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Macroeconomic Factors Affecting Performance in Air Cargo Transportation: A Panel Data Analysis of 17 European Countries*

(Research Article)

Hava Kargo Taşımacılığında Performansı Etkileyen Makroekonomik Faktörler: 17 Avrupa Ülkesine Yönelik Panel Veri Analizi

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ABSTRACT

Air cargo transportation is a major industry that accounts for a significant share of global trade and generates both economic and social benefits. The success of this industry, which involves multiple actors with diverse roles, is closely linked to macroeconomic indicators. The aim of this study is to examine the effects of macroeconomic indicators on air cargo performance by analyzing their short- and long-term impacts. Data from 17 European countries with the highest air cargo traffic during 2002–2022 were analyzed using the Panel ARDL method. Air cargo volume in ton-km was used as the dependent variable, while GDP, population, foreign trade volume, foreign direct investment, and the number of departures were considered as independent variables. Results show that in the short term, a one percent increase in economic growth raises air cargo volume by 0.619 percent, and population growth by 1.206 percent. Foreign trade volume has a negative short-term effect but a positive long-term effect. Foreign direct investment has no significant impact, whereas the number of departures positively affects air cargo traffic across all periods. Given that existing studies largely focus on passenger transport demand, the multidimensional and comparative approach of this study offers a valuable contribution to the literature.

Anahtar Kelimeler: *Hava Kargo Taşımacılığı, Havayolu Taşımacılığı Performansı, Avrupa Hava Kargo Taşımacılığı, Makroekonomik Göstergeler*

ÖZET

Hava kargo taşımacılığı, dünya ticaret hacminin büyük bir bölümünü karşılayan, ekonomik ve sosyal faydalar yaratan önemli endüstrilerden biridir. Farklı görevlerle donatılmış birden çok aktörün yer aldığı bu endüstrinin başarısı, makro ekonomik göstergelerle de yakın ilişki içerisindedir. Bu çalışmanın temel amacı, makroekonomik göstergelerin hava kargo taşımacılığı performansı üzerindeki etkisini inceleyerek sektörün performansını yönlendiren değişkenlerin kısa ve uzun dönemli etkilerini analiz etmektir. Çalışmada, 2002–2022 döneminde Avrupa'da en yoğun hava kargo taşımacılığı yapan 17 ülkenin verileri Panel ARDL yöntemiyle incelenmiştir. Ton-km cinsinden hava kargo hacmi bağımlı değişken olarak alınmış; GSYH, nüfus, dış ticaret hacmi, doğrudan yabancı yatırımlar ve kalkış sayısı bağımsız değişkenler olarak değerlendirilmiştir. Araştırma sonuçlarına göre kısa dönemde ekonomik büyümedeki %1'lik artış, hava kargo taşımacılığını %0,619, nüfus artışı ise %1,206 oranında pozitif etkilemektedir. Dış ticaret hacmi kısa dönemde negatif, uzun dönemde ise pozitif etki göstermektedir. Doğrudan yabancı yatırımların hava kargo taşımacılığı üzerinde anlamlı bir etkisi bulunmazken kalkış sayısı tüm dönemlerde hava kargo trafiğini olumlu etkilemektedir. Literatürde makroekonomik değişkenlerin genellikle yolcu taşımacılığı talebi açısından incelendiği, hava kargo taşımacılığına yönelik kısa ve uzun dönemli analizlerin ise sınırlı olduğu dikkate alındığında, bu çalışmanın hava kargo performansını çok boyutlu ve karşılaştırmalı biçimde ele almasının, literatüre katkı sağlayacağı değerlendirilmektedir.

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1. INTRODUCTION

Air cargo transportation accounts for 33 % of global trade volume, making it one of the main components of the global supply chain and international transportation (IATA, 2023). It is particularly preferred for high-value, perishable goods that require rapid distribution, thereby enhancing the efficiency of global trade networks. It is favored due to product characteristics, distribution requirements, demand fluctuations, as well as high reliability and low inventory costs.

Air cargo transportation is not limited to the transportation of goods solely by air but involves a complex process with many stakeholders. Differences in the business models of airlines, freight forwarders, ground services, and airports are factors that determine air cargo performance. Considering that 60% of the total cargo is transported through combined transportation, differences in business models impact air cargo performance.

The success of the industry depends on both the performance of domestic market players and external factors and macroeconomic indicators. Indicators such as trade volume, economic size, and population structure are among the factors affecting air cargo performance. Therefore, a broad economic perspective must be considered when evaluating air cargo performance.

Financial and operational indicators are used to measure the performance of airlines, including factors such as the amount of cargo transported, ton-kilometer values, and customer satisfaction. Accurate demand forecasting enhances the efficiency of air cargo transportation and ensures its alignment with global trade. Airlines employ various forecasting techniques for demand prediction and efficient network capacity utilization.

Numerous studies in the literature have examined the relationship between air cargo transportation and macroeconomic indicators. For example, Kasarda and Green (2005) emphasized the strong link between growth in air cargo volumes and economic development, highlighting the supporting roles of liberalization and customs efficiency. Chang and Chang (2009) identified a bidirectional causality between air cargo expansion and GDP growth. Hakim and Merkert (2016) found that economic growth positively affects air cargo transportation in South Asia, although the reverse relationship was not observed. Mehmood et al. (2015) showed that air transportation contributes positively to macroeconomic performance in Asian countries, while Bannò and Redondi (2014) identified a significant relationship between air transportation, foreign trade, and foreign direct investment. These studies demonstrate that air cargo is not only influenced by macroeconomic indicators but also acts as a strategic factor influencing those indicators.

