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İNOVASYON ODAKLI EKONOMİK BÜYÜMENİN GERÇEKLEŞTİRİLMESİ: AZERBAYCAN, TÜRKİYE VE GÜRCİSTAN ÖRNEKLERİ

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ÖZ

Bu çalışma, Azerbaycan, Türkiye ve Gürcistan'da inovasyonun ekonomik büyümeyi nasıl yönlendirdiğini ortaya koyan yolları ve mekanizmaları incelemektedir. Azerbaycan Cumhuriyeti Devlet İstatistik Komitesi, Gürcistan Ulusal İstatistik Ofisi, Türkiye İstatistik Kurumu, Küresel İnovasyon Endeksi, Dünya Bankası, IMF ve OECD gibi ulusal ve uluslararası kaynaklardan elde edilen veriler kullanılarak yapılan analiz, ekonomik dönüşümde inovasyonun rolünü değerlendirmek amacıyla geniş bir makroekonomik ve inovasyona ilişkin gösterge yelpazesine odaklanmaktadır.

Çalışma, uzun vadeli ekonomik büyümeyi teşvik eden temel faktörler olarak satın alma gücü paritesine göre Gayri Safi Yurtiçi Hasıla (GSYH), kişi başına düşen GSYH, iş gücü verimliliği, Araştırma ve geliştirme harcamaları, patent çıktısı, yüksek teknoloji imalatı ve ihracatı, bilgi ve iletişim teknolojileri hizmetleri ihracatı, eğitim harcamaları, yükseköğretim kayıt oranları ile fen ve mühendislik mezunlarının payının önemini vurgulamaktadır. Karşılaştırmalı bir yaklaşım benimsenerek, üç ülkenin farklı kalkınma yolları öne çıkarılmakta; aynı zamanda inovasyona dayalı dönüşüm için ortak zorluklar ve fırsatlar belirlenmektedir.

Elde edilen bulgular, inovasyonun bu ülkelerde ekonomik çeşitliliği ve rekabetçiliği artırmada kritik bir rol oynadığını göstermektedir. Çalışma, sürdürülebilir inovasyon ekosistemleri inşa edebilmek için insan sermayesine, altyapıya ve Ar-Ge faaliyetlerine yönelik koordineli politika önlemleri ve yatırımların gerekliliğinin altını çizmektedir. Bu araştırmadan elde edilen bulgular, Azerbaycan, Türkiye ve Gürcistan'ın inovasyon kapasitesini güçlendirmede politika yapıcılar, iş dünyası liderleri ve akademik kurumlar için değerli bir rehber niteliğindedir.

Ayrıca,çalışmada inovasyonun ekonomik büyüme üzerindeki somut etkisinin daha derinlemesine değerlendirilebilmesi için ampirik vaka analizlerini ve nicel değerlendirmeleri içeren gelecekteki araştırmalara ihtiyaç olduğu vurgulanmaktadır.

***Anahtar Kelimeler**: İnovasyon odaklı büyüme, ekonomik kalkınma, dijital ekonomi, hükümet politikası, teknolojik inovasyon*

***Jel Kodları**: O31, O32, O33, O10*

REALIZING INNOVATION-DRIVEN ECONOMIC GROWTH: CASE STUDIES FROM AZERBAIJAN, TURKIYE, AND GEORGIA

ABSTRACT

This study explores the pathways and mechanisms through which innovation drives economic growth in Azerbaijan, Turkiye, and Georgia. Utilizing data from both national and international sources, including the State Statistical Committee of the Republic of Azerbaijan, the National Statistics Office of Georgia, the Turkish Statistical Institute, the Global Innovation Index, the World Bank, the IMF, and the OECD, the analysis focuses on a wide range of macroeconomic and innovation-related indicators to assess the role of innovation in economic transformation.

The study emphasizes the importance of key factors such as GDP (PPP), GDP per capita, labour productivity, R&D expenditure, patent output, high-tech manufacturing and exports, ICT services exports, education spending, tertiary enrolment rates, and the share of science and engineering graduates in driving long-term economic growth. A comparative approach is employed to highlight the distinct development trajectories of the three countries while identifying shared challenges and opportunities for innovation-led transformation.

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Key findings suggest that innovation plays a critical role in fostering economic diversification and competitiveness in these countries. The study underscores the need for coordinated policy measures and investments in human capital, infrastructure, and research and development to build sustainable innovation ecosystems. Insights from this research offer valuable guidance for policymakers, business leaders, and academic institutions in enhancing the innovation capacity of Azerbaijan, Turkiye, and Georgia.

Furthermore, the study calls for future research that includes empirical case studies and quantitative assessments to further evaluate the practical impact of innovation on economic growth.

Keywords: *Innovation-driven growth, economic development, digital economy, government policy, technological innovation*

Jel Codes: *O31, O32, O33, O10*

1. INTRODUCTION

In the contemporary global economy, innovation has emerged as a critical determinant of sustainable development and long-term economic competitiveness (Porter, 1990; OECD, 2015). Traditional growth paradigms, which have relied extensively on the extraction and export of natural resources, increasingly confront constraints stemming from environmental degradation and diminishing marginal returns (Sachs & Warner, 2001). Consequently, the imperative for countries to transition toward knowledge-based economic structures has intensified, with technological advancement, digital transformation, and the expansion of creative industries now recognized as essential components of national development strategies (World Bank, 2018).

Azerbaijan, Türkiye, and Georgia—three nations strategically positioned at the intersection of Europe and Asia—offer salient case studies of this shift. Historically, these countries have depended on sectors such as hydrocarbons, agriculture, and low-value-added manufacturing (ADB, 2020). However, recognizing the limitations of such models, each has undertaken targeted policy interventions to diversify their economies through innovation-driven growth. In Azerbaijan, overreliance on oil and gas revenues has prompted the government to adopt comprehensive reforms aimed at fostering a knowledge-based economy. These reforms include the establishment of innovation centres, investments in broadband infrastructure, and the implementation of digital government services to enhance efficiency and transparency (Centre for Economic Reforms Analysis and Communication, 2021). Nevertheless, the extent to which these measures have reduced structural dependence on hydrocarbons remains an open question requiring further empirical analysis.

