

Araştırma Makalesi | Research Article

Kentleşme, Ar-Ge, Ekonomik Büyüme ve Hava Ulaşım İlişkisi: Üst- Orta Gelirli Ülkeler Analizi

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Öz

Günümüz dünyasında özellikle ülkelerin ve şehirlerin araştırma geliştirme faaliyetleri, kentlerde yaşanan gelişmeleri ve ekonomilerinde yaşanan gelişmeler hava ulaşım üzerinde önemli etkiler bırakmaktadır. Bu çalışmanın amacı, araştırma ve geliştirme (Ar-Ge) harcamalarının, kentleşme nüfus oranının ve gayrisafi yurt içi hasılanın (GSYİH) havayolu ulaşımına etkisinin panel veri analiz yöntemi ile incelenmesidir. Araştırmada, üst-orta ülke grubuna ait ülkelerin (Türkiye, Malezya, Arjantin, Çin, Bulgaristan, Güney Afrika, Kolombiya, Ekvator) 1995-2019 dönemi verileri kullanılmıştır. Bu bağlamda, hava taşımacılığı ulaşımı üzerinde etkili olan faktörü belirlemek için bağımlı değişken olarak hava ulaşımına ait yolcu sayısı, bağımsız değişken olarak kentleşme nüfus oranı, Ar-Ge harcamaları ve GSYİH seçilmiştir. Uygulanan bu iki testin ardından, seçilen faktörler arası uzun dönem katsayılarının tespiti için panel otoregresif dağıtılmış gecikme (autoregressive distributed lag [ARDL]) yöntemi kullanılmıştır. Kentleşme, Ar-Ge, ekonomik büyüme ve hava ulaşımı arasındaki nedensellik Granger nedensellik testi ile incelenmiştir. Araştırmanın ekonometrik analiz bulgularına göre, Ar-Ge harcamaları, kentleşme nüfus oranı ve GSYİH'nin taşınan yolcu sayısını uzun dönemde artırdığı sonucuna varılmıştır.

Anahtar Kelimeler: kentleşme nüfusu, araştırma ve geliştirme, gayrisafi yurt içi hasıla, hava ulaşımı

Relationship between Urbanization, R&D, Economic Growth and Air Transportation: Analysis of Upper-Middle Income Countries

Abstract

In today's world, research and development activities of countries and cities, urban developments and economic developments have significant impacts on air transportation. The purpose of the study is to examine the effects of research and development (R&D) expenditures, urbanization population rate and gross domestic product (GDP) on air transportation using panel data analysis method. In the study, data of the upper-middle country group (Türkiye, Malaysia, Argentina, China, Bulgaria, South Africa, Colombia, Ecuador) for the period 1995-2019 were used. In this context, to determine the factors influencing air transportation, the number of air passengers was selected as the dependent variable, while the urbanization population rate, R&D expenditures, and GDP were selected as independent variables. The analysis included Delta homogeneity tests and cross-sectional dependence tests. Unit root analysis was conducted to assess the stationarity of the selected variables. Following the unit root tests, Pedroni cointegration, Kao, and Westerlund tests were conducted to determine the existence of a long-term relationship between the variables. After these two tests were applied, the panel ARDL method was used to determine the long-term coefficients between the selected factors. The causality between urbanization, R&D, economic growth and air transportation was examined with the Granger causality test. According to the econometric analysis findings of the research, it was concluded that R&D expenditures, urbanization population rate and GDP increased the number of passengers carried in the long term.

Keywords: urbanization population, research and development, gross domestic product, air transportation

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Relationship between Urbanization, R&D, Economic Growth and Air Transportation: Analysis of Upper-Middle Income Countries

1. Introduction

The aviation sector has become an open industry in recent years due to the rapidly developing globalization process. This situation has increased the likelihood that the airline industry is influenced by economic, social, and political factors. Additionally, it has been debated that the sector may also be affected by other macroeconomic developments and indicators within the country (Eren et al., 2020). These macroeconomic factors that affect the aviation industry are inflation, interest rates, GDP, exchange rates, unemployment, etc. Based on this debate, countries are also classified according to their income levels.

Air transportation has become an indispensable element of the modern world. As a significant factor in the global economy, it rapidly connects people, goods, and services around the world. This facilitates international trade and strengthens global economic integration. At the same time, it offers significant advantages to businesses and consumers with its fast delivery and reliability. It stimulates tourism, promotes economic growth, and plays a critical role in international logistics. The primary purpose of passenger air transportation is to facilitate access to distant opportunities that would otherwise be difficult or impossible to reach. Considering this understanding, the level of accessibility provided by air transportation can be seen as a fundamental performance measure of the air transportation system. In the context of transportation research, accessibility is generally defined as the ease or potential of spatial interaction (Bruinsma & Rietveld, 1998).

Classifying country income levels and determining the necessary conditions for transitioning to higher income brackets are of critical importance for economic development and growth. As countries increase their per capita income through economic growth, they progress from low-income to lower-middle-income, then to upper-middle-income, and ultimately to high-income status (Göktaş, 2021). When classifying countries into income groups, the following criteria should be considered: countries with an income of \$1,045 or less are categorized as "low-income," while those with an income between \$1,046 and \$12,736 are classified as "middle-

income" (Bozkurt et al., 2016). Due to the significant income disparity within the middle-income group, it is further divided into two sub-groups: "lower-middle-income" for incomes ranging from \$1,046 to \$4,125, and "upper-middle-income" for incomes from \$4,126 to \$12,736. Countries with incomes exceeding \$12,736 fall into the "high-income" category. In this context, to enhance the resilience of upper-middle-income countries compared to high-income countries, higher investment expenditures are required (Aykırı, 2017).

In this world of rapidly increasing global competition, research and development (R&D) has become a topic of debate due to its impact on the economic and social life of upper-middle-income countries. Economic growth is critical to every national economy. Science, technology, and innovation policies are considered the main drivers of sustainable growth. Innovation can be achieved through the R&D activities of companies and countries, as well as through technology transfer from developed countries. R&D activities conducted by companies encourage technological advancements, and these advancements play a significant role in the economic growth process (Ülger, 2019).

R&D investments are a key indicator of the importance a country places on innovation and technology. Factors such as government policies, incentives, and a skilled workforce influence these investments (Erdil et al., 2003). R&D expenditures are quite high in developed countries, and these countries have achieved significant success in science, technology, and competitiveness. These investments are a key component of economic development and growth, contributing significantly to the national economy (Kaya, 2019).

