerin türetilişi, yazıda açıkça gösterilmemişse, hakemlerin değerlendirmesi için türetme işlemi bütün basamaklarıyla ayrı bir sayfada verilmelidir.

5. Yazılarda yapılan atıflara ilişkin dipnotlar sayfanın altında yer almalıdır.

6. Kaynaklara göndermeler dipnotlarla değil, metin içinde, sayfa numaralarını da içererek, aşağıdaki örneklerde gösterildiği gibi yapılmalıdır:

..... belirtilmiştir (Alkin, 1982: 210-215).

..... Griffin (1970a: 15-20) ileri sürmektedir.

(Gupta vd., 1982: 286-287).

(Rivera-Batiz & Rivera-Batiz, 1989: 247-249; Dornbusch, 1980: 19-23).

7. Metinde gönderme yapılan bütün kaynaklar, sayfa numaraları, varsa DOI adresleri ya da internet adresleri ile birlikte, “Kaynaklar” (“Kaynakça” diye yazılmayacak) başlığı altında ve aşağıdaki örneklerle uygun olarak belirtilmelidir:

Kitaplar: Kenen, P.B. (1989), *The International Economy*, Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Dergiler: Kapıcıoğlu, R. & H. Ekelik (2026), “Hofstede's Cultural Dimensions and Tax Compliance: Analysis Using the CART Algorithm at the Country Level”, *Sosyoekonomi*, 34(68), 59-80. DOI: 10.17233/sosyoekonomi.2026.02.03

Derlemeler: Krugman, P. (1995), “The Move Toward Free Trade Zones”, içinde: P. King (ed.), *International Economics and International Economic Policy: A Reader* (163-182), New York: McGraw-Hill, Inc.

Diğer Kaynaklar: Türkiye Cumhuriyet Merkez Bankası (2001), *2002 Yılında Para ve Kur Politikası ve Muhtemel Gelişmeler*, Basın Duyurusu, 2 Ocak, Ankara, <<http://www.tcmb.gov.tr>>.

Chang, R. (1998), “The Asian Crisis”, *NBER Discussion Paper*, 4470, National Bureau of Economic Research, Cambridge, MA.

8. Kaynaklar kısmında web sitelerine yapılan atıflar muhakkak alındıkları tarih itibarıyla gün, ay ve yıl olarak, tam adresleriyle birlikte belirtilmelidir.

....., <<http://www.sosyoekonomijournal.org>>, 18.12.2025.