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Structural and Financial Determinants in the Development of the Aviation Sector: Evidence from Türkiye

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Abstract

Within the scope of this study, it is aimed to address the structural and financial determinants of passenger and freight transportation in the aviation sector. In order to analyze the sensitivity of the traffic in air transportation to various macroeconomic factors, two separate baseline equations were constructed using a semi-logarithmic framework, which covers the period between 1993-2023 and utilizes annual data. In the empirical analysis process, the ARDL Bounds Test approach was adopted to determine the long-term cointegration relationships between the variables; the Fourier Toda-Yamamoto test, which takes structural breaks into account and prevents information loss, was used to analyze causality relationships. In light of the empirical findings obtained, it is demonstrated that domestic credit expansions (DCREDIT) and market valuations (MCAP) play a dominant role in long-term growth in both passenger (PAX) and freight/cargo (FRE) models. Moreover, the findings indicate that the value-added of Machinery and Transport Equipment (MTE) manufacturing is significant and positive at the 1% level in the passenger transportation model and the 10% level in the freight transportation model; thus, technological production, such as machinery and transport equipment, is of vital importance in the development of the sector. In addition to this, the Foreign Direct Investments (FDI), in other words, foreign capital inflows have not been able to trigger structural expansion in the development of air transportation as expected. Finally, the results of the Error Correction Mechanism in the scope of the model showed that short-term shocks converge back to long-run equilibrium at a statistically significant speed.

1. Introduction

Especially in recent years, the aviation sector, having transformed into one of the building blocks of the global economic system, has gone beyond being merely a mode of transportation in the modern world; it has risen to the position of the most fundamental catalyst of international trade, technological diffusion, and strategic mobility (Chaitarin et al., 2025). Considering the role, it plays in terms of the development of the tourism sector and international trade, the contribution of air transportation to the social and economic development of countries comes to the forefront more. The air transportation sector is the most preferred transportation mode by individuals due to factors such as the comfort, safety, and speed it offers them (Öcal, 2021). Considering the rapidly shrinking factors of time and space in today's world, the aviation sector constitutes an indispensable structural element for national economies to integrate into global value chains. In this regard, it is assessed that the historical growth path followed by the sector in recent years reflects the concrete projections not only of technological progress but also of global welfare, capital mobility, and trade liberalization (Cristea et al., 2025).

Air transportation, which is far more than a simple mode of transport and essentially forms the global economy's capillaries, acts as a vital catalyst for international trade, technological diffusion, and strategic mobility today. Because it holds such a strategic importance for both tourism and international trade, air transportation also supports the social and economic development of nations. By promising high benefits to individuals in terms of comfort, speed, and safety, this mode of transport stands out as a highly preferred option (Öcal, 2021). In the economic conjuncture of our current world, where time and space are shrinking for everyone, air transportation is an indispensable structural element for national economies to integrate into global value chains. Especially when we look at its historical growth path in recent years, it reflects not only a technological advancement but also arguably a concrete projection of global prosperity, capital mobility, and commercial liberalization (Cristea et al., 2025).

The aviation sector is undergoing a significant development and transformation process in Türkiye, just as it is on a global scale. Especially, considering its strategic location; Türkiye, situated at the crossroads of continents such as Asia, Europe, and Africa, has covered a significant distance in air transportation at both national and international levels with its modern infrastructure and developing economic dynamics (Özbey and Akan, 2022). When the air passenger transportation data in Türkiye are analyzed, it can be seen that a significant momentum has been captured. Indeed, while the number of passengers carried in 2003 was 34.4 million, this number reached 213.7 million in 2023 (Aslan, 2025). Changing customer habits and increasing demand trends play a major role in this momentum captured in the aviation sector. Consequently, Türkiye continues to evolve into a powerful and preferred strategic hub within the global aviation network, offering a competitive alternative to established international transit centers (Ozan et al., 2014).

The striking volumetric expansion recorded by the Turkish aviation sector has mostly been interpreted in the empirical literature through standard macroeconomic parameters (GDP, population, inflation, etc.) and demand-side elasticities; the structural dynamics and financial ecosystem, which are the real pillars behind the sector, have been largely ignored (Marazzo et al., 2010; Fernandes and Pacheco, 2010; Chang and Chang, 2009; Hu et al., 2015; Şimşek, 2019; Güzel and Tunalı, 2025). However, aviation is by its very nature an industry that consumes an extraordinary amount of capital and whose operational costs are highly sensitive to exchange rates. Expanding next-generation aircraft fleets through purchase or leasing, implementing mega-airport infrastructure projects, and constructing maintenance and repair facilities that meet global standards cannot be financed solely by increasing passenger or cargo demand.