Per capita income in cities is generally higher than that in the agricultural sector. Furthermore, urban organizations such as unions have increased the price of labor in cities compared to rural areas. Cities are also advantageous locations for banking services and entrepreneurship. Furthermore, individuals living in cities have access to a wider range of employment opportunities and various goods and services that are difficult to find in rural areas. These relative economic advantages offered by cities increase with urban growth and tend to attract more individuals from rural areas to cities. This situation demonstrates the significant impact of push factors on migration (Keleş, 1992).

The aviation sector is experiencing rapid technological advancements, and a significant portion of these developments is supported by R&D activities. R&D expenditures play a critical role in the renewal of aviation technologies, increased efficiency, and environmental sustainability. Urbanization, on the other hand, presents both opportunities and challenges for the aviation sector. Population growth in major cities allows for increased airport traffic and increased passenger capacity for airlines. However, the complexity of urban transportation and infrastructure challenges can also limit aviation sector growth. Especially in upper-middle-income countries, aviation sector growth is often closely linked to urbanization processes. Urban growth in these countries can contribute to the expansion of the aviation industry by increasing demand for air travel. In this context, the importance of R&D expenditures for aviation should be emphasized in terms of developing innovative solutions and achieving a competitive advantage in the sector.

Therefore, upper-middle-income countries should focus on increasing their national savings rates and investments in R&D. In this context, the selected variables are chosen based on the assumption that R&D expenditures, urban population growth, and GDP growth influence the aviation sector. A review of the literature indicates that the causal relationship between R&D expenditures, urban population growth, and airline passenger numbers has not been tested. Thus, the findings of this study are expected to contribute to future research in both the aviation sector and econometrics.

In this study, the impact of R&D expenditures, urban population growth, and GDP on air cargo volumes and passenger numbers was analyzed using annual data from 1995 to 2019 for eight upper-middle-income countries (Malaysia, Türkiye, China, South Africa, Colombia, Argentina, Ecuador and Bulgaria). In this study, first, an introduction and literature review are presented. Second, the study's methodology is discussed. Third, a statistical analysis is conducted. Finally, a general evaluation and policy recommendations are presented.

A review of the literature on aviation transportation reveals that studies frequently examine its relationship with economic growth. However, research exploring the connections between aviation transportation, R&D, and urbanization is relatively

scarce. The limited number of such studies highlights the originality of this research.

Studies examining the relationship between airline transportation and urbanization often focus on the environmental impacts of aviation rather than directly addressing airline transportation itself. For instance, Song et al. (2023) investigated the relationship between logistics efficiency and urbanization for Korea using Granger causality tests for the period 2010-2018. Their study found a long-term, unidirectional causal relationship between growing exports, urbanization, and industrialization, and the variables and changes in air traffic considered for airline transportation.

In Rahian (2025), sustainable aviation fuels (SAF), electric and hydrogen-based propulsion systems, and the modernization of air traffic management are identified as the primary focus areas for the transformation of the aviation sector. The study emphasizes that economic feasibility, the level of technological maturity, regulatory uncertainties, and consumer behavior constitute critical determinants of this transition. Moreover, the adoption of integrated policy approaches, the strengthening of public-private partnerships, increased investments in R&D activities, and the encouragement of consumer engagement are highlighted as key enablers in facilitating systemic change within the sector.

In the literature review of this study, studies examining the relationship between urbanization, R&D, economic growth and air transportation factors are included in the tables.

Table 2 presents studies examining airline transportation and economic growth. The common finding across these studies is that there is a positive relationship between airline transportation and GDP.

In the study conducted by Mishra (2025), the decisive impacts of the aviation sector on global economic development are examined. The research findings, based on both quantitative survey data and qualitative interviews, reveal that aviation makes significant contributions to GDP growth, employment, trade facilitation, and foreign direct investment.

Table 1. R&D and Urbanization Studies

Author	Period	Country	Method	Variables	Results
Wang et al. (2012)	1997-2010	China	STIRPAT Model	GDP Per Capita, R&D Output, Urbanization, Energy Intensity	Urbanization, economy and industrialization have been seen to have a positive effect on CO2 emissions. In addition, industrial rate R&D and energy intensity are seen to have a negative effect.
Xu and Lin (2016)	2000-2013	China	LLC, Breitung and Hadri Test	R&D Investments	Large differences in R&D investments are higher compared to western regions and the center. It has regional differences in terms of urbanization due to differences in real estate development and human capital accumulation.
Dai et al. (2017)	2005-2007	China	Urban Economics, R&D Applications, Total Factor Productivity	Air Passenger Numbers, Air Cargo Volumes, GDP	It presents a non-linear relationship between urban economies and the TFP of Chinese R&D practitioners.
Estrin et al. (2017)	2006-2010	18 European Countries	R&D Intensity, Annual R&D Expenditure	Passenger and Cargo Transportation, GDP	As urbanization expands abroad, it appears to partially replace internal R&D capabilities while complementing firm financial resources.

Table 2. Economic Growth and Air Transportation Studies

Author	Period	Country	Method	Variables	Results
Hu et al. (2015)	2006-2012	China	System Generalized Method of Moments Granger Causality	GDP, Domestic, Air Passenger Traffic	It shows evidence of a long-term relationship between GDP and domestic air travel. Specifically, it was found that a 1% increase in air travel resulted in a 0.943% increase in real GDP
Manga et al. (2019)	1967-2015	Türkiye	VECM Granger Causality	Air Passenger Numbers, Air Cargo Volumes, GDP,	In the long term, the aviation sector is observed to have a unidirectional and positive impact on economic growth.
İslamoğlu (2022)	1960-2019	Türkiye	Hatemi-J (2008) Double Threshold Cointegration Fmols (Full Modified Ordinary Least Square)	Passenger and Cargo, Transportation, GDP	According to the long-term coefficient estimation, a 1% increase in passenger numbers leads to a 0.249% increase in economic growth, while a 1% increase in cargo transportation results in a 0.440% increase in economic growth.
Atioğlu. (2021)	1971-2019	Türkiye	Johansen Cointegration Vector Error Correction	GDP, Number of Single Operations (Landings) Conducted by Aircraft Domestically and Internationally Air Transportation	It has been observed that the operations (landings) conducted by Turkish-registered aircraft both domestically and internationally have a significant impact on GDP.
Çelik et al. (2025)	1970-2021	Top ten countries with the largest air transport volume worldwide	Toda-Yamamoto and bootstrap Fourier Toda-Yamamoto causality tests		The empirical findings reveal the existence of a unidirectional causal relationship running from air transportation to economic growth in all countries except Russia and Brazil.