The aim of this study is to examine the effects of macroeconomic variables that drive the performance of the air cargo transportation industry. The study addresses the conceptual development of air cargo and transportation and examines the indicators used in performance evaluation. The relationship between the performance of 17 European countries with the highest air cargo transportation volume—Belgium, Switzerland, Germany, Spain, Finland, France, the United Kingdom, Italy, Luxembourg, the Netherlands, Poland, Portugal, Russia, Sweden, Turkey, Austria, and Ireland—and selected macroeconomic indicators was investigated using panel data analysis. These countries were included in the sample based on their air cargo volumes over the past five years, covering a large portion of air cargo operations in Europe.In this study, air cargo volume (in ton-kilometers) was used as the dependent variable, while the independent variables included gross domestic product (GDP), population, foreign trade volume, foreign direct investment (FDI), and the number of flight departures from airports. The panel data method was chosen because it combines time series and cross-sectional data, providing more observations and greater statistical power while allowing country-specific effects to be modeled. In particular, the Panel ARDL (Pooled Mean Group – PMG) method was applied, as it enables simultaneous estimation of both short- and long-term relationships while accounting for country heterogeneity. This approach allows each country's short-term dynamics to be assessed individually while testing for the presence of a long-term equilibrium relationship across countries. The study aims to contribute to the literature on the effects of macroeconomic factors on air cargo performance, particularly in the European context.

2. CONCEPTUAL FRAMEWORK

2.1. Air Cargo and Air Cargo Transportation

Air cargo is a crucial component of the aviation supply chain. It refers to the transportation of freight, express packages, mail, and courier parcels by air (Morrell, 2016). In a general sense, air cargo refers to all goods transported in the cargo hold of a passenger aircraft, excluding passenger baggage, which is considered an extension of the passenger themselves (O'Connor, 2000; 153).

Air cargo transportation, on the other hand, involves the packaging, labeling, documentation preparation, and shipment of air cargo in accordance with the regulations set by the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA), taking into account country and carrier

restrictions (Turşucu, 1995; 9). Various aviation sector organizations provide services throughout this process between the sender and the recipient of the air cargo.

Air cargo transportation is particularly important for items that need to be delivered quickly due to their time-sensitive nature. As economies grow and the demand for rapid delivery increases, this mode of transportation becomes increasingly significant (Carman et al., 2019). High-value and time-sensitive e-commerce products are of great importance to global trade and the economy, and their transportation by air enhances the efficiency of logistics processes (Dalba, 2022). Air cargo transportation is characterized by its ability to rapidly adapt to changes in the global economy, openness to technological innovations, and continuous development. Research shows that particularly during the pandemic, logistics businesses have increased the share of air cargo transportation in their investment strategies (Merzlikin et al., 2022). These preferences are directly related to the efficiency of air cargo transportation in the creation of multimodal systems, its capacity to offer optimal delivery times, and its effectiveness in providing integrated transportation services (Roa, 2022). Additionally, the advantages offered by aircraft in cargo transportation, such as security, stability, and low inventory costs, support these preferences (Dresner, 2017). The decision to use air cargo transportation is influenced by factors such as product characteristics, market demand dynamics, and distribution channel requirements. The fast, reliable, and worldwide coverage of air cargo services makes it a preferred option for perishable goods, high-value products, and supply chains requiring rapid delivery. Moreover, air cargo services provide a competitive advantage by offering shorter transit times and enabling businesses to respond quickly to market changes and consumer preferences.

2.2. Performance Indicators in Air Cargo Transportation

Performance, in its broadest sense, can be defined as an organization's ability and effectiveness in achieving its set goals. It is a multidimensional concept reflecting the evolving nature of success in a competitive and risky environment, encompassing not only financial indicators but also efficiency, effectiveness, and various parameters (Issor, 2017).

Performance measurement in air cargo transportation is a multifaceted process involving various metrics such as load factor, freight ton-kilometers (FTK), and revenue ton-kilometers (RTK). These multifaceted metrics are used to evaluate the efficiency, effectiveness, and economic impact of air cargo operations, just as in general airline transportation. FTK (Freight Tonne-Kilometer) is calculated based on the transportation of one tonne of freight and mail over one kilometer, while RTK (Revenue Tonne-Kilometer) includes all revenue-generating loads carried over one kilometer, including the notional weight of passengers. While FTK is mainly used to represent cargo transportation, RTK encompasses both passenger and cargo transport. In cargo-focused airlines, these two indicators are often very close, whereas in passenger-oriented airlines, RTK is typically higher than FTK. Different airlines can reach similar RTK values through different compositions of cargo and passenger loads. The load factor, another key performance indicator in air cargo transportation, reflects how efficiently an airline utilizes its cargo capacity by showing the percentage of available capacity that is actually used. This metric is essential for understanding the operational efficiency of air cargo services. Freight ton-kilometers represent the volume of cargo transported, calculated by multiplying the tonnage of cargo by the distance traveled. It is a commonly used, yet limited, traditional transport measurement for characterizing the importance of transport modes (Išoraite, 2004). Revenue ton-kilometers measure the total revenue cargo (passenger, mail, and freight) kilometers and serve as an indicator of the economic performance of air cargo transportation. The RTK metric allows performance evaluation from an economic efficiency perspective (Gosling, 1999). Performance measurement in air cargo transportation also includes considering broader economic and environmental impacts. For example, the performance of the aviation system, including air cargo, is assessed not only in terms of direct benefits to users but also in terms of its contribution to economic development and environmental impacts (Kassoff, 2001; Dalton et al., 2001). This holistic approach to performance measurement is essential for making investment and policy decisions. Performance measurement in air cargo transportation includes a range of metrics such as load factor, FTK, and RTK, each providing insights into different aspects of air cargo operations. These indicators are important for evaluating and improving the performance of the air cargo sector in terms of economic impact and environmental sustainability.

When examining the performance of air cargo transportation by country, it is evident that the most fundamental input determining performance is the demand for air cargo transportation. As research has demonstrated, air cargo demand is influenced by many different factors. Economic, operational, and technological conditions of countries are key elements determining the dynamics of air cargo demand. Factors affecting air cargo demand include GDP, external trade, foreign direct investment, interest rates, jet fuel prices, population, exchange rates, production indices, and efficient logistics planning. These factors influence the growth potential and revenue generation in the air cargo sector (Basak et al., 2013; Zhou et al., 2022; Alnıpak and Kale, 2022; Karunathilake et al., 2023; Anguita et al., 2023). Economic development and foreign direct investment play a significant role in promoting air cargo demand by stimulating airline trade. High levels of foreign direct investment between countries facilitate the rapid growth of global value chains, thereby promoting air transport and increasing air cargo demand (Yu et

al., 2022). The presence of trade barriers, product characteristics, and the connectivity of air transport networks also significantly impact air cargo traffic (Alnıpak and Kale, 2022). Investments in airport infrastructure, airport capacity, and suitability for use are also important for air cargo performance. Particularly, the capacity and facility adequacy of airports primarily serving combined carriers are crucial to ensure that cargo transportation is not overshadowed by passenger transportation and to provide adequate support. Security measures, although causing a slight increase in air cargo prices, are among the factors that increase air cargo demand. International organizations such as the International Civil Aviation Organization enhance confidence in air cargo transportation through security oversight, thereby supporting demand (Park et al., 2023).