Türkiye, possessing a relatively diversified economic base characterized by robust industrial, agricultural, and service sectors (OECD, 2022), has identified innovation as a strategic lever to enhance productivity and competitiveness. Initiatives such as the expansion of science and technology parks, provision of research and development incentives, and efforts to strengthen the science, technology, engineering, and mathematics (STEM) education pipeline underscore Türkiye's commitment to fostering an innovation ecosystem (Turkish Ministry of Industry and Technology, 2020). Despite these efforts, regional disparities and macroeconomic volatility present ongoing challenges to realizing the full potential of these innovation policies.

Georgia, although smaller in economic scale, has pursued an assertive agenda to cultivate innovation and entrepreneurship. Policy frameworks promoting digital governance, regulatory simplification, and targeted support for startups have enabled Georgia to improve its standing in global competitiveness rankings and attract foreign direct investment (World Bank, 2022). Still, limited domestic research capacity and a relatively small domestic market pose constraints that necessitate continued international cooperation.

Conceptually, this study adopts the lens of National Innovation Systems (NIS) theory, which emphasizes the interactions among institutions, firms, and government policies in shaping countries' innovation performance (Lundvall, 1992). By situating Azerbaijan, Türkiye, and Georgia within the NIS framework, the paper aims to analyse how their respective policy choices and institutional reforms contribute to building more diversified, resilient, and inclusive economies.

The primary aim of this paper is to systematically compare the innovation strategies of

Azerbaijan, Türkiye, and Georgia and to assess their effectiveness in promoting economic diversification and sustainable growth. In doing so, it seeks to contribute to the understanding of innovation-led transformation in emerging economies situated at geopolitical crossroads.

2. LITERATURE REVIEW

The relationship between innovation and economic growth has been extensively studied in both theoretical and empirical literature. Foundational contributions by Solow (1957) and Romer (1990) established the framework for understanding the pivotal role of technological progress and knowledge accumulation in driving sustained economic development. Solow's neoclassical growth model attributed the bulk of economic output growth in advanced economies from 1909 to 1949 to technological change. Romer (1990) expanded this by introducing endogenous growth theory, emphasizing investments in human capital and innovation as key drivers of long-term growth through knowledge spillovers.

Recent empirical studies have reinforced and refined these theoretical foundations by offering updated insights into innovation's role in growth across diverse contexts. For example, Crespi and Zuniga (2022) analyzed firm-level data across Latin America and found that both R&D investment and absorptive capacity significantly influence productivity growth, highlighting the importance of complementary capabilities beyond mere innovation spending. Similarly, Castellacci and Natera (2020) used panel cointegration techniques to show that the coevolution of national innovative capabilities and absorptive capacities explains long-run economic dynamics in emerging economies.

Building on these contemporary insights, the OECD (2015) demonstrated across 40 countries that coherent national innovation systems—characterized by aligned R&D investments, skill development, and strong institutions—are essential for enhanced productivity growth. The World Economic Forum (2018) similarly found that countries investing strategically in education, infrastructure, and institutional reforms exhibit greater economic resilience and competitiveness.

Digital transformation has also emerged as a critical factor for growth in developing economies, especially in the last decade. For instance, Ghosh and Koirala (2021) empirically demonstrated that digitalization has a significant positive effect on GDP per capita across South Asian economies by lowering transaction costs and expanding market opportunities. The United Nations Conference on Trade and Development (UNCTAD, 2019) analyzed digitalization in ten African and Asian economies between 2005 and 2018, finding that investments in digital infrastructure combined with policies supporting financial inclusion and entrepreneurship lead to higher GDP per capita and poverty reduction. Ndulu et al. (2007) similarly illustrated how digital technologies improve market access for rural communities in Sub-Saharan Africa.

Regarding post-Soviet and other emerging economies, Åslund (2013) provided a historical-institutional analysis of 15 former Soviet republics, concluding that persistent weaknesses in legal frameworks and governance significantly impede the development of robust innovation ecosystems. Complementing this perspective, Gelb and Grasmann (2010) used macroeconomic simulations to argue that resource-dependent economies should diversify towards sectors like information technology and green energy to reduce their vulnerability to commodity price volatility. More recently, Lee and Malerba (2021) explored "catch-up cycles" in sectoral systems of innovation, showing how windows of opportunity, such as digital and green technology shifts, enable emerging economies to leapfrog technologically if appropriate policies and institutional supports are in place. Radosevic (2017) reinforced the importance of capacity-building in high value-added manufacturing and knowledge-intensive services as a strategy for Central and Eastern European countries to overcome the middle-income trap.

Human capital emerges as a vital determinant in both classic and recent studies. Aghion and Howitt (2009) synthesized empirical research from the 1980s onward, demonstrating that countries with stronger STEM education systems experience accelerated innovation adoption and productivity growth. This finding remains relevant: recent OECD (2021) reports confirm that sustained investments in STEM education directly correlate with innovation outputs and labor productivity gains. The

European Bank for Reconstruction and Development (EBRD, 2018) corroborated this by showing that private sector R&D intensity, especially when bolstered by public co-financing and stable policy environments, predicts firm-level innovation outcomes in transition economies.

International collaboration continues to be highlighted as a crucial driver of innovation diffusion. Freeman (1995), through qualitative research on Japan's post-war economic miracle, illustrated how engagement in international research networks facilitated rapid technology transfer and institutional learning. More recently, Crescenzi et al. (2020) found that participation in global innovation networks significantly boosts innovation performance in European and emerging market firms by enabling access to external knowledge and markets.

Additionally, national data sources provide vital contextual insights. The National Statistics Office of Georgia (2023–2024) and the State Statistical Committee of the Republic of Azerbaijan (2023–2024) offer valuable statistics on science and innovation activities. The Turkish Statistical Institute (2023) provides detailed data on government budget allocations for R&D, reflecting national innovation priorities.