Table 3. Air Transportation and R&D Expenditure Studies

Author	Period	Country	Method	Variables	Results
Wang (2011)	2001-2008	Taiwan	Panel Data Analysis Method	Airline Transportation, R&D Expenditures	It was confirmed that the level of R&D corresponds to optimum performance and that there is a threshold value indicating the minimum level of R&D required.
Ergün (2021)	2000-2016	11 Developing Countries	Hausman and Wald Test	R&D Expenditures, Financial Leverage Ratio	According to the findings obtained from the analysis, significant and positive relationship between financial development and R&D expenditures has been identified.
İqbal et al. (2022)	2000-2019	Brazil, China, South Africa, Mexico, Türkiye	Dynamic Ordinary Least Squares (DOLS),	Air Transportation, R&D Applications	Air transportation load, foreign direct investment technological innovation, and positively impact economic growth.

Liang et al. (2025) examined the complex relationship between aviation logistics and regional economies in their study and developed a System Dynamics model to identify the dynamic mechanisms and key determinants that drive high-quality and sustainable regional economic development through aviation logistics. The findings indicate that aviation logistics makes a significant contribution to regional economic development.

Studies examining the relationship between airline transportation and urbanization often focus on the environmental impacts of aviation rather than directly addressing airline transportation itself. For instance, Song et al. (2023) investigated the relationship between logistics efficiency and urbanization for Korea using Granger causality tests for the period 2010-2018. Their study found a long-term, unidirectional causal relationship between growing exports, urbanization, and industrialization, and the variables and changes in air traffic considered for airline transportation.

Kuz (2021) The study was conducted using secondary data obtained from the annual reports of 19 European airlines that are members of the European Common Aviation Area (ECAA). Using panel data analysis for the 2007–2017 period, it concluded that globalization has a significant and positive effect on operational performance. In their study, Kuyucak et al. (2008) focused on the growth and business strategies of TAV Airports Holding, which operates as a constructor, operator, and service provider at both national and international levels, taking globalization criteria into account. The findings show that the privatization of airport terminals in Türkiye achieved success beyond expectations in a very short period, and that the transfer of the acquired know-how to other countries has contributed to internationalization efforts. In their study, Guimera et al. (2005) examined the structure of the global air transportation network, a critical infrastructure with significant impacts on national and international economies. The findings reveal that this network exhibits scale-free and small-world characteristics.

In his study, Ergün (2022) investigated the effect of R&D expenditures in the Turkish aviation sector on the sector's financial performance by analyzing annual industry data covering the period 2008–2021. The analysis results indicate that R&D expenditures in the aviation sector have a statistically significant and positive effect on the sector's financial

performance. In their study, Pereira et al. (2021) noted that various innovative solutions have been developed in the aviation sector, benefiting the air travel industry as well as many other industrial and service organizations. However, to recall these innovations and, more importantly, to evaluate how they add value to aviation enterprises, they conducted a systematic literature review. By analyzing 57 peer-reviewed academic publications from 1999 to 2018, they identified 114 value-creating innovations in the areas of “efficiency,” “convenience, new features, and portfolio differentiation,” and “sustainable growth and environment. In their study,

Baltacı et al. (2015) applied a region-fixed effects model and the two-stage least squares (2SLS) method using panel data for 26 sub-regions at the NUTS 2 level in Türkiye, covering the period 2004–2011. The findings indicate that the increase in the number of active airports and traffic frequency has a positive effect on regional economic growth. In their study, Zhang and Graham (2020) aimed to present a synthesis review of the channels through which the aviation sector interacts with the regional economy. The review focuses on quantitative studies that contribute to the most up-to-date understandings of causality. The findings reveal that the reciprocal causal relationship is more likely to prevail in less developed economies.

In national sustainability practices, transportation systems make significant contributions to national sustainable growth. Air transportation is a cornerstone of economic growth, development, and the enhancement of people's overall well-being. It enables and supports trade, facilitates tourism, creates job opportunities, and brings people closer together. Passenger transportation has become an indispensable element of the modern world. This mode of transportation plays a significant role in economic, social, and cultural aspects. Aviation strengthens global connections, deepens economic integration, and maintains its position as a key component of sustainable development. The aviation industry has been a rapidly growing and developing sector in recent years, and the importance of sustainability has been increasing in this process.

R&D activities conducted to drive innovation in the economy can impact the sustainability of GDP, employment generation potential, productivity growth, and consequently, socioeconomic development. In this context, the selected variables,

R&D expenditures, were chosen considering that the growth in urban populations and GDP growth will affect air transportation in countries. The literature review revealed that the relationship between R&D expenditures, urban population growth, and air transportation has not been examined in upper- and middle-income countries. Therefore, this study, which uses econometric analysis, is expected to contribute to the air transportation literature.

2. Method

In this study, air passenger numbers (APN) are the dependent variable, while R&D expenditures, urban population rate (UP), and gross domestic product are the independent variables.

The study uses the panel ARDL method. Econometric data for analysis are generally classified as cross-sectional data and time series data. Unlike time series data, panel data includes both horizontal and vertical (time) dimensions of the data.

Panel data are defined by different names depending on the data type. If each unit is observed continuously, it is called a balanced panel; if data for some units are missing or incomplete, it is called an unbalanced panel. If the number of units in a panel data set equals the number of observations, it is called a balanced panel; if not, it is called an unbalanced panel. If the cross-sectional dimension of a panel data set is longer than the time dimension, it is called a short panel. Otherwise, it is called a long panel (Tatoğlu, 2012). When using panel data models, more observations are examined because time and measurement units are considered together (Wooldridge, 2015).

Unlike the Johansen and Juselius (1990) cointegration procedure, the autoregressive distributed lag (ARDL) approach to cointegration helps determine cointegration vectors. That is, each of the underlying variables stands as a single long-run relationship equation (Özel, 2022). With the ARDL method, the short-run and long-run relationship between variables can be assessed simultaneously. On the other hand, unlike traditional cointegration tests, the ARDL method allows for specifying different lags for each variable in the model (Özel, 2022). Because ARDL is a dynamic single-model equation and has the same form as the error correction model (ECM), reparameterization is possible. The distributed lag model means

incorporating unlimited lags of regressors into a regression function (Esen et al., 2012).

In the study, annual R&D expenditures, urban population, air cargo volumes, number of air passengers, and GDP data are utilized. GDP is represented by GDP per capita in constant 2010 US dollars, R&D expenditures are expressed as a percentage of GDP, and urban population is presented as a percentage of the total population. The data, sourced from the World Bank (2022), are used as sustainable development goal indicators. The analysis focuses on 8 upper-middle-income countries with data available for the period 1995-2019. To reduce variance, all variables are used in their natural logarithmic form.