When looking at factors causing a decline in air cargo demand, it is observed that studies generally focus on economic crisis periods. It is known that during crisis periods, consumer demand declines and production stagnates. Additionally, during these periods, businesses often prefer to reduce their dependence on air transportation, which, although safe compared to other modes of transport, is more costly, in order to lower costs. This situation becomes more pronounced during times when economic crises significantly affect air cargo volumes, making air cargo one of the first sectors to experience disruptions during economic downturns (Hylton et al., 2018). Economic crises, characterized by trade barriers and connectivity of air transport networks, also impact air cargo demand, revealing the complex interaction of factors that may reduce demand across various countries. Environmental concerns and regulations are increasingly affecting the air cargo market, with stakeholders facing high uncertainties and cost increases due to the need for sustainable practices (Abeyratne, 2018). Pandemics, wars, terrorism, and trade embargoes and restrictions are also significant issues affecting the sector. Despite the negative impacts of the COVID-19 pandemic on passenger air transport, it can be said that air cargo transportation has maintained its performance due to its flexibility and adaptability in demand. Overall, instability and unpredictable demand present significant challenges for air cargo. The complex interaction of these factors complicates the understanding of economic, operational, and technological dynamics affecting global air cargo demand. However, recognizing the interactions of these elements and managing them through informed strategic planning can enable the air cargo transportation sector to achieve a sustainable growth trajectory.

2.3. Studies Focused on the Relationship Between Air Cargo Performance and Macroeconomic Indicators / Literature Summary

The relationship between air cargo transportation and macroeconomic indicators is complex and multifaceted. As expressed in the previous section, macroeconomic factors such as GDP growth rate, international trade, foreign direct investment, interest rates, fuel prices, population, production index, and exchange rates have a direct impact on air cargo demand and, consequently, on the performance and profitability of the sector. It is generally emphasized that air cargo transportation is influenced by variations in macroeconomic conditions and therefore, changes in the sector need to be evaluated from a broad perspective. Findings and methodologies of various studies conducted in the literature are summarized in Table 1.

Table 1. Literature Review

Study	Scope	Methodology	Key Findings
Kasarda and Green (2005)	Effects of air cargo on economic growth	Econometric analysis	Strong link between air cargo and economic growth; importance of liberalization and customs efficiency.
Chang and Chang (2009)	Relationship between air cargo expansion and economic growth in Taiwan (1974-2006)	Granger causality test, cointegration	Bidirectional relationship between air cargo expansion and economic growth.
Chang and Ying (2008)	Relationship between trade deficit, air transport volume, and GDP per capita in Africa (1970-2002)	Panel cointegration analysis	Air transport plays a significant role in trade deficit and economic growth.
Button and Yuan (2013)	Relationship between air transport and economic development in the USA (1990-2009)	Causality analysis	Air transport contributes to local economic development but is a weaker factor in metropolitan regions.
Bourguignon and Darpeix (2016)	Relationship between air transport and economic growth in developing countries	Panel data analysis	Air traffic has a flexible relationship with economic growth, especially in developing countries.
Marazzo et al. (2010)	Relationship between air transport demand and GDP in Brazil (1966-2006)	Causality analysis	Economic growth increases air transport demand, critical for sector development.
Mehmood et al. (2015)	Relationship between air transport and macroeconomic performance in Asian countries (1970-2014)	Econometric analysis	Air transport contributes positively to economic growth in Asia.

Study	Scope	Methodology	Key Findings
Hakim and Merkert (2016)	Relationship between air cargo transport and economic growth in South Asia (1973-2014)	Causality analysis	Economic growth increases air cargo transport, but not vice versa.
Hakim and Merkert (2019)	Determinants of air transport demand in South Asia (1973-2015)	Panel data analysis	Per capita income and FDI play significant roles in both passenger and cargo demand.
AitBihiOuali et al. (2020)	Impact of air cargo and passenger volumes on GDP per capita and employment	Panel data analysis	Air passenger traffic increases GDP per capita more significantly than air cargo.
Higgoda (2020)	Aviation activities, GDP, and FDI in Sri Lanka	Econometric analysis	Air transport has a stable long-term relationship with tourism and FDI.
Avcı (2022)	Impact of air cargo transport on international trade and logistics performance (2012-2018, 85 countries)	Econometric analysis	Positive relationship between air cargo volume and both logistics performance and economic development.
Ateş (2022)	Examination of logistics performance in G-20 countries (2007-2018)	Ordered logistic regression model	Foreign trade volume, national income, and air transport significantly affect logistics performance.
Danış and Bozkurt (2022)	Comparison of air cargo transport in Turkey and OECD countries (2000-2019)	Comparative analysis	Significant improvements in Turkey's air cargo sector; emphasis on the importance of geographic location.
Chi and Baek (2013)	Relationship between air transport and economic growth in the USA (including periods of terrorism, wars, and crises)	Short- and long-term analysis	Long-term support of economic growth by air passenger and cargo services.
Dobruszkes et al. (2011)	Air traffic and economic decision-making processes in urban areas in Europe	Econometric analysis	Air traffic is linked to the city's economic power and decision-making capabilities.
Gürsoy (2023)	Relationship between air cargo transport, GDP, inflation, and unemployment in 10 countries (2009-2019)	Panel data analysis	Bidirectional causality between air cargo transport, GDP, inflation, and unemployment.
Nguyen (2023)	Causality between air transport (passenger and cargo) and economic growth in Asia	Panel data analysis	Bidirectional causality in most regions of Asia; economic growth enhances air transport.
İslamoğlu (2024)	The long-term relationship between air transport and economic growth in Turkey.	Econometric analysis	Both passenger and freight air transport positively influence economic growth.
Kılıç et al. (2024)	The asymmetric relationship between air transport and economic growth in Turkey.	Econometric analysis	Air transport fosters economic growth, with effects varying by growth level.
Uçar et al. (2024)	The interaction between air transport and economic growth in BRICS-T countries.	Panel data analysis	Freight transport promotes, whereas passenger transport hinders economic growth.