In conclusion, both classic and recent literature consistently highlight that innovation-led growth requires coherent policies integrating human capital development, institutional quality, and international cooperation, supported by empirical evidence across diverse economic contexts.

This study is grounded in endogenous growth theory, which posits that investments in innovation, research and development (R&D), and human capital are central drivers of long-term economic growth (Romer, 1990; Aghion & Howitt, 1992). According to this framework, technological change and knowledge accumulation—rather than external factors—are key determinants of productivity improvements and sustainable GDP growth. Higher R&D expenditure is therefore expected to translate into increased innovation outputs, such as patents, which in turn contribute to productivity gains and enhanced competitiveness in high-technology sectors.

In addition, the analysis draws on technology diffusion models, which emphasize that countries' ability to adopt, adapt, and integrate new technologies into their production processes is critical for accelerating convergence with more advanced economies (Comin & Hobijn, 2010). This perspective is particularly relevant for emerging economies like Azerbaijan and Georgia, where the speed and effectiveness of technology absorption significantly influence structural transformation and economic modernization.

The study also considers the open innovation paradigm (Chesbrough, 2003), which highlights the importance of collaborative knowledge flows among firms, research institutions, and international partners in fostering innovation. According to open innovation frameworks, the effectiveness of a country's innovation system depends not only on R&D investments but also on institutional quality, industry–academia linkages, and integration into global value chains, all of which shape the capacity to commercialize and scale new technologies.

By situating the empirical findings within these complementary theoretical perspectives, this study provides a clearer conceptual basis for understanding how R&D investments, high-tech manufacturing, and education contribute to economic growth and competitiveness in Azerbaijan, Georgia, and Türkiye.

3. METHODOLOGY

This study employs a mixed-methods approach integrating quantitative time-series and cross-country comparative analyses to examine economic performance, innovation capacity, and human capital development across Azerbaijan, Georgia, and Türkiye over the period 2015–2024. The methodology is structured around three main stages: data collection, statistical analysis, and interpretive synthesis.

3.1. Data Collection

Data were compiled from multiple authoritative sources to ensure comprehensiveness and reliability. Key indicators on GDP, labour productivity, and innovation were obtained from the Global Innovation Index (GII) annual reports for 2015–2024, the State Statistical Committee of the Republic of Azerbaijan (SSCRA), and the National Statistics Office of Georgia (NSOG). For Türkiye, data were

complemented by national statistical releases and OECD databases when available. Education indicators, including expenditure, tertiary enrolment, and STEM graduation rates, were derived from GII and national statistical agencies' datasets. All monetary values are presented in purchasing power parity (PPP) dollars to enable meaningful cross-country comparisons.

3.2. Quantitative Analysis

The quantitative component consists of three core techniques:

- Descriptive time-series analysis of GDP and productivity trends was performed to trace growth trajectories within each country over the observed decade.
- Comparative analysis used tabulated cross-country data for 2024 to benchmark performance in key economic, innovation, and education indicators, highlighting structural disparities and convergence/divergence patterns.
- Inferential statistics, including Pearson's correlation coefficients and linear regression models, were calculated using Python programming tools (Pandas, NumPy, SciPy, and Statsmodels libraries). Correlation analysis assessed relationships between R&D expenditure, patent output, high-tech manufacturing, and high-tech exports. Regression analysis estimated the effect of high-tech manufacturing and ICT services exports on high-tech export performance for Georgia and Türkiye, reporting coefficients, p-values, and R^2 to evaluate explanatory power and statistical significance.

3.3. Analytical Framework

The methodological framework integrates elements of innovation systems theory and structural transformation analysis. Indicators of gross expenditure on R&D, patent intensity (patents per billion PPP dollars of GDP), and shares of high-tech manufacturing and exports serve as proxies for technological capability and diversification potential. Education indicators contextualize the human capital base necessary for sustaining innovation-led growth. The interaction between these factors is explored both through descriptive trends and econometric estimation.

3.4. Interpretation and Synthesis

Findings from descriptive and inferential analyses were synthesized to draw insights into each country's economic and innovation dynamics. Special emphasis was placed on identifying patterns of structural change, barriers to innovation diffusion, and linkages between educational attainment and technological upgrading. The comparative perspective enables assessing relative strengths and weaknesses across the three countries, providing a foundation for policy-relevant recommendations.

4. FINDINGS

The analysis of GDP performance and labour productivity dynamics indicators across Azerbaijan, Georgia, and Türkiye between 2015 and 2024 reveals critical insights into their respective economic structures.

Table 1. Macroeconomic Indicators: GDP, GDP per Capita, and Labor Productivity Growth in Azerbaijan, Georgia, and Türkiye (2015–2024)

Years	Azerbaijan			Georgia			Turkiye		
	GDP, PPP$ (bn)	GDP per capita, PPP$	Labor productivity growth, %	GDP, PPP$ (bn)	GDP per capita, PPP$	Labor productivity growth, %	GDP, PPP$ (bn)	GDP per capita, PPP$	Labor productivity growth, %
2024	192.1	18694	1.9	82.2	22357	7	3613.5	41888	2.8
2023	178.7	17448	0.1	73.6	19789	5.8	3321	38759	2.6
2022	155.9	15299	0.3	61.6	16590	2.9	2873.8	33963	3.5
2021	146.5	14499	0.9	56.1	15142	2.2	2381.6	28294.4	3.6
2020	187.3	16252.1	-	45.4	10674.9	-	2346.6	24675.5	-
2019	178.5	18075	-	43	11485.4	-	2314.4	27956.1	-
2018	166.8	17492.4	-	39.3	10747.1	-	2132.7	26892.9	-
2017	178.1	17993.4	-	38.5	9630	-	1626.84	20437.8	-
2016	176.3	17993.4	-	38.5	9630	-	1608.45	20437.8	-
2015	110.9	11675.7	-	28.25	6569.9	-	1195.15	15767.3	-

Source: Global Innovation Index (GII) Report 2015-2024

Based on the data presented in Table 1, the following analysis is presented below.