Due to the meaninglessness of the data for the years 2020-2021, when air transportation came to a halt due to the Covid epidemic in the world, and the limitation of fully disclosing the current data, current data could not be used in the study.

3. Results

To test the long-term relationship between R&D expenditures, urbanization, and GDP with the number of air passengers transported for the selected country group, the Pedroni and Kao cointegration tests are employed. To examine how the independent variables—R&D expenditures, urbanization, and GDP—affect the dependent variable, which is the number of air passengers transported, the panel ARDL coefficient estimation test is used. Additionally, to test the causality among the variables, the Granger causality test is applied.

The empirically relevant variables included in our model are summarized in Table 4. Due to data limitations, there are a maximum of 200 observations, and there are 4 variables in total, with only one of them being dependent on the others.

Table 4. Descriptive Statistics

	GDP	R&D	UP	APN
Mean	9.22E+11	0.520247	97472623	444230.13
Median	3.04E+11	0.454915	31173124	118979.67
Max	1.15E+13	2.185680	8.43E+08	6.60E+08
Min	3.11E+10	0.000000	5256027.	62798.00
Std. dev.	2.01E+12	0.488592	1.97E+08	1.01E+08
Probability	0.000000	0.000000	0.000000	0.000000
Obs	200	200	200	200

Table 5 shows the delta homogeneity test results. The Pesaran-Yamagata slope homogeneity test

results reveal that variables affecting aviation transportation respond differently across countries. This demonstrates that cross-country differences must be taken into account and that uniform policy recommendations cannot have the same impact across countries.

Table 5. Delta homogeneity test results

Test	Statistic	P-value
Δ	6.929	0.000
Δ adj	7.747	0.000

Table 6 shows the cross-sectional test results. The results indicate a strong cross-sectional dependence between the aviation transportation variable in the study and the independent variables.

Table 6. Results from cross-section independence test

	Y1	X1	X2	X3
CD-test	21.378	25.569	9.422	26.185
p-value	0.000	0.000	0.000	0.000

3.1. Unit Root Tests

According to Levin, Lin, and Chu (LLC, 2002), individual unit root tests may have limited power against alternative hypotheses that suggest deviations from equilibrium, particularly in small samples. Levin et al. (2002) proposes a more powerful panel unit root test where different unit root tests can be applied for each cross-section. The alternative hypothesis for the panel unit root test suggests that each time series in the panel is stationary, while the alternative includes a unit root (Levin et al., 2002, as cited in Baltagi, 2005).

The panel unit root test proposed by LLC (2002) is evaluated by comparing it with the critical values provided by Levin et al. (2002). If the null hypothesis is rejected, it is concluded that each series in the panel does not follow a unit root process, meaning it is stationary (Levin et al., 2002, as cited in Baltagi, 2005 and Tatoğlu, 2013). To apply the panel unit root test, the series must form a balanced panel.

The Im, Pesaran, and Shin (IPS, 2003) panel unit root test removes the requirement of homogeneity of autoregressive coefficients across cross-sections, which is a fundamental assumption of the LLC (2002) test, and allows for heterogeneity in the coefficients (Levin et al., 2002 and IPS, 2003 as

cited in Baltagi, 2005). In other words, unlike panel unit root tests such as those by LLC (2002) and Harris and Tzavalis (1999), which assume that the series for all units should have a common autocorrelation coefficient, the IPS (2003) test allows each unit to have its own autocorrelation coefficient, and it is accepted that ρ can vary across units (Levin et al., 2002 and Harris & Tzavalis 1999, as cited in Tatoğlu, 2013).

In the IPS (2003) unit root test, the heterogeneity of the coefficient y_{it-1} is considered, and a test process is followed based on the average of unit root test statistics for all series.

The panel IPS (2003) unit root tests for all variables are conducted at both levels and first differences, as shown in Table 7. It can be inferred from Table 7. that the unit root hypothesis is rejected when the variables are considered at the level. However, when first differences are used, it is accepted that the unit root is stationary at the 1% significance level. These results allow for the testing of cointegration among variables that are I(1).

Table 8 shows the cross-sectionally Im-pesaran-shin (CIPS) and cross-sectionally augmented dickey-fuller (CADF) test results. The CIPS and CADF tests used in the study were applied to test the stationarity of the variables at the level and when the first differences were taken. The findings reveal that first differences must be taken for all variables to become stationary.

3.2. Cointegration Test

When the data are stationary or homogeneous, the panel cointegration test determines whether there is a long-term stable relationship between the stationary or first-differenced integrated variables (Mamedov, 2023). If a long-term stable relationship exists, an appropriate method for prediction can be selected; if not, further progress cannot be made, and reconsideration of the variable selection may be necessary. In this study, the Pedroni panel cointegration test developed by Pedroni (2001) has been used. As shown in Table 9, the Pedroni and Kao cointegration test indicates that there is no long-term cointegrated relationship among the variables.

As shown in Table 9, the results of the Pedroni cointegration test indicate that none of the four panel statistics are statistically significant. Additionally, the group statistics also do not show statistical significance. Since both the panel variance and

group rho statistics are not significant, the null hypothesis (H0), which states that "there is no cointegration," has been accepted. In this context, it is concluded that there is no long-term relationship among the variables based on the test results.

Table 10 shows the Westerlund test for cointegration results. Westerlund test results support the existence of a long-run cointegration relationship in the model.

Table 7. Results of IPS Unit Root Tests

(LLC)				
Variables	I [0]		I [1]	
	Individual Effects	Individual Linear Trends	Individual Effects	Individual Linear Trends
APN	9.73930	0.03104	-4.72404***	-5.85133***
R&D	-1.08807	6.17060	- 5.63977***	-3.63821***
UP	-2.91075	-0.14059	- 2.09495	-13.8228***
GDP	3.02668	-1.66856	-4.08817***	- 6.80837***

(IPS)				
Variables	I [0]		I [1]	
	Individual Effects	Individual Linear Trends	Individual Effects	Individual Linear Trends
APN	8.56139	2.60640	-4.37218***	-4.80284***
R&D	-3.08272	2.59111	-6.71033***	-5.65408***
UP	-0.88564	-1.63085	- 0.99072	-4.91940***
GDP	6.06215	1.55749	-4.89042***	-4.98163***

Note. *** Statistical significance at the 1% level

Table 8. CIPS & CADF Tests

Variables	CIPS		CADF	
	I(0)	I(1)	I(0)	I(1)
Y1	-1.264	-4.206***	-1.264	-4.813***
X1	-1.065	-3.754***	-1.352	-3.902***
X2	-2.544**	-4.903***	-3.093***	-5.121***
X3	-2.360**	-4.142***	-2.432**	-4.142***

Note. ***, **, and * indicate stationarity at the 1%, 5%, and 10% levels, respectively.