3. METHOD

In this study, factors affecting air cargo transportation were examined using data from 2002 to 2022. To achieve this, the Autoregressive Distributed Lag (ARDL) model was employed within the framework of panel data analysis. The study selected 17 European countries with high cargo transportation activity and evaluated their data for the 2002-2022 period. Data were obtained from the International Air Transport Association (IATA) and the World Bank Development Indicators (WDI). The choice of the ARDL model is justified by its ability to analyze both short-term and long-term effects.

The research incorporated variables previously used in the literature to study the factors affecting air cargo performance. Macroeconomic factors such as GDP, foreign trade, foreign direct investment, population, and the number of aircraft departures from airports were used as explanatory variables. The dependent variable for air cargo performance was the volume of cargo transported in ton-kilometers. Data were sourced from the World Bank's "Development Indicators" (WDI), the International Monetary Fund's (IMF) "World Economic Outlook," the United Nations Population Fund's (UNFPA) "World Population Prospects," and the European Statistical Office's (Eurostat) "Demographic Statistics" databases.

3.1. Data Set

This study aimed to measure the impact of macroeconomic factors on air cargo transportation in 17 European countries from 2002 to 2022. The details of the dependent and independent variables considered in this study are provided in Table 2. The selection of the countries included in the panel data set was based on the countries with

the highest cargo transportation activity over the past five years. Stata 15 was used for data management, statistical analysis, and graphical representation of the data.

Table 2. Definition and Representation of Variables

Indicator	Source and Period	Definition	Abbreviation
Cargo Volume (Ton-Km)	WDI, IATA (2002-2022)	Measures the amount of cargo transported, calculated as the product of the weight of cargo and the distance it is transported, expressed in ton-kilometers.	AT
Gross Domestic Product (GDP)	WDI, IMF (2002-2022)	GDP represents the total value of all goods and services produced within a country in a year, calculated by subtracting subsidies and adding taxes.	GDP
Population (POP)	WDI, UNFPA, Eurostat (2002-2022)	Total population includes all residents regardless of legal status or citizenship.	POP
Foreign Trade (DT)	WDI, IMF (2002-2022)	Represents the total level of goods and services imports and exports.	DT
Foreign Direct Investment (FDI)	WDI, IMF (2002-2022)	Represents the net difference between foreign investments into a country and investments made by that country abroad. Net FDI shows how much of the total foreign investment in a country remains within the country. Data is expressed in current USD.	FDI
Number of Departures (ATR)	WDI (2002-2022)	The number of departures includes both domestic and international flights by registered airlines in the country.	ATR

3.2. Analysis

To work with elasticity values, natural logarithms of certain variables have been utilized, consistent with the literature. The descriptive statistics of the data used are presented in Table 3 below.

Table 3. Descriptive Statistics

Variable	Observation	Mean	Std. Deviation	Min	Max
LAT (Air Transport, Freight Cargo Volume in Ton-Km - Logarithm)	357	7.076388	1.390245	3.674223	9.352972
LGDP (Gross Domestic Product - Logarithm	357	27.21088	1.074934	23.88662	29.08462
LPOP (Population - Logarithm)	357	16.76806	1.386654	13.00847	18.79436
LDT (Foreign Trade – Logarithm)	357	27.10153	.8486173	24.80567	29.03653
FDI (Foreign Direct Investment)	351	8.82e+09	4.54e+10	-2.92e+11	1.62e+11
LATR (Number of Departures - Logarithm)	357	12.46532	.9319312	10.1307	14.03303

To test the hypothesis regarding air cargo transportation based on macroeconomic factors, the following econometric model (Model 1) is specified:

$$\left(LAT_{i,t}\right) = \mu_i + \delta_t + \beta_1\left(GDP_{i,t}\right) + \beta_2\left(POP_{i,t}\right) + \beta_3\left(DT_{i,t}\right) + \beta_4\left(FDI_{i,t}\right) + \beta_5\left(ATR_{i,t}\right) + \varepsilon_{i,t} \quad (1)$$

Here, the number of observations is: n=İ x T (group count × time periods) $\forall_i \in [1, N]$ and $\forall t \in [1, T]$. μ_i and δ_t it captures country-specific and time-specific effects that are not observed. $\varepsilon_{i,t}$ is the error term.

In the analysis, the amount of air cargo transported (LAT) is considered the dependent variable, while GDP, POP, ATR, FDI, and DT, in their nominal values, are considered the independent variables. Detailed descriptions of these variables are provided in Table 4.

Roadmap for Obtaining Equation and Parameter Estimates

To obtain the equation and parameter estimates expressed in Equation (1), the following roadmap will be followed:

1. Autocorrelation
2. Cross-sectional Dependence Test
3. Stationarity Testing Using Unit Root Tests
4. Cointegration Analysis
5. Panel ARDL Method and PMG Estimators

The first step in the applied analysis is to investigate whether cross-sectional dependence exists among the series. Cross-sectional dependence is a significant issue in panel data econometrics. Traditional first-generation panel data models assume no cross-sectional dependence among errors and that slopes are homogeneous. If there is cross-sectional dependence among errors, traditional unit root test results may suffer from substantial size distortions (O'Connell, 1998). Moreover, using fixed and random effects models without considering cross-

sectional dependence may lead to inconsistent and biased results (Sarafidis and Robertson, 2009). Therefore, this study first analyzes cross-sectional dependence using the Cross-Sectional Dependence (CD) test proposed by Pesaran (2004) and the Bias Adjusted LM Test proposed by Pesaran et al. (2008). Additionally, before analyzing cross-sectional dependence, multicollinearity among the variables was tested using the Variance Inflation Factor (VIF).