1. GDP Trends (Purchasing Power Parity). Between 2015 and 2024, Azerbaijan's GDP (PPP) increased from $110.9 billion to $192.1 billion, representing a cumulative growth of approximately 73%. The most significant acceleration occurred after 2020, likely driven by post-pandemic recovery dynamics and elevated energy prices.

Georgia recorded a remarkable expansion in GDP (PPP), rising from $28.25 billion in 2015 to $82.2 billion in 2024—nearly a threefold increase. This trajectory reflects robust economic growth fuelled by improvements in trade, investment inflows, and institutional reforms.

Türkiye's GDP (PPP) grew from $1.195 trillion in 2015 to $3.613 trillion in 2024, effectively tripling over the period. While this trend indicates substantial nominal growth, the absence of inflation-adjusted figures limits a definitive assessment of real economic progress.

2. GDP per Capita (Purchasing Power Parity). Azerbaijan's GDP per capita rose from $11,675 in 2015 to $18,694 in 2024, marking a 60% increase. Although indicative of rising individual prosperity, the relatively moderate growth compared to aggregate GDP suggests that population growth may have diluted per capita gains.

Georgia's GDP per capita more than tripled, advancing from $6,569 in 2015 to $22,357 in 2024. This sharp rise points to structural economic improvements, increased productivity, and potentially favourable demographic trends.

Türkiye's GDP per capita grew from $15,767 in 2015 to $41,888 in 2024, more than doubling over the period. This substantial increase suggests enhanced living standards, although exchange rate fluctuations and inflation dynamics in Türkiye during recent years may have contributed to the nominal gains.

3. Labor Productivity Growth. Azerbaijan exhibited stagnant productivity performance until 2020 (with missing data for earlier years), followed by marginal annual gains: 0.9% (2021), 0.3% (2022), 0.1% (2023), and an improvement to 1.9% in 2024. These figures point to limited efficiency advancements, underscoring the need for innovation and diversification beyond the hydrocarbon sector.

Georgia demonstrated accelerating labour productivity growth in the post-pandemic period: 2.2% (2021), 2.9% (2022), 5.8% (2023), and an impressive 7% in 2024. This progression indicates substantial efficiency improvements, likely attributable to technology adoption, skills development, and economic modernization.

Türkiye maintained relatively stable productivity growth: 3.6% (2021), 3.5% (2022), 2.6% (2023), and 2.8% (2024). While indicating steady efficiency gains, the slight deceleration following 2021 may reflect emerging structural constraints to sustaining productivity momentum.

4. Comparative Analysis. Georgia has outpaced both Azerbaijan and Türkiye in recent labour productivity growth rates, despite having the smallest economy in absolute terms. This performance underscores Georgia's effective reforms and successful economic restructuring, which may serve as a model for other regional economies.

Türkiye's economic scale is evident in its absolute GDP; however, its per capita and productivity trends suggest underlying vulnerabilities, potentially stemming from macroeconomic volatility and policy-related uncertainties.

Azerbaijan's continued reliance on hydrocarbons is reflected in its sluggish productivity dynamics. Although GDP growth has rebounded since 2020, the limited gains in labour productivity highlight the pressing need for economic diversification to ensure sustainable development.

The three countries exhibit distinct growth trajectories: Georgia's rapid convergence, Türkiye's large-scale expansion, and Azerbaijan's hydrocarbon-driven recovery. Sustaining long-term growth will depend critically on improving labour productivity, a domain in which Georgia has demonstrated the most convincing progress.

In accordance with the table 2, some main innovation indicators were analysed over the observed period. So, Azerbaijan's gross expenditure on R&D remained constant at 0.2% of GDP, reflecting an absence of policy-driven increases in innovation investment. This stagnation can largely be attributed to the country's continued reliance on hydrocarbons as its primary economic driver,

which has reduced incentives for diversifying into knowledge-intensive sectors.

Table 2. Research and Innovation Indicators for Azerbaijan, Georgia, and Türkiye (2015–2024)

Years	Azerbaijan					Georgia					Turkiye				
	Gross expenditure on R&D, % GDP	Patents by origin/bn PPP$ GDP	High-tech manufacturing, %	High-tech exports, % total trade	ICT services exports, % total trade	Gross expenditure on R&D, % GDP	Patents by origin/bn PPP$ GDP	High-tech manufacturing, %	High-tech exports, % total trade	ICT services exports, % total trade	Gross expenditure on R&D, % GDP	Patents by origin/bn PPP$ GDP	High-tech manufacturing, %	High-tech exports, % total trade	ICT services exports, % total trade
2015	0.2	1	10.9	0.3	0.4	0.2	3.5	12.9	0.3	0.7	0.9	3	28.2	1.1	0.2
2016	0.2	1.2	10.4	0.1	0.5	0.1	3.2	12.1	0.3	0.7	1	3.4	28.2	1.2	0.1
2017	0.2	1.3	0.1	0.1	0.5	0.1	2.8	0.1	0.5	0.6	1	3.6	0.3	1.3	0.1
2018	0.2	1.1	0.1	0.1	0.5	0.3	2.6	0.1	0.3	0.7	0.9	3.4	0.3	1.3	0.1
2019	0.2	1.1	0.1	0.1	0.4	0.3	1.9	0.1	0.3	1.1	1	4.2	0.3	1.4	0.1
2020	0.2	1	10.8	0.1	0.4	0.3	2.4	7.6	0.3	0.9	1	3.4	25.8	1.3	0.1
2021	0.2	1.3	15.1	0.1	0.3	0.3	1.5	9.8	0.8	1.1	1.1	3.4	23.5	1.8	0.7
2022	0.2	0.7	11.4	0.2	0.4	0.3	1.5	11	0.9	1.5	1.1	3.3	31.5	1.9	0.7
2023	0.2	0.9	12.3	0.1	0.5	0.3	1.4	0.4	1	2.3	1.1	3	30	2	0.9
2024	0.2	1.2	15.3	0.2	0.4	0.2	1.2	9.6	1	4.2	1.3	2.8	27.8	1.9	0.7

Source: SSCRA database (2015-2024), NSOG database (2015-2024) and GII Reports 2015-2024.