Table 9. Results of the Pedroni Cointegration and Kao Tests

Pedroni	Statistic (Panel)	Weighted Statistic
V	0.367876	-0.327701
Rho	0.666115	1.379663
PP	-0.894351	-0.120366
ADF	0.089385	-0.673040
V	0.367876	-0.327701

Alternative hypothesis: individual AR coefs. (between-dimension)		
Statistic (Group)		
Pedroni		
Rho	2.320334	
PP	0.206041	
ADF	-0.739184	

Kao	
ADF	1.872275***
Residual variance	0.007298
HAC variance	0.006900

Table 10. Westerlund Test for Cointegration

	Statistic	p-value
Variance ratio	-2.3861	0.0085***

Note. ***, **, and * indicate stationarity at the 1%, 5%, and 10% levels, respectively.

3.2. Panel Autoregressive Distributed Lag Model

Before estimating the ARDL model, a unit root test is performed, followed by a cointegration test. The ARDL model offers a suitable method for small sample sizes and allows for distinguishing between short-term and long-term coefficients. Additionally, it is useful for examining long-term data (Tukhtamurodov et al., 2024).

The model used in the study is formulated below.

$$F(APN) = [\{R\&D, GDP, UP\}] \quad (1)$$

$$APN_t = \beta_0 + \beta_1 R\&D_t + \beta_2 GDP_t + \beta_3 UP_t + \mu_t \quad (2)$$

Table 11 presents the results of the long-term ARDL coefficient estimation test for the countries included in the analysis. When examining Table 11, it is observed that in the long term, R&D expenditures, urbanization population, and GDP have a positive effect on the number of air passengers. Among the variables considered, GDP and urbanization population ratio are statistically significant at the 1% level, except for R&D expenditures. When examining the short-term results, GDP and R&D expenditures negatively affect the number of air passengers.

Table 11. ARDL Test Results (Dependent Variable: Air Passenger Count)

Variable	Coefficient	Std. Error	t-S
Long Run Equation			
GDP	0.889286***	0.189228	4.699538
R&D	0.128309	0.105906	1.211536
UP	1.292339***	0.314131	4.114014
Short Run Equation			
COINTEQ01	-0.451315***	0.139649	-3.231770
D(GDP)	1.140826***	0.337635	3.378872
D (GDP (-1))	-1.289416***	0.409932	-3.145434
D (GDP (-2))	-0.537023	0.422757	-1.270290
D (R&D)	-0.035948	0.105102	-0.342027
D (R&D (-1))	-0.176865	0.113000	-1.565170
D (R&D 2))	-0.175229***	0.073646	-2.379344
D (UP)	12.88659	21.90780	0.588219
D (UP (-1))	-4.368382	29.58665	-0.147647
D (UP (-2))	-2.476570	13.78728	-0.179627
C	-5.608667***	1.864448	-3.008218

Note. *** Statistical significance at the 1% level

3.4. Granger Causality Results

Cointegration relationship tests the causality of variables in one direction. To test the causality in both directions between variables, the panel-based Granger causality test developed by Engle and Granger is used (Engle & Granger, 1987).

The Granger causality model is demonstrated using Formula 3. This test analyzes whether the coefficients of the lagged values of the independent variables in Formulas 3 and 4 are collectively equal to zero at a certain significance level. If the coefficients in Formula 3 are found to be significantly different from zero, it is concluded that X Granger-causes Y. Similarly, if the coefficients in Formula 4 are found to be significantly different from zero, it is concluded that Y Granger-causes X (Engle & Granger, 1987).

$$y_{1t} = \alpha_{10} + \beta_{11}y_{1t-1} + \beta_{12}y_{2t-1} + \gamma_{11}y_{1t-2} + \gamma_{12}y_{2t-2} + \delta_{11}y_{1t-3} + \delta_{12}y_{2t-3} + u_{1t} \quad (3)$$

$$y_{2t} = \alpha_{20} + \beta_{21}y_{1t-1} + \beta_{22}y_{2t-1} + \gamma_{21}y_{1t-2} + \gamma_{22}y_{2t-2} + \delta_{21}y_{1t-3} + \delta_{22}y_{2t-3} + u_{2t} \quad (4)$$

As seen in Table 12, there is a one-way relationship from GDP to the number of air passengers. However, no causality relationship was found between R&D expenditures and urbanization population with the number of air passengers. Similarly, when examining the relationships among the independent variables, it was concluded that there is a one-way causality relationship from GDP to R&D expenditures. No causality relationship was found between urbanization population and GDP.

Table 12. Granger Causality Results

	F-Statistic	Prob.	Result
GDP → APN	2.89659	0.0578***	Causality exists.
APN ---- GDP	1.12511	0.3269	No causality.
R&D---- APN	0.02608	0.9743	No causality.
APN ---- R&D	0.02608	0.9743	No causality.
UP ---- APN	1.36490	0.2581	No causality.
APN ---- UP	1.84806	0.1605	No causality.
R&D ---- GDP	0.12622	0.8815	No causality.
GDP → R&D	3.89228	0.0221***	Causality exists.
UP ---- R&D	2.40794	0.0929	No causality.
R&D ---- UP	0.61251	0.5431	No causality.

Note. *** Statistical significance at the 1% level

4. Discussion and Conclusion

The significance of the aviation industry in terms of sustainability is substantial. The sector's impact on technological innovations and R&D expenditures is a crucial factor in the economic growth strategies of countries and is continuously assessed in the global economy.

In a globalizing world, it is becoming increasingly important for countries to achieve economic growth alongside their sustainable development goals. The rise in technology usage during this process has made the impact of R&D expenditures on GDP more pronounced. Recent studies have shown that increases in R&D expenditures indirectly positively affect economic growth. However, it should also be noted that this relationship can vary depending on the income levels of the countries.

Given the technological and institutional differences between developed and underdeveloped countries, the usefulness of R&D expenditures in predicting innovation outcomes and their impact on market competition remains uncertain. In particular, in underdeveloped countries, the relationship between R&D expenditures and innovation outcomes tends to be more transparent, as the institutional environments in these countries are often less complex and R&D activities may have a more noticeable effect.