The VIF measures the extent of multicollinearity in regression analysis and indicates how much the variance of the estimated regression coefficients increases due to multicollinearity among the variables (Mulyanto, 2022). Low VIF values (around 1 to 5) indicate a low level of correlation among variables and high prediction reliability, while high VIF values (especially above 10) indicate strong correlations among variables and potential negative effects on the prediction process. The Mean VIF value obtained in the study is 4.75, suggesting that multicollinearity is not significant.

Cross-sectional dependence tests determine whether the relationships among variables are independent. Cross-sectional dependence refers to interdependencies in error terms that are not attributed to common time effects and can arise from shared economic policies, environmental factors, or spatial proximity (Basak and Das, 2018). Various tests have been developed to assess this dependence, including the LM test by Friedman (1937), the LM test by Breusch and Pagan (1980), the CDLM test by Pesaran (2004), and the Bias Adjusted CD Test by Pesaran and Xie (2021). The choice of test depends on the time and cross-sectional dimensions of the panel. The Breusch and Pagan (1980) Lagrange Multiplier (LM) test is used for panels where the time dimension is larger than the cross-sectional dimension, while the Pesaran (2004) Cross-Sectional Dependence (CD) test is used when both dimensions are large (Göçer et al., 2012). The CDLM test developed by Pesaran (2004) is valid for both scenarios regarding time and cross-sectional dimensions. However, this test may not account for cases where cross-sectional means may differ from zero. To address this issue, Pesaran, Ullah, and Yamagata (2008) corrected the test statistic by adding variance and mean terms, resulting in the CDLMadj test (Mercan, 2014).

Based on the results of the cross-sectional dependence tests, the Pesaran (2004) CD test and the Bias Adjusted LM Test by Pesaran et al. (2008) were used. Since the p-value was greater than 0.05, the null hypothesis (no cross-sectional dependence) was accepted, indicating that there is no cross-sectional dependence. This result suggests that first-generation unit root tests are appropriate. To determine the stationarity of the series, first-generation unit root tests were applied. Tests such as those by Im, Pesaran, and Shin (2003), Maddala and Wu (1999), and Choi (2001) were used based on the assumptions of homogenous and heterogeneous models. The test developed by Maddala and Wu (1999) uses the bootstrap method to determine the distribution of test statistics while considering cross-sectional correlated errors. The test results indicated that some variables are stationary, while others became stationary after taking the first difference (Table 4).

Tablo 4. First-Generation Panel Unit Root Test Results

Variables	**Maddala and Wu (1999)**		**Pesaran ve Shin (2003)**	
	Intercept	Intercept &trend	Intercept	Intercept &trend
LGDP	23.554 (0.910)	15.983 (0.996)	-1.1003 (0.1356)	-1.2646 (0.1030)
dLGDP	76.130 (0.000)	65.575 (0.001)	-19.7246 (0.0000)	-16.3284 (0.0000)
LPOP	21.293 (0.956)	42.144 (0.159)	1.6498 (0.9505)	1.1064 (0.8657)
dLPOP	1.457 (0.000)	2.681 (0.000)	-0.6870 (0.000)	1.2854 (0.0000)
DT	22.817 (0.998)	2.914 (0.998)	1.6627 (0.9518)	-1.7905 (0.0367)
dDT	262.505 (0.000)	188.219 (0.000)	-12.3262 (0.0000)	-9.5824 (0.0000)
LATR	32.670 (0.533)	12.355 (1.000)	-1.0026 (0.1580)	-0.4377 (0.3308)
dLATR	-3.963 (0.000)	-1.969 (0.024)	-16.0700 (0.0000)	-13.3958 (0.0000)
FDİ	63.395 (0.002)	59.582 (0.004)	-8.7489 (0.0000)	-8.2659 (0.0000)

Finally, cointegration analysis was conducted using the Kao (1999) cointegration test. The results led to the rejection of the null hypothesis (no cointegration) and acceptance of the alternative hypothesis (cointegration exists), indicating a statistically significant and long-term relationship among the variables (Naimoğlu, 2021).

4. FINDINGS

In this study, the Pooled Mean Group (PMG) estimator, developed by Pesaran, Shin, and Smith (1999), was employed to analyze time series data for multiple cross-sections. The ARDL model, used in both time series and panel data analysis, was chosen for this purpose. Pesaran (1999) examined various estimators within this model. The PMG estimator retains homogeneity in the long run while addressing heterogeneity and differences between panel units in the short run (Çınar et al., 2014). The primary feature of the PMG model is its ability to estimate both short-term and long-term relationships while accounting for cross-sectional dependence. It allows for

analyzing both the immediate effects and the long-term trends of the interaction between variables. The model estimates separate equations for each cross-section, capturing the short-term dynamics between the variables (Table 5). This is particularly useful when comparing multiple countries or regions (Pesaran et al., 1999; Topal, 2019).By employing this method, the study can account for varying temporal behaviors across different sections, providing a comprehensive view of the factors influencing air cargo transportation across multiple regions.

Table 5. PMG Estimator Short-Term Results

Variable	Coefficient	Standard Error	t-Statistic	p-Value
LGDP	.6193686	.1199452	5.16	0.000 *
LPOP	1.206259	.2760899	4.37	0.000 *
DT	-7.39e-13	1.23e-13	-6.00	0.000*
FDİ	2.49e-13	2.73e-13	0.91	0.362
LATR	.7425696	.0613225	12.11	0.000 *

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

GDP is statistically significant and has a positive effect on AT. Accordingly, a 1% increase in GDP raises AT by 0.619%. Similarly, Bourguignon and Darpeix (2016) found that a 1% increase in GDP results in a 1.4% increase in air traffic. As a country's economic prosperity increases, demand for air cargo services also rises (Bozan, 2019). GDP is considered a measure of a country's economic level, and since economic activities are a major driver of air cargo movements, the growth rate emerges as an explanatory factor in most cargo demand models (Baxter et al., 2018). This shows that air cargo transportation is closely linked to economic growth.