For developing countries like Turkey, international capital integration and financial depth are critical buffers for the sustainability of sectors that require huge investments, such as the aviation sector (Rajan and Zingales, 1998; Bannò and Redondi, 2014; Desbordes and Wei, 2017). Particularly when considering the aviation sector, it is highlighted that if there are financial market contractions or global liquidity shocks, it will immediately limit the supply capacity of the sector, even if potential passenger demand is high. Therefore, there is a need for a hybrid modeling approach that is at the intersection between transport economics and financial economics in analyzing sectoral growth.

Based on this theoretical and practical necessity, the main objective of the present study is to examine the development path of the Turkish aviation sector not merely as a transportation service, but as a multidimensional industrial transformation shaped by financial and structural factors. Accordingly, this study aims to test the sensitivity of volumetric growth in the sector (in terms of passenger and freight transportation) to foreign capital inflows, domestic credit expansion, and machinery and transportation equipment manufacturing capacity within the framework of an econometric model. The empirical findings are expected to unveil the growth dynamics of the aviation sector beyond conventional parameters; thus guiding decision-makers, airlines, and investors in developing a resilient and sustainable growth strategy against sectoral crises.

The following sections of the study are organized as follows: The second section critically presents the empirical literature examining aviation demand and sectoral growth. The third section details the data set underlying the research, the structural definitions of the variables, and the econometric methodology used. The fourth chapter discusses the analysis findings within a statistical and economic framework, while the final chapter presents general assessments and policy recommendations in light of the results obtained.

2. Literature Review

The structural evolution of aviation is one of the most critical supporting pillars of global economic integration and international trade and mobility networks, and considerable attention has been devoted to this phenomenon. The history of the sector in passenger and freight transport volume growth and what was the basic cause of this continuous growth has been studied by various experts and studies have been conducted in different areas. Literature focusing on the dynamics of the aviation industry indicates that sectoral growth is fundamentally shaped by a complex interplay of macroeconomic drivers, socio-demographic variables, and institutional regulations, extending beyond simple transportation demand.

A vast majority of studies in the literature identify economic growth, representing income, as the primary driving force within this multi-dimensional model. For instance, Valdes (2015), in a panel data analysis encompassing middle-income countries, determined that income growth constitutes the most critical determinant of airline demand. Similarly, Gümüş Akar (2025) concluded that a unidirectional causal relationship exists from economic growth toward air cargo in developed economies. This robust and cointegrated relationship between GDP and aviation demand is a well-established phenomenon in the literature regarding emerging markets. Indeed, empirical research focusing on Brazil (Marazzo et al., 2010; Fernandes and Pacheco, 2010), Taiwan (Chang and Chang, 2009), and China (Hu et al., 2015) has identified a long-term equilibrium and a strong causal nexus between economic growth and air transport volume. Empirical findings from Türkiye further corroborate this global trend. Although İlarslan et al. (2018) argued that the multiplier effect of per capita GDP growth on passenger demand remains limited, researchers such as Seçilmiş and Korap (2017), Kiracı (2018), Eren et al. (2020), and Altuntaş and Kılıç (2021) have provided statistical evidence demonstrating the positive causal impact of economic growth on airline passenger traffic.

Beyond this foundational ground formed by income growth and economic growth; it is frequently emphasized in the literature that fluctuations in exchange rates and inflationary pressures play a critical role in the elasticity of aviation demand. Particularly, the effect of the exchange rate shows significant differences according to the dynamics of the country examined and the length of the term. In this context, Chi (2014) identified that the impact of exchange rates on airline travel demand remains limited in the short term within the US axis. In contrast, Öcal (2021), who examined the US economy using the ARDL model, found that increases in the exchange rate reflected positively on transportation volume. In developing country examples, exchange rate sensitivity is much more pronounced. Avcı and Avcı (2025) found that although the exchange rate has no long-term effect on domestic passenger demand, a 1% increase in the rate in the short-term increases demand by 1.47%. Similarly, Güzel and Tunalı (2025) empirically demonstrated that the real exchange rate expands air cargo demand in Türkiye, while inflationary trends create a contractive effect. In the example of Nigeria, a different market, Oyakegha et al. (2025) emphasized that the sector is highly sensitive to exchange rate shocks, finding that interbank exchange rate fluctuations create a significant and negative effect on sector output, while black market and official rates remain ineffective in the short term.