This study aims to investigate the effects and relationships of R&D expenditures, urbanization, and GDP on the aviation sector using data related to sustainable development goals. For the period 1995–2019, the ARDL coefficient estimation test, Pedroni and Kao cointegration tests, and Granger causality approach were applied to a group of 8 upper-middle-income countries. In the study, the number of air passengers was selected as the dependent variable, while GDP, R&D expenditures, and urbanization population were considered as independent variables. The research initially includes descriptive statistics. Subsequently, unit root tests were performed to assess the stationarity of the variables. Following this, the long-term and short-term relationships between the variables were analyzed using panel ARDL coefficient estimation.

According to the results of the ARDL coefficient test (with the number of air passengers as the dependent variable), GDP and the urbanization population ratio have a positive long-term effect on the number of air passengers, with data showing

statistical significance at the 1% level. However, R&D expenditures are not statistically significant. A 1% increase in GDP leads to a 0.8% increase in the number of air passengers. This may be attributed to the increased international liberalization programs or liberalization movements in the aviation sector, which could lead to a highly competitive environment. In this competitive environment, passengers may benefit from lower transportation costs. Contrary to this finding, a study by Altuntaş and Kılıç (2021) found a cointegrated relationship between passenger volume and GDP, but they could not establish a significant long-term impact of passenger and cargo volume on economic growth. A 1% increase in urbanization population results in a 1.2% increase in the number of air passengers. This increase may be due to improved labor productivity in cities, which are typically places with more intense economic activities. As economic activities in cities grow, job opportunities, income levels, and consumption patterns in urban areas may boost air travel. Supporting this observation, Beyzatlar (2021) provided empirical evidence of the relationship between urbanization and the number of air passengers. The results indicate that transportation is dynamic in relation to urbanization, and urbanization plays a facilitating role. The effectiveness of transportation services, especially in urban areas, is significant. On the other hand, it was found that R&D expenditures have no effect on the number of air passengers.

Our study found a statistically significant relationship between GDP and air transport. These results are consistent with the studies by Hu et al. (2015), Manga et al. (2019), İslamoğlu (2022), Atioğlu (2021), and Çelik et al. (2025) in the literature. Therefore, the analysis supports the relationship between GDP and air transport obtained in the results. This situation reveals that the economic activities of upper and middle-income countries are aligned with each other, especially in the planning of state support, infrastructure, and investments related to aviation. However, a possible reason for this result may be that the total value of goods transported by air represents 33% of all international trade. This share can be explained by the preference for air transport in the delivery of high-value commercial goods because it provides a fast and reliable transportation service (Akar, 2025). It can be said that the increase in GDP in upper and middle-income countries, along with increased production and expanding foreign trade, increases

the demand that fuels air transport. Therefore, it is thought that the increase in GDP increases business travel in terms of air transportation. Zhang and Graham (2020) have shown that economic growth increases the demand for air transportation in both passenger and cargo sectors. In this context, they stated that there are companies that want to expand in a city after having sufficient air services. In this case, countries will prioritize the development of the aviation sector and encourage the improvement of air services before companies actually expand. According to Stephens et al. (2014), air transportation is quite effective in attracting customers to a country for foreign direct investment. Marazzo et al. (2010) have shown that increases in GDP cause a high level of increase in demand for passenger numbers. In this context, it is thought that investments in air transportation should be planned appropriately, taking into account the volume of economic growth.

Our findings indicate that urbanization is the most influential variable on air transportation. It was found to have a statistically significant positive effect on air transportation. These results are consistent with the studies of Song et al. (2023) and Kuz (2021) in the literature. Bozma (2020) stated that with the increase in urbanization, the use of individual and public transportation vehicles (buses, airplanes, etc.) has increased. These results highlight the necessity of air transportation and airport planning in cities. Furthermore, they provide some justifications for giving more importance to the provision of aviation services and adequate airport infrastructure. Goetz (1992) revealed the relationship between air transportation and urbanization on a national scale and emphasized the need to give more importance to airport infrastructure. Beyzatlar and Dündar (2021) demonstrated the interaction between urbanization and air transportation and, based on the results, suggested that international transportation policies should be integrated around the axis of urbanization. The strong influence of urbanization on air transport in the analysis results indicates that air transport is not limited to a specific country but has spread to all middle-income countries with which it interacts due to accessibility. Özbay (2018) suggests that in order to make the journey within the city to the airport as quick as possible, connections providing access to airports within the city should be fast, have multiple options, and be easy to use.

Our analysis revealed that R&D expenditures did not yield statistically significant results. Possible reasons for this result include the fact that upper and middle-income countries do not make sufficient R&D expenditures to impact the aviation sector. Furthermore, the high cost of the aviation sector and the existence of international standards from organizations such as International Civil Aviation Organization (ICAO) and International Air Transport Association (IATA) can weaken the relationship between air transport and R&D expenditures. Güngör (2022) emphasized that aviation sector firms need significant resources during the investment phase, as well as substantial resources to continue their operations. Aktürk (2024) stressed that civil aviation is subject to strict legal regulations, and standards focused on flight safety and security are determined by authorities such as ICAO, European Union Aviation Safety Agency (EASA), and directorate general of civil aviation. He also stated that the advantages brought to the sector by current technological developments also bring new challenges. Advantages such as tax incentives and low-interest loans offered to the air transport sector can increase R&D investments. These investments can have a positive impact on air transport. In contrast to our study, Ergün (2022) found a positive relationship between aviation and R&D expenditures.

Based on the results obtained, the investment attractiveness and reliability of countries for foreign investors can be increased. The implementation of policies aimed at improving socioeconomic well-being and ensuring economic stability will positively impact air transport. The establishment of cultural and commercial bridges between countries and the facilitation of cross-border travel should be encouraged. With increasing urbanization, policies and regulations focusing on safety, security, compliance with international standards, and environmental friendliness can be developed. As countries' economic activities and urbanization increase, occupancy rates and capacity utilization rates in air transport also increase. In this context, planning new airport investments and modernizing existing airports may be necessary. The growth of the air transport sector can encourage the entry of new airlines into the market. This can benefit the sector in terms of competition.

Ethics Committee Approval Statement

Due to the method used in this study, ethics committee approval is not required.