POP is statistically significant and has a positive effect on AT. A 1% increase in POP leads to a 1.206% increase in AT. As the population grows, demand for air cargo transportation also rises. Mohammadian (2019) notes that a 10% increase in population results in a 12% increase in passenger demand, particularly on long-distance routes. Hakim et al. (2017) found in their analysis, where air cargo volume was the dependent variable, that GDP, population, flight frequency, and foreign direct investment positively impact air cargo demand, while jet fuel prices have a negative impact. Population, as a potential market, is an important variable in forecasting airline passenger and cargo demand (Karunathilake & Fernando, 2024). When examining the coefficients of the variables in this study, population and then economic growth are found to be the main factors affecting air cargo demand.

DT is statistically significant and negatively affects AT in the short term. When examining the relationship between foreign trade and air cargo among European countries, it can be said that an increase in foreign trade leads to a short-term decrease in air cargo. This could be explained by the preference for other modes of transportation in European countries with close geographical connections in short-term foreign trade growth. Taşdemir and Yıldız (2022) state that in 11 European countries with the highest GDP, air cargo transportation impacts GDP, imports, and exports, and some countries actively use air cargo transportation for imports, while others use it for exports. Italy, for example, predominantly uses other modes of transportation (such as sea, rail, road, pipeline transportation, etc.) for exports, while the Netherlands emphasizes different transportation modes for both imports and exports. The short-term negative relationship between trade volume and air cargo transportation can be attributed to Europe's advanced road and rail network, the faster and cheaper nature of sea transport, and overall competition among alternative transportation modes. Similarly, the effects of jet fuel prices, exchange rates, customs regulations, security restrictions, airport capacities, and other factors on air cargo demand should also be considered.

A more comprehensive assessment of the short-term negative relationship is closely linked to competition among transport modes, sectoral capacity constraints, and the structural characteristics of trade. Increases in foreign trade often involve high-volume but low-value goods, which are typically routed through more cost-effective modes such as road and maritime transport (Nordås, 2006). Air cargo infrastructure and operators may be unable to respond swiftly to sudden spikes in demand, which can limit short-term air cargo demand. Additionally, carbon emission targets and environmental regulations are among the factors that may restrict the use of air cargo (European Commission, 2023).

FDI is statistically insignificant. Foreign direct investment (FDI) does not impact air cargo transportation in the European countries studied. These results are consistent with Kalaycı and Yangınlar's (2016) study on air passenger demand but differ from Hakim and Merkert's (2019) findings in their study on regional airline demand in South Africa. This suggests that the level of foreign direct investment a country attracts may influence air transportation. Moreover, the development of air transportation has a positive impact on attracting FDI, as stated in the literature (Tanaka, 2019; Bannò & Redondi, 2014). The indirect effect of economic growth on air cargo

demand due to changes in FDI should be considered, and more subjective variables need to be included in the analysis.

The lack of a statistically significant effect of FDI on air cargo transportation in European countries can be attributed to regional economic saturation and investment preferences. In these developed economies, where air transport infrastructure is already mature, new investments in the sector remain limited and existing capacity is largely sufficient, which may weaken the observable impact of FDI. Furthermore, in recent years, foreign direct investment has increasingly shifted towards sectors such as digital services and renewable energy (UNCTAD, 2023). It is also noted that the contribution of air transport investments to economic growth is more pronounced in developing regions (ATAG, 2020). ATR is statistically significant and positively affects AT. A 1% increase in

ATR results in a 0.742% increase in AT. An increase in the number of connections and total departures from a country's airports leads to a rise in air cargo volumes. However, the negative effect of high departure frequency, particularly at airports with a high volume of multimodal transport operators, can result in delays in operations due to increased flight frequency (Lange, 2019).

Table 6. ***The long-term results of the PMG estimator.***

Variables	Coefficient	Standard Error	t-statistic	P-value
LGDP	-.3384499	.2468486	-1.37	0.170
LPOP	4.103095	5.814082	-0.71	0.480
DT	1.13e-12	5.72e-13	1.97	0.048**
FDİ	-2.38e-13	1.08e-12	-0.22	0.826
LATR	.2939816	.0811815	3.62	0.000*

When looking at the long-term relationships (Table 6), it is observed that the total number of flight departures from airports (ATR) maintains a significant and positive relationship with air cargo transportation in the long run. Similarly, while the volume of foreign trade shows a negative relationship with air cargo in the short term, it exhibits a positive relationship in the long term. Altuntaş and Kılıç (2021) also state in their study that passenger and cargo traffic do not have a statistically significant impact on economic growth in the long run (Altuntaş and Kılıç, 2021). When examining the periods in cross-section for the years 2019-2020, considering the global impact of the COVID-19 pandemic, air cargo transportation across the examined European countries saw a decline of 33% in 2020 compared to the previous year. However, in contrast to the general trend in Europe, Germany, Turkey, and Luxembourg observed an increase in air cargo transportation during this period. Austria, Sweden, Spain, Finland, and Poland experienced the highest percentage losses. The pandemic's sharpest impact on the sector was seen at the beginning of 2020, due to travel restrictions, quarantines, disruptions in the global supply chain, and the slowdown in production. Despite this decline, air cargo transportation stood out as a key sector due to increased demand for specific products such as medical supplies and e-commerce goods, which mitigated the losses in air passenger transportation. It is estimated that while the losses of 2020 were quickly recovered in 2021, reaching pre-pandemic volumes might extend to the 2024-2025 period.

These findings indicate a divergence between short- and long-term dynamics. For instance, the foreign trade volume shows a negative impact on air cargo demand in the short term, which may be attributed to modal competition or infrastructure bottlenecks; however, in the long term, its positive effect suggests structural alignment with global value chains. Likewise, the elasticity of GDP and population differs across time horizons, reflecting the delayed yet strengthening influence of economic growth and demographic trends on the expansion of air cargo services.