Beyond macroeconomic and demographic determinants, the industry's growth is significantly shaped by structural dynamics, governmental policies, and operational cost structures. Valdes (2015) and Erraitab et al. (2016), for example, have found that institutional regulations and international aviation agreements such as "Open Skies" are the basis for passenger traffic volume and the "structural dynamics of the industry" in such an analysis. In the national literature, Yılmaz (2020) and Aslan (2025) have quantified that the development of aircraft fleet, investment in airports and tourism-oriented development policies are the major drivers of aviation growth in Türkiye.

If we take operational costs, sectoral investment and microeconomic factors into account and we analyze them in terms of FDI and pricing then foreign direct investment (FDI) and pricing are in play. Hakim and Merkert (2019) found in the South Asian market that the growth in foreign direct investments and flight frequency increases the sectoral volume while the rise in jet fuel costs suppresses demand. In another comprehensive study to analyze cost and macroeconomic dynamics simultaneously, Baikgaki and Daw (2013) were also able to predict domestic airline passenger demand in South Africa in the period 1971-2012 using Stepwise Multiple Regression Analysis (SMA). In their study, it was also found that an increase in ticket prices at the micro level is negative for demand whereas household consumption and oil prices at the macro level were positive for demand. Moreover, they proved that population growth, as a demographic factor, drives demand for airlines very strongly.

When the existing empirical literature is evaluated from a holistic perspective, it is seen that the causal relationship between the aviation sector and economic growth is generally explained through traditional macroeconomic parameters such as GDP per capita, inflation, and exchange rates. However, the fact that aviation demand beyond being a mere derivative of income growth carries a structural quality directly related to the country's industrial composition, the depth of its financial markets, and its level of integration into global capital networks has been largely neglected in the literature. Especially in emerging markets, empirical evidence regarding how high-value-added technological production and financial liquidity trigger sectoral mobility is quite limited. Moving from this research gap, the current study aims to differentiate itself from classical growth-aviation models by testing the structural and financial determinants of sectoral development through a specific model.

3. Data Set and Methodology

3.1. Data Set and Variables

In this study, the financial and structural determinants shaping the development path of the Turkish aviation sector are analyzed using annual time series data covering the 1993-2023 period. The variables included in the analysis were selected in accordance with the theoretical framework of transportation economics and macro-financial literature. In the empirical architecture of the study, two different dependent variables representing the aviation sector volume (passenger and freight transportation) and four independent variables expected to affect this volume from the supply/finance side were used. In order to stabilize variance fluctuations in time series analyses and reduce the massive figures in aviation volume to modellable dimensions, the natural logarithm of the dependent variables was taken. On the other hand, the independent variables included in the model were included in the analysis in their natural forms as they already express shares within the gross domestic product (GDP) or percentage rates. The definitions, data sources, and measurement units of the variables used within the scope of the study are detailed in Table 1.

Table 1. Definitions and Data Sources of Variables

Variable Code	Definition and Scope	Data Source	Functional Form
lnPAX	Air Transport, Passengers Carried: Total number of passengers carried by domestic and international flights.	World Bank (WDI)	Logarithmic
lnFRE	Air Transport, Freight: The volume of air cargo and freight carried (measured in million ton-km).	World Bank (WDI)	Logarithmic
FDI	Foreign Direct Investment: Net inflows of foreign direct investment as a percentage of GDP.	World Bank (WDI)	Level (%)
MTE	Machinery and Transport Equipment: Value added in machinery and transport equipment manufacturing as a percentage of total manufacturing value added.	World Bank (WDI)	Level (%)
DCREDIT	Domestic Private Sector Credit: Domestic credit provided to the private sector by banks as a percentage of GDP.	World Bank (WDI)	Level (%)
MCAP	Market Capitalization: The total market value of listed domestic companies (Stock Market Capitalization) as a percentage of GDP.	World Bank (WDI)	Level (%)
COVID	COVID-19 Dummy Variable: A binary variable to control for the structural shock of the pandemic (1 for 2020 and 2021; 0 otherwise).	Constructed by Author	Dummy (0,1)

Source: Compiled by the author.