References

- Akar, P. G. (2025). The impact of air transportation on economic growth: Novel findings from the CS-ARDL model. *Transport Policy*, 103788. <https://doi.org/10.1016/j.tranpol.2025.103788>
- Aktürk, E. B. (2024). Sivil havacılıkta kalite ve entegre yönetim sistemlerinin yeri ve önemi. *Namık Kemal Üniversitesi Sosyal Bilimler Meslek Yüksek Okulu Dergisi*, 6(2), 1–18. <https://doi.org/10.56493/nkusbmyo.1511572>
- Altuntaş, M., & Kılıç, E. (2021). Havayolu taşımacılığı ile ekonomik büyüme arasındaki ilişkinin incelemesi: Türkiye örneği. *Afyon Kocatepe Üniversitesi Sosyal Bilimler Dergisi*, 23(1), 187–202. <https://doi.org/10.32709/akusosbil.716045>
- Atioğlu, E. (2021). Türk sivil havacılık sektörünün ekonomik büyüme üzerindeki etkisi. *Nevşehir Hacı Bektaş Veli Üniversitesi SBE Dergisi*, 11(4), 1936–1945. <https://doi.org/10.30783/nevsosbilen.872160>
- Aykırı, M. (2017). Ekonomik büyümenin sürdürülebilirliği ve orta gelir tuzağından çıkışta beşerî sermayenin önemi: Yüksek ve üst orta gelirli ülkeler üzerine bir uygulama. *Uluslararası Ekonomik Araştırmalar Dergisi*, 3(4), 683–706.
- Baltacı, N., Sekmen, O., & Akbulut, G. (2015). The relationship between air transport and economic growth in Turkey: Cross-regional panel data analysis approach. *Journal of Economics and Behavioral Studies*, 7(1), 89.
- Baltacı, B. H. (2005). *Econometric analysis of panel data*. John Wiley & Sons.
- Beyzatlar, M., & Dündar, T. (2021). Hava taşımacılığı ve kentleşme: Türkiye ve Avrupa'nın en kalabalık dört ülkesindeki bağlantılılık bulguları. *Dokuz Eylül Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 23(4), 231–248. <https://doi.org/10.16953/deusosbil.1055653>
- Bozkurt, E., Sevinç, H., & Çakmak, E. (2016). Orta gelir tuzağı: Üst orta gelirli ülkeler üzerine panel veri analizi. *Ege Akademik İnceleme*, 16(2).

- Bozma, G. (2020). Havacılık sektöründe çevre yönetimi, ekonomik büyüme ve kentleşme ilişkisi: Çevresel Kuznets eğrisi üzerine bir inceleme. *Turan-Sam*, 12(48), 132–146.
- Bruinsma, F., & Rietveld, P. (1998). The accessibility of European cities: Theoretical framework and comparison of approaches. *Environment and Planning A*, 30(3), 499–521. <https://doi.org/10.1068/a3004>
- Çelik, A. K., Yalçınkaya, Ö., & Kutlu, M. (2025). The causal relationship between air transport and economic growth: Evidence from top ten countries with the largest air transport volume. *Transport Policy*, 162, 521–532. <https://doi.org/10.1016/j.tranpol.2025.01.002>
- Dai, M., Li, X., & Lu, Y. (2017). How urbanization economies impact TFP of R&D performers: Evidence from China. *Sustainability*, 9(10), 1766. <https://doi.org/10.3390/su9101766>
- Engle, R. F., & Granger, C. W. J. (1987). Cointegration and error correction: Representation, estimation and testing. *Econometrica*, 55(2), 251–276. <https://doi.org/10.2307/1913236>
- Erdil, E., İmamoğlu, S. Z., & Keskin, H. (2003). *Türkiye'de araştırma-geliştirme faaliyetleri ve yatırımlar: Mevcut durum ve politika önerileri*. TÜBİTAK.
- Eren, A. S., Eryer, A., & Eryer, S. (2020). Havayolu taşımacılığı ve ekonomik büyüme ilişkisinin incelenmesi Türkiye örneği: Ampirik bir analiz. *Uluslararası Sosyal Bilimler ve Eğitim Dergisi*, 2(3), 236–257.
- Ergün, H. O., & Ergün, T. (2021). Ar-Ge harcamaları ve finansal gelişme ilişkisi: Gelişmekte olan ülkeler örneği. *Bartın Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 12(23), 39–55. <https://doi.org/10.47129/bartiniibf.798155>
- Ergün, T. (2022). Reflection of R&D spending on financial performance: Case of aviation sector. *Anadolu Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 23(4), 443–463. <https://doi.org/10.53443/anadoluibfd.1143489>
- Esen, Ö., Süslü, B., & Akdoğan, K. (2012). Sınır testi kullanılarak ARDL modelinin test edilmesi. *Uygulamalı İstatistik Bilimleri Dergisi*, 21(2), 209–222.
- Estrin, S., Nielsen, B. B., & Nielsen, S. (2017). Emerging market multinational companies and internationalization: The role of home country urbanization. *Journal of International Management*, 23(3), 326–339. <https://doi.org/10.1016/j.intman.2016.11.006>
- Goetz, A. R. (1992). Air passenger transportation and growth in the US urban system, 1950–1987. *Growth and Change*, 23(2), 217–238. <https://doi.org/10.1111/j.1468-2257.1992.tb00580>
- Göktaş, Ö. (2021). Üst orta-gelir düzeyinde olan ülkeler orta gelir tuzağındalar mı? Fourier birim kök testlerinden kanıtlar. N. Çil (Ed.), *Ekonometride güncel yöntemler ve uygulamalar: Prof. Dr. Ahmet M. Gökçen'e armağan* içinde (ss. 207–224). İstanbul University Press.
- Guimera, R., Mossa, S., Turttschi, A., & Amaral, L. N. (2005). The worldwide air transportation network: Anomalous centrality, community structure, and cities' global roles. *Proceedings of the National Academy of Sciences*, 102(22), 7794–7799. <https://doi.org/10.1073/pnas.0407994102>
- Gujarati, D. N. (2004). *Basic econometrics* (4th ed.). McGraw-Hill.
- Güngör, H. Y. (2022). Çalışma sermayesi yönetiminin firma finansal performansına etkisi: Havacılık sektörüne yönelik bir çalışma. *Ömer Halisdemir Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 15(4), 866–878. <https://doi.org/10.25287/ohuiibf.1074978>
- Hu, Y., Xiao, J., Deng, Y., Xiao, Y., & Wang, S. (2015). Domestic air passenger traffic and economic growth in China: Evidence from heterogeneous panel models. *Journal of Air Transport Management*, 42, 95–100. <http://doi.org/10.1016/j.jairtraman.2014.09.003>
- Iqbal, A., Tang, X., Jahangir, S., & Hussain, S. (2022). The dynamic nexus between air transport, technological innovation, FDI, and economic growth: Evidence from BRICS-MT countries. *Environmental Science and Pollution Research*, 29(45), 68161–68178. <https://doi.org/10.1007/s11356-022-20633-z>