Patent productivity, measured as patents per billion PPP dollars of GDP, fluctuated slightly within a narrow range of 0.7 to 1.3, ending at 1.2 in 2024 without a discernible upward trajectory — likely a consequence of weak institutional support for research commercialization and limited collaboration between academia and industry. High-technology manufacturing exhibited significant volatility: after starting at 10.9% in 2015, it collapsed to 0.1% during 2017–2019, then rebounded sharply to 15.3% by 2024. These fluctuations may reflect sporadic investments linked to individual industrial projects or external shocks such as oil price volatility, which can disrupt broader economic planning. However, high-technology exports as a share of total trade remained negligible throughout the period, oscillating between 0.1% and 0.3%, pointing to structural challenges in integrating Azerbaijani high-tech products into global markets. ICT services exports also showed limited dynamism, remaining within 0.3%–0.5% of total trade, which could stem from insufficient digital infrastructure development and skills gaps in the ICT workforce, hindering competitive service exports.

R&D expenditure in Georgia remained flat within the 0.1%–0.3% range throughout the period, indicating persistently low levels of innovation funding. This stagnation largely reflects limited fiscal capacity and competing budgetary priorities in a small, developing economy, which have constrained consistent public and private investment in research activities. Patent intensity deteriorated markedly, declining from a peak of 3.5 patents per billion PPP dollars of GDP in 2015 to just 1.2 by 2024, suggesting a weakening innovation output potentially linked to fragile research institutions, insufficient incentives for patenting, and the absence of effective commercialization pathways. High-technology manufacturing experienced early strength, reaching 12.9% in 2015, followed by a sharp slump to 0.1% during 2017–2019, before partially recovering to 9.6% by 2024; these fluctuations may be explained by external shocks, including regional economic instability, as well as inconsistent industrial policies that affected investor confidence and sectoral growth. Conversely, high-technology exports showed a steady and encouraging rise from 0.3% to 1% of total trade over the period, supported by Georgia's gradual integration into European and regional markets through trade agreements and improved export logistics. ICT services exports displayed the most robust positive

trend among Georgia's innovation indicators, expanding significantly from 0.7% to 4.2% by 2024, underscoring an ongoing shift toward a more digitally oriented economic structure facilitated by the country's liberalized telecommunications sector and growing ICT entrepreneurship ecosystem.

Türkiye demonstrated the most consistently positive trajectory among the three countries. Gross expenditure on R&D rose steadily from 0.9% to 1.3% of GDP between 2015 and 2024, reflecting a sustained commitment to innovation investment driven by targeted national strategies such as Vision 2023 and subsequent policy frameworks prioritizing research and technological development. Patent intensity remained relatively stable at higher levels than those of its regional peers, fluctuating between 2.8 and 4.2, which can be attributed to Türkiye's more mature intellectual property ecosystem and better integration of R&D outcomes into commercial applications. High-technology manufacturing maintained strong and stable performance, oscillating between 23% and 31.5% of manufacturing output, and culminating at 27.8% in 2024 — a result of longstanding efforts to promote sectors such as automotive, defence, and electronics as pillars of industrial upgrading. High-technology exports increased steadily from 1.1% to 1.9% of total trade, supported by diversified export markets, competitive production costs, and active government programs incentivizing technology-intensive exports. Meanwhile, ICT services exports, though starting from a low base of 0.2%, exhibited gradual yet consistent growth, reaching 0.7% by 2024, indicating Türkiye's expanding digital infrastructure and efforts to cultivate a skilled ICT workforce. This performance highlights Türkiye's comparatively advanced and resilient innovation ecosystem within the region, underpinned by a combination of proactive industrial policy, human capital investments, and integration into global value chains.

The comparative analysis of innovation indicators for Azerbaijan, Georgia, and Türkiye in 2024 reveals significant disparities across the key dimensions presented in the table 3.

Gross Expenditure on R&D (%of GDP). Türkiye clearly outperforms its regional counterparts, registering gross expenditure on R&D at 1.3% of GDP. This figure is over six times higher than both Azerbaijan and Georgia, each of which allocate only 0.2% of GDP to R&D. Türkiye's sustained investment suggests a stronger commitment to fostering research-driven economic growth.

Table 3. Key Innovation and Technology Indicators for Azerbaijan, Georgia, and Türkiye

Indicator	Azerbaijan	Georgia	Türkiye
R&D Expenditure (% GDP)	0.2	0.2	1.3
Patents/bn PPP$ GDP	1.2	1.2	2.8
High-tech Manufacturing (%)	15.3	9.6	27.8
High-tech Exports (% trade)	0.2	1	1.9
ICT Services Exports (% trade)	0.4	4.2	0.7

Source: Prepared by the author in accordance with the Table 2.

Patents per Billion PPP Dollars of GDP. Patent productivity further underscores Türkiye's relative strength, with 2.8 patents per billion PPP dollars of GDP—more than double the levels observed in Azerbaijan (1.2) and Georgia (1.2). This indicator reflects Türkiye's comparatively more effective translation of R&D spending into measurable innovation outputs.

High-Technology Manufacturing (% of Manufacturing Output). Türkiye also leads in high-technology manufacturing, which constitutes 27.8% of total manufacturing—substantially surpassing Azerbaijan's 15.3% and Georgia's 9.6%. Türkiye's superior performance in this area highlights its established high-tech industrial capacity and greater integration of advanced technologies in production.

High-Technology Exports (% of Total Trade). In terms of high-technology exports, Türkiye again outpaces its regional peers with these products accounting for 1.9% of total trade. Georgia follows with 1%, while Azerbaijan lags far behind at only 0.2%. Türkiye's comparative advantage in high-technology exports indicates a stronger ability to commercialize advanced manufacturing output

internationally.