In the long-run analysis, the statistical insignificance of certain variables is not solely a reflection of the econometric specification but also relates to their structural characteristics and context-specific influences. The weak effect of FDI on air cargo demand, particularly in developed economies, can be attributed to infrastructure saturation and a shift in investment priorities toward non-transport sectors. Lakshmanan (2011) emphasizes that the broader economic impacts of transport infrastructure investments may vary across contexts and manifest gradually over time. In terms of population, the general demographic stagnation and low growth rates observed in Europe may limit its role as a significant long-term determinant of air cargo demand. As noted by Graham and Guyer (2000), demographic variables may not directly influence transport demand but can exert indirect effects through consumption patterns and regional preferences. Therefore, evaluating statistically insignificant variables within their structural and contextual framework contributes to the analytical coherence of the study. When

evaluating the results, it can be said that while some variables were influential across all countries, others showed variations between countries.

When each country is examined individually, independent variables produced different results. One of the advantages of panel data analysis is that it allows for the observation of country-specific results. Country-specific outcomes are presented in Table 7.

Table 7. Country-Specific Results

Countries	LGDP	LPOP	DT	FDI	LATR
1 Belgium					.3840026 (0.002)
2 Switzerland		-32.5988 /(0.002)			.2981407 (0.014)
3 Germany	1.792142 (0.002)		-5.13e-13 (0.003)		
4 Spain	-.4975016 (0.048)		6.33e-13 (0.004)		.3928564 (0.002)
5 Finland		-42.13192 (0.089)	4.13e-12 (0.056)	-4.52e-12 (0.019)	.4331644 (0.022)
6 France	1.388971 (0.018)	-39.85217 (0.005)	-5.29e-13 (0.109)		1.02763 (0.000)
7.United Kingdom		-18.51986 (0.002)			.2592492 (0.000)
8 Italy	-1.883733 (0.002)		2.37e-12 (0.000)	3.59e-12 (0.034)	
9 Luxsemburg		-45.63757 (0.000)			
10 Netherlands	-1.491885 (0.000)		1.41e-12 (0.000)		-.205078 (0.008)
11 Polond					.6769948 (0.032)
12 Portugal			5.32e-12 (0.074)		
13 Russia	-1.268906 (0.060)		1.86e-12 (0.029)		
14 Sweden		30.22395 (0.002)			.700905 (0.000)
15 Turkey	-.891032 (0.001)				.321677 (0.032)
16 Austria			5.26e-12 (0.064)	-1.23e-11 (0.090)	.634578 (0.000)
17 Ireland		10.12379 (0.006)	-1.25e-12 (0.046)	-1.45e-12 (0.001)	

In terms of the effect of economic growth, it is observed that GDP has a significant impact on air cargo transportation in Germany, Spain, France, Italy, the Netherlands, Russia, Sweden, and Turkey. Similarly, Taşdemir and Ünlü, in their studies examining the impact of air cargo on GDP over different periods, indicate that air cargo transportation has an effect on GDP in Germany, France, Sweden, and the UK, while Italy and the Netherlands have been able to focus on different types of transportation for imports and exports (Taşdemir and Ünlü, 2022).

When examining the impact of population on air cargo transportation, it is seen to have a significant effect in Ireland, Sweden, Luxembourg, the UK, Switzerland, Finland, and France. It is possible to say that during the examined periods, the demand for air cargo has interacted with the increase in population density. Between 2002 and 2022, Ireland and Sweden, with a 30% and 20% increase in population respectively, are major actors positively influencing air cargo demand. It would be beneficial to evaluate factors such as the distribution of the young population, which affects consumption/production levels along with population growth.

Among the key criteria affecting air cargo transportation, the number of departures affects air cargo transportation in all other countries except Germany, Italy, Portugal, Russia, Ireland, and Luxembourg. This situation may indicate that in the specified countries, there is a focus on combined transportation and prioritization of passenger air travel.

External trade indicators have a greater impact on air cargo transportation in Germany, Spain, Finland, France, Italy, the Netherlands, Portugal, Russia, Austria, and Ireland, while direct foreign investment is statistically

insignificant overall, though it remains a significant factor in air cargo transportation in Finland, Italy, Austria, and Ireland.

5. CONCLUSION

Air cargo transportation is one of the largest industries, accounting for approximately 35% of global trade with its $175 billion revenue. The success of this industry, which involves multiple actors equipped with different functions, depends on the performance of domestic market players as well as external factors and macroeconomic indicators. The adequacy of airport facilities, ground service providers, air cargo agents, or transportation organizers affects the performance of air cargo carriers in terms of sectoral factors. For air cargo carrier businesses, factors prioritized in the measurement of adequacy vary depending on the adopted business model. The fundamental needs and performance-affecting factors of airlines engaged in combined transportation differ from those focusing solely on cargo transportation or integrated transportation.

In addition to the effects stemming from all these industry stakeholders and internal variables of the business, it is observed that the trade volume, economic size, and population of the country in which the activity takes place are significant elements influencing air cargo performance. After examining the complex nature of the air cargo sector in this study, the determination of performance has been explored. It has been determined that financial and operational indicators, also used in non-aviation sectors, form the basis of performance measurement. Specifically for the aviation sector, operational indicators include the volume of cargo transported, ton-kilometers, and revenue per ton-kilometer. Additionally, indicators such as personnel productivity per aircraft, cost per seat, on-time departure success rate, customer satisfaction, and load factor are also used in performance measurement.

The study has examined macroeconomic indicators thought to affect air cargo performance in European countries with the highest cargo transportation volume. According to the research results, a 1% increase in economic growth positively affects air cargo transportation by 0.619% in the short term. Similarly, population growth positively affects air cargo transportation by 1.206%. While external trade volume negatively affects air cargo volume in the short term, it has a positive effect in the long term. Direct foreign investment does not have a significant impact on air cargo transportation across the studied countries. The most important factor positively affecting air cargo traffic across all periods and countries is the number of departures from airports.