3.2. Econometric Model

To measure the sensitivity of passenger and freight transportation within the aviation sector to structural and financial determinants, two distinct baseline equations have been constructed. Semi-logarithmic long-run cointegration models, formulated in accordance with the data structures of the variables, are as follows:

Model 1 (Passenger Traffic Model):

$$\ln PAX_t = \alpha_0 + \alpha_1 FDI_t + \alpha_2 MTE_t + \alpha_3 DCREDIT_t + \alpha_4 MCAP_t + \delta\, COVID_t + \varepsilon_{1t}$$

Model 2 (Freight/Cargo Traffic Model):

$\ln FRE_t = \beta_0 + \beta_1 FDI_t + \beta_2 MTE_t + \beta_3 DCREDIT_t + \beta_4 MCAP_t + \varepsilon_{2t}$

In these equations, α_0 and β_0 represent the constant terms, t denotes the time index (1993–2023), and ε_t signifies the error terms is further ensured by testing for potential biases and maintaining a parsimonious specification for each dependent variable.

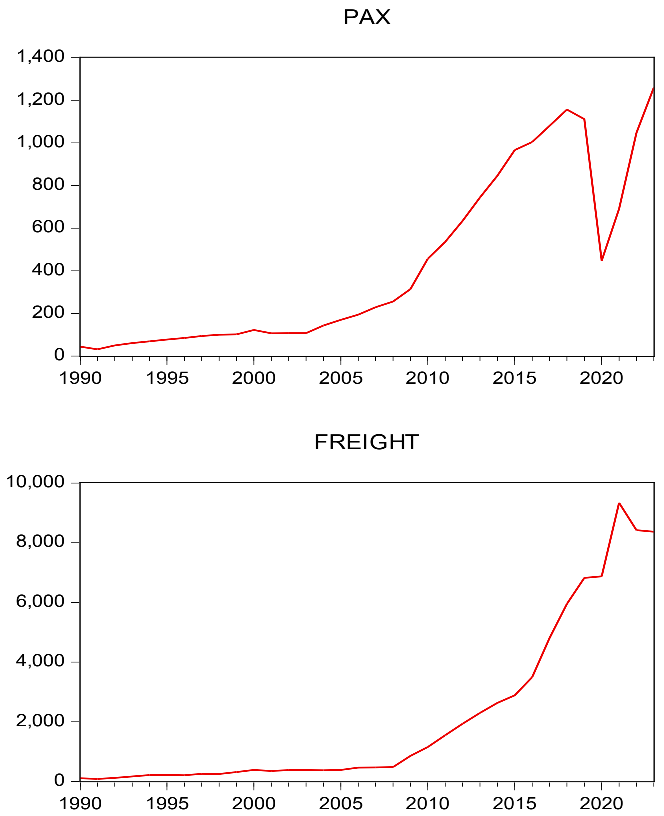

Figure 1. Trends in Annual Air Passenger and Freight Traffic (1990–2023)

Notes: The upper panel (PAX) displays air passenger numbers, and the lower panel (FREIGHT) shows freight volumes in ton-kilometers, with both scales denominated in millions.
Source: Authors' illustration based on World Bank (2025) World Development Indicators ((Accessed: March 20, 2026).

The inclusion of dummy variables, however, follows a differentiated approach based on the specific dynamics of the two primary transport types in aviation. As illustrated in Figure 1, the COVID-19 pandemic triggered a profound divergence between passenger and freight traffic. While passenger transportation suffered a nearly total collapse creating a severe outlier that could bias long-run estimations the air freight segment remained highly resilient, even transitioning into an accelerated growth phase. Consequently, to neutralize this unprecedented exogenous shock and prevent parameter bias, a dummy variable ($COVID_t$) has been incorporated exclusively into Model 1 (Passenger Traffic Model), with δ representing its coefficient. This binary variable is defined as 1 for the crisis years of 2020 and 2021 and 0 otherwise, ensuring that the structural break in passenger demand does not distort the overall econometric results.

The econometric models constructed in this study are designed to test a set of core hypotheses regarding the structural and financial drivers of the Turkish aviation sector. By estimating Equation (1) for passenger traffic (PAX) and Equation (2) for cargo volume (FRE), the study seeks to examine the following research hypotheses:

H_1: Foreign direct investment (FDI) inflows exert a significant positive impact on the long-term expansion of both passenger and cargo capacities.