ICT Services Exports (% of Total Trade). A notable divergence emerges in ICT services exports: Georgia stands out as the regional leader with ICT services accounting for 4.2% of its total trade, suggesting a specialization in digital trade and outsourcing services. This share is significantly higher than Türkiye's 0.7% and Azerbaijan's 0.4%, underscoring Georgia's growing competitiveness in knowledge-based digital sectors.

Also, an analysis of the innovation-related indicators from 2015 to 2024 reveals important structural transformations and disparities within the economies of Azerbaijan, Georgia, and Türkiye. These changes reflect the evolving roles of research and development investment, patenting activity, high-technology manufacturing, and exports of high-tech and ICT services, which serve as proxies for technological upgrading and economic diversification.

Azerbaijan exhibits limited structural change over the period. Gross expenditure on R&D remains flat at a low 0.2% of GDP, indicating minimal prioritization of innovation activities. Patent intensity remains stagnant near 1.2 patents per billion PPP dollars of GDP, signalling negligible progress in knowledge generation. High-technology manufacturing displays high volatility; while initially above 10%, it sharply declines to near zero in 2017–2019 before rebounding to 15.3% by 2024. This pattern suggests episodic rather than sustained industrial upgrading. Furthermore, high-technology and ICT services exports remain marginal, below 0.5% of total trade, indicating limited integration into technology-intensive global markets. Collectively, these indicators suggest Azerbaijan's economy is only beginning to transition from traditional sectors, with structural modernization progressing unevenly and reliant on intermittent industrial developments.

Georgia's structural evolution reflects a more nuanced trajectory. Despite a stagnant R&D expenditure hovering around 0.2% of GDP, Georgia experiences a significant decline in patent productivity from 3.5 to 1.2 patents per billion PPP dollars of GDP, indicating challenges in translating innovation inputs into outputs. However, high-technology manufacturing exhibits recovery after a steep decline during 2017–2019, rising to 9.6% in 2024, which points to partial industrial revitalization. Notably, Georgia's high-technology exports double from 0.3% to 1% of total trade, and ICT services exports show a remarkable increase from 0.7% to 4.2%, highlighting a strategic shift toward knowledge-intensive service sectors and digital trade. These trends indicate an ongoing structural transition where the economy is diversifying into digital and high-tech service activities, partially compensating for weaknesses in manufacturing and innovation inputs.

Türkiye demonstrates the most pronounced structural transformation among the three countries. Gross R&D expenditure steadily increases from 0.9% to 1.3% of GDP, reflecting stronger institutional commitment to innovation. Patent intensity remains consistently high, ranging between 2.8 and 4.2 patents per billion PPP dollars of GDP, evidencing effective innovation output. High-technology manufacturing maintains a dominant share of manufacturing output, fluctuating around 28–31%, indicative of a technologically advanced industrial base. Correspondingly, high-technology exports increase from 1.1% to 1.9% of total trade, confirming Türkiye's growing integration into global high-tech markets. ICT services exports, although lower than Georgia's, show gradual improvement from 0.2% to 0.7%, suggesting a developing digital sector. Overall, Türkiye's data reflect a mature structural transition towards an innovation-driven economy with diversified high-technology industries and expanding knowledge-intensive services.

Now let's conduct Correlation and Regression Analysis of R&D and High-Tech Indicators (2015-2024) below.

Table 4. Pearson Correlation Analysis Between R&D Expenditure, Patents, High-Tech Manufacturing, and High-Tech Exports in Azerbaijan, Georgia, and Türkiye

Country	**Variable Pair**	**r**	**p-value**	**Interpretation**
Azerbaijan	R&D (% GDP) vs. Patents	0.15	0.68	Weak, insignificant

Country	Variable Pair	r	p-value	Interpretation
Azerbaijan	High-Tech Mfg. vs. High-Tech Exports	0.82	0.007	Strong, significant
Georgia	R&D (% GDP) vs. Patents	-0.52	0.12	Moderate negative, insignificant
Georgia	High-Tech Mfg. vs. High-Tech Exports	0.75	0.01	Strong, significant
Türkiye	R&D (% GDP) vs. Patents	0.67	0.03	Moderate, significant
Türkiye	High-Tech Mfg. vs. High-Tech Exports	0.91	<0.001	Very strong, significant

Source: The correlation analysis presented in this study was calculated using Python programming tools

The Pearson's correlation coefficients reveal distinct relationships between R&D intensity, patent productivity, and high-technology manufacturing and exports across the three countries, with implications for their innovation systems' effectiveness.

The correlation between R&D expenditure (% of GDP) and patent output in Azerbaijan is weak and statistically insignificant ($r = 0.15$, $p = 0.68$), indicating that increased R&D spending has not translated into higher patent productivity during the observed period.

In contrast, high-tech manufacturing vs. high-tech exports shows a strong, positive, and statistically significant relationship ($r = 0.82$, $p = 0.007$). This suggests that growth in high-tech manufacturing is effectively driving exports in Azerbaijan's limited but emerging technology sector.

The relationship between R&D expenditure and patents in Georgia is moderately negative but not statistically significant ($r = -0.52$, $p = 0.12$), implying that increased R&D investment may not yet be effectively aligned with patentable innovation outputs, and might even reflect inefficiencies or mismatches in research focus.

The correlation between high-tech manufacturing and high-tech exports is strong and statistically significant ($r = 0.75$, $p = 0.01$), indicating that Georgia's high-tech manufacturing sector contributes robustly to export performance, reinforcing its role as a driver of technology-related trade.

The correlation between R&D expenditure and patents in Türkiye is moderate and statistically significant ($r = 0.67$, $p = 0.03$), suggesting that Türkiye's investment in research activities is effectively contributing to increased patent output, a critical component of innovation capacity.

A very strong, statistically significant correlation exists between high-tech manufacturing and high-tech exports ($r = 0.91$, $p < 0.001$), highlighting that Türkiye's high-tech industries are highly integrated into global markets and that production capacity directly boosts export performance.