GDP is considered a measure of a country's economic level and, given that economic activities are the main driving force behind air cargo movements, GDP growth rate emerges as an explanatory factor in most cargo demand models (Baxter et al., 2018). This situation reveals that air cargo transportation is closely related to economic growth. The impact of economic growth on air cargo demand is also influenced by factors such as GDP, interest rates, and the macroeconomic performance of countries involved in commercial relations. Moreover, the level of economic development of countries can also produce different effects on air cargo transportation. In high-income countries, economic growth not only expands demand but also cyclically supports the development of air transportation, leading to more infrastructure support for air cargo services. Thus, in developed countries, a bidirectional relationship may emerge where air cargo transportation supports economic development and vice versa. In developing countries, while economic growth positively affects air cargo transportation due to increased demand, the transformation of this improvement into aviation infrastructure and enhancements might be less pronounced compared to developed countries. Additionally, the existing economic structures of countries also influence the situation. Countries with export-oriented economies need extensive air transportation for international operations.

When examining the relationship between external trade and air cargo among European countries, it can be said that an increase in external trade leads to a decrease in air cargo in the short term. This short-term negative relationship can be attributed to the preference for other types of transportation in European countries with close geographical connections. Taşdemir and Yıldız (2022) note that the air cargo transportation of the 11 European countries with the highest GDP has an effect on GDP, imports, and exports, with some countries actively using air cargo for imports and others for exports. Italy focuses on different types of transportation for exports, while the Netherlands emphasizes different types for both imports and exports. The short-term negative relationship between external trade volume and air cargo transportation can be related to the developed road and rail networks in Europe, the faster and cheaper sea transportation, and the overall competition among alternative transportation types. It may also be important to consider the level of development of countries' main production sources and whether technology-intensive or labor-intensive industries are more advanced. As mentioned under air cargo, countries focusing on technology-intensive, valuable, perishable, or fast-market distribution production tend to prefer air cargo transportation. The industrial structures of countries and the advantages and cost structure of air cargo significantly affect its preference in trade. Similarly, it is important to evaluate the effects of jet fuel prices, exchange rate impacts, customs regulations and security-related strict regulations, airport capacities, and other factors on air cargo demand.

To mitigate the short-term negative impacts of increasing foreign trade volume on air cargo transportation, several strategies can be implemented. Flexible fleet and capacity management practices, strengthening infrastructure for expedited customs clearance, ensuring logistical integration through cargo villages, and offering freight incentives for high value-added and time-sensitive product groups can help alleviate short-term pressures. Additionally, the development of trade growth forecasts through big data–based early warning systems can enhance the sector's resilience to fluctuations.

Direct foreign investment is statistically insignificant. Generally, direct foreign investment does not have an impact on air cargo transportation in the examined European countries. The literature indicates that the development of air transportation positively influences the attraction of direct foreign investment to a country (Tanaka, 2019). It can be suggested that the indirect effect of economic growth and more country-specific subjective variables should be considered in the effect of changes in direct foreign investment on air cargo demand.

Population is statistically significant and positively affects air cargo transportation. A 1% increase in population leads to a 1.206% increase in air cargo. As the population increases, the demand for air cargo transportation also rises. Population growth has an indirect effect on increasing air cargo demand through increased consumer demand and support for production activities. While it is generally possible to discuss this effect, different variables by country can lead to varying results. In developing countries, the driving force created by population growth in the economy may have a more pronounced effect on air cargo transportation. Air cargo is a crucial link in developing countries' global value chains, especially as it facilitates access to international markets. In the examined samples, some countries may not experience an effect or a negative effect on air cargo demand despite population growth, which could be due to general economic stagnation or crises. During economic downturns, consumer spending and investments halt, leading to decreased air cargo demand despite population growth. Additionally, there may be a shift towards more cost-effective alternative transportation networks during these periods. In some developed countries, the increase in population may not reflect in air transportation due to market saturation in certain markets. As economies develop, consumption rates may stabilize despite population growth. In saturated market areas, demand may increase for services not requiring air cargo.

The total number of aircraft departures from airports is statistically significant and positively affects air cargo transportation. A 1% increase in the number of departures results in a 0.742% increase in air cargo volume. The increase in the number of connections and total departures from a country's airports increases air cargo volume. However, differences by country indicate that in some countries, despite an increase in departures, the amount of air cargo remains unaffected. This may suggest that these countries focus on combined transportation and prioritize passenger air travel. A common criticism of a high number of departures, especially in airports with intensive combined transportation, is that it can cause delays, negatively affecting operational efficiency.

In determining air cargo demand, the economic structures and levels of development of countries, external trade indicators, population dynamics, the number of air connections, and airport usage strategies play significant roles. These factors create a complex dynamic that cyclically affects each other and determines the air cargo performance of countries. In addition to economic data, this structure also needs to be evaluated in conjunction with environmental sustainability goals. In order to make air cargo transportation more sustainable and competitive, the literature suggests several structural reforms, including the liberalization of the air cargo market, the expansion of bilateral aviation agreements, the digitalization of customs procedures, and the establishment of integrated logistics centers within free trade zones. Moreover, providing tax advantages for eco-friendly fleets, implementing incentive mechanisms for new cargo routes, and integrating digital tracking systems into the sector have the potential to enhance operational efficiency while reducing environmental impact.

Furthermore, in line with the European Union's 2050 carbon-neutral targets, air cargo transportation is expected to undergo a sustainability-oriented transformation. In this process, strategies such as the widespread use of sustainable aviation fuels (SAF), adoption of low-emission aircraft, development of digital logistics systems, and enhancement of intermodal integration are coming to the forefront.

While macroeconomic variables affecting the demand for passenger air transportation have been more extensively examined in the literature, studies that analyze the short- and long-term effects on air cargo transportation while also accounting for cross-country differences remain limited. In this regard, the present study is considered to provide a valuable contribution to the literature. Future research would benefit from incorporating country-specific constraints such as jet fuel prices, exchange rate fluctuations, labor force participation rates, e-commerce volume, periods of economic stagnation or crisis, political embargoes, and trade restrictions. Additionally, the regional competitiveness of alternative modes of transportation should also be included in the analysis. Studies utilizing micro-level operational data from airline companies or conducting comparative regional analyses across different continents may yield more in-depth and differentiated insights. Furthermore, research that adopts scenario-based approaches to assess the impacts of environmental regulations, carbon taxation, or pandemic-like shocks would further enrich the literature.

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