H_2: Domestic credit expansion (DCREDIT) serves as a primary financial catalyst, significantly and positively influencing the sector's growth.

H_3: The manufacturing capacity of machinery and transport equipment (MTE) has a significant positive relationship with the industry's structural development.

H_4: Financial market capitalization (MCAP) provides a significant positive impetus to the long-term sustainability of aviation investments.

The validation of these hypotheses depends on the statistical significance and the signs of the long-run coefficients obtained from the ARDL Bound Test estimations.

3.3. Methodology and Analytical Procedure

The empirical analysis process of this study was conducted through the following sequential stages, in accordance with the principles of time-series econometrics:

3.3.1. Pre-tests and Stationarity Analysis

First, descriptive statistics were calculated for the statistical distribution of the variables we have included in our model. Then, Variance Inflation Factor (VIF) values were analyzed to detect potential multicollinearity issues. To avoid the spurious regression problem commonly encountered in time series analysis, the orders of integration of the series were calculated, and the widely accepted Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were applied. These tests are essential to obtain the main requirement of the ARDL model: the requirement that no series is integrated of order two, I(2), in order to get the proper integration level.

3.3.2. ARDL Bounds Testing Approach

To examine the existence of a long-run cointegration relationship between the variables, the ARDL Bounds Test approach developed by Pesaran et al. (2001) was adopted. This method was preferred due to its flexibility in allowing variables to be stationary at different levels either I(0) or I(1) and its ability to produce more robust estimates, particularly in relatively small samples (Narayan, 2005). The Unrestricted Error Correction Model, which forms the basis of the ARDL bounds testing approach, is formulated as follows:

$$\Delta Y_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i} \Delta Y_{t-i} + \sum_{j=1}^{k} \sum_{i=0}^{q_j} \alpha_{2ij} \Delta X_{jt-1} + \theta_0 Y_{t-1} + \sum_{j=1}^{k} \theta_j X_{jt-1} + \varepsilon_t \quad (1)$$

3.3.3. Estimation of Cointegration and Error Correction Mechanism

In this model, Δ represents the first-difference operator, while p and q denote the optimal lag lengths determined by information criteria. The α parameters represent the short-run dynamics of the series, whereas the θ parameters represent the long-run coefficients. Y_t signifies the dependent variable, and

X_{jt} expresses a vector consisting of k independent variables. Furthermore, ε_t is included in the model as the error term with white noise properties.

In the first stage of the methodology, the existence of a long-run cointegration relationship between the series is examined using the F-statistic (Wald Test). Within the constructed UECM equation, the null hypothesis (H_0: $\theta_0 = \theta_1$ = …..=θ_k=0), which states that the long-run coefficients are jointly equal to zero, is tested. If the calculated F-statistic is above the upper critical bound value presented in tabular form by Pesaran et al. (2001), the null hypothesis of "no cointegration relationship" is rejected, and the existence of a long-run relationship between the series is accepted.

Following the verification of the cointegration relationship, the analysis continues with the estimation of the long-run ARDL coefficients and the short-run Error Correction Model (ECM), respectively. The error correction equation, which indicates at what velocity short-term shocks converge toward the long-run equilibrium, is as follows:

$$\Delta Y_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i}\Delta Y_{t-i} + \sum_{j=1}^{k}\sum_{i=0}^{q_j} \beta_{2ij}\Delta X_{jt-i} + \gamma ECT_{t-1} + \mu_t \quad (2)$$

In this equation, ECT_{t-1} represents the error correction term lagged by one period, while γ denotes the error correction coefficient. To econometrically demonstrate that the system converges toward its long-run equilibrium, this coefficient is expected to be statistically significant and carry a negative sign ($-1 < \gamma < 0$) (Banerjee et al., 1998; Pesaran et al., 2001).