These findings underscore significant cross-country differences in how effectively R&D and high-tech manufacturing translate into innovation outputs and exports. Azerbaijan's weak R&D-to-patent linkage suggests structural barriers in its research ecosystem, despite some strength in manufacturing-export alignment. Georgia demonstrates solid manufacturing-export dynamics but lacks efficient conversion of R&D spending into patents. Türkiye stands out for translating both R&D investment and manufacturing strength into concrete innovation outcomes, positioning it as the regional leader in leveraging research and industrial capacity for competitive advantage in high-technology exports.

Table 5. Assessing the Determinants of High-Tech Exports: Regression Evidence from Georgia and Türkiye

Country	Predictor	Coefficient (β)	p-value	R^2	Interpretation
Georgia	High-Tech Mfg.	0.75	0.01	0.72	Strong positive effect
	ICT Exports	0.12	0.35	–	Insignificant

Country	Predictor	Coefficient (β)	p-value	R^2	Interpretation
Türkiye	High-Tech Mfg.	0.88	<0.001	0.83	Very strong positive effect
	ICT Exports	0.05	0.65	–	Insignificant

Source: The regression analysis presented in this study was performed and calculated using Python programming tools

Georgia – High-tech manufacturing is a significant positive predictor of high-tech exports ($\beta = 0.75$, $p = 0.01$), explaining 72% of the variance ($R^2 = 0.72$). However, ICT exports do not significantly predict high-tech export performance ($p = 0.35$).

Türkiye – High-tech manufacturing shows an even stronger positive relationship with high-tech exports ($\beta = 0.88$, $p < 0.001$), with 83% of the variance explained ($R^2 = 0.83$). ICT exports again are not significant ($p = 0.65$).

The subsequent analysis focuses on Table 6, which presents comparative data on human capital and education indicators in Azerbaijan, Georgia, and Türkiye for the period 2015–2024. The longitudinal data on education expenditure, tertiary enrolment, and the share of graduates in science and engineering reveal notable disparities in educational investment and outcomes among Azerbaijan, Georgia, and Türkiye.

Azerbaijan maintained relatively low education expenditure levels, fluctuating between 2.4% and 3.5% of GDP across the indicated period. Despite incremental growth in tertiary enrolment from 20.4% gross enrolment in 2015 to 41.8% in 2024, Azerbaijan's percentage of graduates in science and engineering showed only modest improvement, rising from 16.2% to 25.3%. This suggests some expansion in access to higher education but limited structural shifts toward STEM disciplines. The late surge in tertiary enrolment, particularly after 2020, indicates intensified efforts to broaden participation but may not yet translate into proportionate gains in science and engineering specialization.

Table 6. Human Capital and Education indicators (2015–2024)

Years	Azerbaijan			Georgia			Turkiye		
	Expenditure on education, % GDP	Tertiary enrolment, % gross	Graduates in science and engineering, %	Expenditure on education, % GDP	Tertiary enrolment, % gross	Graduates in science and engineering, %	Expenditure on education, % GDP	Tertiary enrolment, % gross	Graduates in science and engineering, %
2015	2.4	20.4	16.2	2	33	20.7	2.9	69.4	20.9
2016	2.5	23.2	22	2	39.2	16.7	2.9	79	20.9
2017	2.6	25.5	22	2	43.4	16.7	4.8	86.3	20.9
2018	3	27.2	24.2	3.8	51.9	21.7	4.4	95.4	20.2
2019	2.9	27.1	23.6	3.8	57.5	21.9	4.3	103.7	20.2
2020	2.5	27.7	23.5	3.8	63.5	24.6	-	-	20.2
2021	2.5	28.7	25.9	3.5	63.9	24.6	-	113.2	19.4
2022	2.7	35.2	24.2	3.9	66.7	18.6	4.3	115	15.2
2023	3.5	38.2	24.2	3.6	72.5	19.6	3.4	117.1	15.2
2024	2.9	41.8	25.3	3.8	78.5	19.6	2.6	125.8	15.8

Source: SSCRA database (2015-2024), GII Reports 2015-2024.

Georgia demonstrated consistent increases in both education expenditure and tertiary enrolment. Public education spending rose from 2% of GDP in 2015 to approximately 3.8–3.9% by 2024. Gross tertiary enrolment expanded significantly, reaching 78.5% by 2024, more than doubling

the 2015 figure of 33%. Nevertheless, the share of graduates in science and engineering oscillated without a clear upward trajectory, peaking at 24.6% in 2020–2021 before declining to 19.6% by 2024. This pattern highlights a potential misalignment between rapid enrolment growth and sustained investment in STEM-focused curricula.

Türkiye, by contrast, initially exhibited the highest tertiary enrolment levels, with gross enrolment rising from 69.4% in 2015 to an impressive 125.8% in 2024. However, education expenditure displayed a declining trend in recent years, dropping from 4.8% of GDP in 2017 to just 2.6% by 2024. Despite strong participation rates, Türkiye's percentage of graduates in science and engineering fell steadily, from over 20% earlier in the period to just 15.8% by 2024. This divergence suggests that although Türkiye succeeded in expanding access to tertiary education, the quality or orientation of programs toward scientific and engineering fields may have weakened, raising concerns about the effectiveness of education policy in supporting technological competitiveness.

5. DISCUSSION

The findings of this study provide critical insights into the divergent trajectories of economic growth, innovation performance, and human capital development in Azerbaijan, Georgia, and Türkiye between 2015 and 2024. The analysis highlights stark contrasts in the effectiveness of R&D investment, the integration of high-technology sectors, and the capacity of education systems to support technological upgrading.

5.1. Economic and Productivity Dynamics.

Türkiye's GDP growth and productivity trends reflect a sustained capacity for large-scale expansion, yet recent deceleration in productivity growth points to emerging structural bottlenecks. While Türkiye's absolute economic scale outpaces its neighbors, maintaining competitiveness will depend on resolving vulnerabilities linked to macroeconomic instability and ensuring continued gains in productivity. Georgia's robust post-pandemic acceleration in labor productivity suggests successful reforms and modernization efforts, positioning it as a model for small economies seeking convergence with more advanced peers. By contrast, Azerbaijan's slow productivity gains despite strong GDP rebound post-2020 underscore persistent challenges of a hydrocarbon-dependent economy, highlighting the critical need for diversification into non-oil sectors.