- İslamoğlu, B. (2022). Türkiye’de havayolu taşımacılığı ile ekonomik büyüme arasındaki ilişkinin yapısal kırılmalı ekonometrik yöntem yaklaşımıyla incelenmesi. *Uluslararası İşletme, Ekonomi ve Yönetim Perspektifleri Dergisi*, 5(2), 749–759. <https://doi.org/10.29228/ijbemp.52883>
- Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration—with applications to the demand for money. *Oxford Bulletin of Economics and Statistics*, 52(2), 169–210.
- Kaya, H. (2019). Ar-Ge faaliyetleri şirketleri rekabet avantajı elde etmeye teşvik ederken maliyetleri düşürmeye ve verimliliği artırmaya yönlendirir. *Bilim, Teknoloji ve Yenilik Dergisi*, 4(2), 45–62.
- Kuyucak, F., Dokmen, T., & Kaya, E. (2008, Temmuz 6–10). *Privatization to globalization: Emerging trends in airport management – TAV airports case study* [Bildiri sunumu]. 12. Air Transport Research Society (ATRS) Dünya Konferansı, Atina, Yunanistan.
- Kuz, A. (2021). *Impact of globalization on European airline market* (PhD Thesis). Vilniaus Universitetas.
- Liang, L., & Chen, P. (2025). A simulation-based empirical study on the role of aviation logistics in driving high-quality and sustainable regional economic development: Focusing on dynamic mechanisms and key factors. *PLoS One*, 20(5), e0323110. <https://doi.org/10.1371/journal.pone.0323110>
- Mamedov, N., & Koç, S. (2023). Bitcoin ile borsa endeksleri ilişkisi: Yükselen piyasa ekonomileri için panel veri analizi uygulaması. *Uluslararası Yönetim İktisat ve İşletme Dergisi*, 19(1), 34–60. <https://doi.org/10.17130/ijmeb.1176842>
- Manga, M., & Akar, H. B. P. G. (2019). Havacılık sektörü ve ekonomik büyüme: Türkiye örneği. *The Journal of Academic Social Science*, 45(45), 353–366. <https://doi.org/10.16992/ASOS.12189>
- Marazzo, M., Scherre, R., & Fernandes, E. (2010). Air transport demand and economic growth in Brazil: A time series analysis. *Transportation Research Part E: Logistics and Transportation Review*, 46(2), 261–269. <https://doi.org/10.1016/j.tre.2009.08.008>
- Mishra, P. K. (2025). The impact of aviation industry on global economic development. *International Journal of Progressive Research in Engineering Management and Science (IJPREMS)*, 5(6), 709–711.
- Özbay, K. (2018). Ulaşım yatırımları ve kentsel mekân ilişkisi. *Kent Akademisi*, 11(3), 367–373.
- Özel, Ö. (2022). *Türkiye bankacılık sektörü sorunlu kredilerinin yapısı ve belirleyicilerinin ARDL sınır testi yöntemi ile analizi* (Doktora tezi). Ankara Üniversitesi Sosyal Bilimler Enstitüsü.
- Pedroni, P. (2001). Fully modified OLS for heterogeneous cointegrated panels. *Nonstationary Panels, Panel Cointegration, and Dynamic Panels* içinde (ss. 93–130). Emerald Group Publishing Limited. [https://doi.org/10.1016/S0731-9053\(00\)15004-2](https://doi.org/10.1016/S0731-9053(00)15004-2)
- Pereira, B. A., Lohmann, G., & Houghton, L. (2021). Innovation and value creation in the context of aviation: A systematic literature review. *Journal of Air Transport Management*, 94, 102076. <https://doi.org/10.1016/j.jairtraman.2021.102076>
- Raihan, A. (2025). Sustainable aviation: A critical review of policies, technologies, and future pathways. *Journal of the Air Transport Research Society*, 100080. <https://doi.org/10.1016/j.jatrs.2025.100080>
- Song, M. J., Seo, Y. J., & Lee, H. Y. (2023). The dynamic relationship between industrialization, urbanization, CO2 emissions, and transportation modes in Korea: Empirical evidence from maritime and air transport. *Transportation*, 50(6), 2111–2137. <https://doi.org/10.1007/s11116-022-10303-x>
- Stephens, M., Ikeogu, V., Stephens, O. B., & Ukpere, W. I. (2014). Empirical analysis of the contribution of the aviation industry to the Nigerian economy. *Mediterranean Journal of Social Sciences*, 5(3), 115–123. <https://doi.org/10.5901/mjss.2014.v5n3p115>
- Tatoğlu, F. Y. (2012). *Panel veri ekonometrisi*. Beta Yayınları.
- Tatoğlu, F. Y. (2013). *Panel veri ekonometrisi: Stata uygulamalı*. Beta Yayınları.

- Tukhtamurodov, A., Sobirov, Y., Toshaliyeva, S., Ibrayimova, D., & Feruz, M. (2024). *Determinants of CO2 emissions in the BRICS. A dynamic panel ARDL approach*. BIO Web of Conferences, 82, 06002. <https://doi.org/10.1051/bioconf/20248206002>
- Ülger, Ö. (2019). *Ar-Ge teşvikleri ve harcamaları ile iktisadi büyüme arasındaki ilişkinin OECD ülkeleri çerçevesinde incelenmesi (1996-2015)*. İksad Yayınevi.
- Wang, C. H. (2011). Clarifying the effects of R&D on performance: Evidence from the high technology industries. *Asia Pacific Management Review*, 16(1).
- Wang, Z., Yin, F., Zhang, Y., & Zhang, X. (2012). An empirical research on the influencing factors of regional CO2 emissions: Evidence from Beijing city, China. *Applied Energy*, 100, 277–284. <https://doi.org/10.1016/j.apenergy.2012.05.038>
- Wooldridge, J. M. (2015). *Introductory econometrics: A modern approach*. Cengage Learning.
- Xu, B., & Lin, B. (2016). Regional differences of pollution emissions in China: Contributing factors and mitigation strategies. *Journal of Cleaner Production*, 112, 1454–1463. <https://doi.org/10.1016/j.jclepro.2015.03.067>
- Zhang, F., & Graham, D. J. (2020). Air transport and economic growth: A review of the impact mechanism and causal relationships. *Transport Reviews*, 40(4), 506–528. <https://doi.org/10.1080/01441647.2020.1738587>