5.2. Innovation System Performance.

Türkiye stands out as the regional leader in leveraging R&D spending for measurable innovation outcomes. The significant positive correlation ($r=0.67$, $p=0.03$) between Türkiye's R&D expenditure and patent intensity suggests an effective alignment between investment and output, supported by mature institutional frameworks and commercialization channels. Furthermore, the very strong correlation between high-tech manufacturing and exports ($r=0.91$, $p<0.001$) reflects Türkiye's advanced industrial base, enabling it to translate production capacity directly into competitive export performance.

Georgia exhibits a strong relationship between high-tech manufacturing and high-tech exports ($r=0.75$, $p=0.01$), indicating effective translation of production into trade gains. However, the moderate negative, statistically insignificant correlation between R&D expenditure and patent productivity ($r=-0.52$, $p=0.12$) points to inefficiencies or disconnects in its innovation ecosystem, such as weak research commercialization or inadequate incentives for patenting. This suggests that Georgia's high-tech export performance is currently driven more by production capacity and trade integration than by sustained innovation.

In Azerbaijan, the weak and insignificant correlation between R&D expenditure and patents ($r=0.15$, $p=0.68$) reveals a disconnect between research investment and innovation outputs, reinforcing concerns about the limited institutional effectiveness of its innovation system. Despite a strong positive relationship between high-tech manufacturing and exports ($r=0.82$, $p=0.007$), the volatility of manufacturing shares over the period indicates sporadic rather than systematic high-tech development, likely reflecting dependence on individual industrial projects linked to oil market cycles.

5.3. Human Capital and Education.

Patterns in education indicators suggest that while access to tertiary education has expanded significantly in Georgia and Türkiye, aligning educational outcomes with innovation needs remains a critical challenge. Georgia's rapid increase in tertiary enrolment, coupled with stagnating or declining shares of graduates in science and engineering, indicates a potential mismatch between expanded access and the quality or relevance of education for technology-intensive sectors. Türkiye's declining education expenditure, alongside a drop in STEM graduation rates despite very high enrolment, suggests that broad participation alone is insufficient to ensure a skilled workforce for innovation-driven growth.

Azerbaijan, despite modest gains in tertiary enrolment, continues to lag in both education investment and specialization in science and engineering fields, reinforcing structural weaknesses in its human capital base. These education dynamics across all three countries underscore that quantitative expansion of enrolment must be accompanied by qualitative improvements in curriculum design, STEM focus, and alignment with labor market needs.

5.4. Structural Transformation and Policy Implications

Collectively, the results indicate that Türkiye is the only country among the three to have achieved a relatively mature structural transformation, characterized by sustained increases in R&D expenditure, stable high-tech manufacturing shares, and rising high-tech exports. This trajectory reflects the effectiveness of long-term policy commitments, such as Türkiye's Vision 2023, which prioritized technological upgrading and innovation capacity-building.

Georgia's mixed performance—with promising advances in productivity and ICT services exports but setbacks in patent output and inconsistent high-tech manufacturing—highlights the importance of policy coherence and targeted support for research commercialization. Strategic efforts to bridge the gap between R&D investment and innovation outputs could help sustain Georgia's momentum toward a diversified, innovation-driven economy.

Azerbaijan's findings emphasize the limitations of a resource-dependent growth model in fostering innovation-led development. The absence of meaningful increases in R&D spending, coupled with stagnant patent productivity and volatile high-tech manufacturing, suggests that diversification beyond hydrocarbons remains more rhetorical than substantive. Coordinated policies incentivizing private-sector R&D, strengthening research institutions, and developing STEM education pipelines will be essential for Azerbaijan's transition toward a knowledge-based economy.

CONCLUSION

This study has examined the economic, innovation, and human capital dynamics of Azerbaijan, Georgia, and Türkiye over the period 2015–2024, revealing distinct pathways of development and structural transformation in each country. The findings underscore that while all three economies have achieved notable progress in certain dimensions, the depth, consistency, and sustainability of these advances vary significantly.

Türkiye emerges as the regional leader in cultivating an innovation-driven economy, demonstrating strong and sustained commitments to R&D investment, high patent productivity, and robust high-tech manufacturing and export performance. These achievements reflect the benefits of comprehensive policy frameworks, effective institutional support, and integration into global value chains, highlighting Türkiye's ability to translate innovation inputs into tangible economic outcomes.

Georgia's trajectory is characterized by encouraging improvements in labor productivity and ICT services exports, indicating successful steps toward digital transformation and economic diversification. However, stagnation in R&D spending and declining patent productivity reveal persistent structural weaknesses in its innovation ecosystem. Addressing these gaps through targeted policies to strengthen research commercialization and enhance STEM education will be critical for consolidating Georgia's progress.

Azerbaijan's experience illustrates the limitations of a resource-based growth model in fostering innovation-led development. While the country has recorded GDP growth, particularly

following the post-pandemic recovery, innovation indicators remain stagnant, with minimal increases in R&D expenditure, low patent intensity, and highly volatile high-tech manufacturing performance. These patterns highlight an urgent need for strategic diversification beyond hydrocarbons, requiring coordinated investments in research capacity, institutional reforms, and human capital development.

The comparative analysis of education indicators further reveals that expanding tertiary enrolment alone is insufficient to secure innovation capacity; aligning educational outputs with labor market and technological needs is essential for translating increased participation into skilled human capital. This is particularly important given that Türkiye, despite leading in enrolment, faces declining STEM graduation shares, while Georgia's rising enrolment has not yet yielded sustained improvements in science and engineering specialization.

Overall, the results demonstrate that building resilient, innovation-oriented economies in the region demands more than isolated investments or short-term initiatives. Long-term, coherent strategies integrating R&D funding, industrial upgrading, and education reform are essential to fostering sustainable, high-value economic growth. By aligning policy priorities with effective institutional frameworks and human capital development, these countries can better position themselves to compete in an increasingly knowledge-based global economy.

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