3.3.4. Causality Analysis: From Granger to Fourier Toda-Yamamoto

The Standard Granger Causality Test, developed by Granger (1969) to analyze causal relationships between variables based on the VAR model, requires the series to be integrated of the same order. However, the differencing process performed to ensure this stationarity can lead to a loss of long-run information. Therefore, to overcome this limitation of the Granger test, the Toda-Yamamoto (1995) causality approach was introduced. Although this test is of great importance as it allows for working with series that have different integration levels, it contains a significant drawback by failing to account for structural breaks in the data. In this context, the Fourier Toda-Yamamoto test, developed by Nazlioglu, Gormus, and Soytas (2016), is designed to resolve both the information loss caused by Granger and the problem of ignoring structural breaks in Toda-Yamamoto within a single framework.

$$y_t = \alpha_0 + \sum_{k=1}^{n} \alpha_{1k} \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} b_{2k} \cos\left(\frac{2\pi kt}{T}\right) + \beta_1 y_{t-1} + \ldots + \beta_{p+d} y_{t-(p+d)} + \varepsilon_t \quad (3)$$

The k parameter in the equation represents the frequency number. Trigonometric terms, such as sine and cosine, are Fourier functions added to the model, allowing for the modelling of structural breaks as smooth transitions. Additionally, the Toda-Yamamoto lag structure, which expresses the sum of the optimal lag length (p) and the maximum order of integration of the series (d), is incorporated into the model.

4. Empirical Findings

In this study, descriptive statistics and VIF values for the annual dataset 31 observations between 1993 and 2023 are summarized in Table 2. As for the descriptive statistics, the mean of the dependent variables, passenger (PAX) and cargo (FRE) capacities, were 17.176 and 6.917, respectively. The low standard deviation of these series for their means are indicative of a consistent growth of capacity from year to year.

On the independent variables side, the highest variability was in Domestic Credit DCREDIT and Market Capitalization (MCAP) series, while Machinery and Transport Equipment (MTE) and Foreign Direct Investment (FDI) variables are more in the homogeneous distribution.

Table 2. Descriptive Statistics and Multicollinearity (VIF) Analysis

Variable	N	Mean	Std. Dev.	Minimum	Maximum	VIF	1/VIF
PAX	31	17.176	1.041	15.62	18.651	--	--
FRE	31	6.917	1.358	5.084	9.142	--	--
MTE	31	17.781	2.881	12.707	23.615	2.22	0.45
DCREDIT	31	36.219	20.293	13.337	69.612	1.75	0.57
FDI	31	1.263	0.853	0.288	3.607	1.45	0.69
MCAP	31	24.687	8.863	8.85	43.914	1.13	0.887
Mean VIF						1.64	

Note: VIF values were calculated to test for multicollinearity between independent variables. Since VIF is not calculated for dependent variables (PAX and FRE), these sections are left blank.

Upon examining the VIF values calculated to test for multicollinearity, it was found that all values remained well below the critical threshold accepted in the literature (VIF < 5). The highest VIF value was calculated for the MTE (2.22) variable, and the overall mean VIF for the model is 1.64. These results confirm that there is no multicollinearity problem among the explanatory variables included in the model. To prevent the spurious regression problem in time series analysis and to determine the integration degrees of the series, Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were applied to the variables, and the findings are presented in Table 3. According to the test results, the Market Capitalization (MCAP) variable was found to be stationary at its level value, I(0), at a 1% significance level according to both ADF and PP test statistics.

Table 3. Augmented Dickey-Fuller (ADF) and Phillips Perron (PP) Unit Root Test Results

Variables	ADF Test Statistic		PP Test Statistic		Entegrasyon Degree
	Level I(0)	First Diff. I(1)	Level I(0)	First Diff. I(1)	
PAX	-1.985	-5.171***	-2.085	-5.175***	I(1)
FRE	-1.567	-4.645***	-1.7	-4.722***	I(1)
DCREDIT	-0.461	-3.246**	-1.16	-3.166**	I(1)
FDI	-2.225	-4.945***	-2.217	-4.944***	I(1)
MCAP	-5.569***	-11.117***	-5.593***	-13.230***	I(0)
MTE	-2.538	-4.737***	-2.747	-4.709***	I(1)

Note: Models with constant and trend were estimated for Level values; only constant models were used for First Difference values. Values in the table are t-statistics. Lag lengths were determined automatically via Schwarz Information Criterion (SIC), and Newey-West bandwidth (lag=3) was used for PP tests. Significance levels: *** p < 0.01, ** p < 0.05, * p < 0.1

In contrast, the dependent variables PAX and FRE, along with the independent variables DCREDIT, FDI, and MTE, were found to be non-stationary at their level values. When the first differences of these variables were taken, they became stationary at the 1% and 5% significance levels, respectively identified as I(1). These findings prove that the series possess different integration degrees, namely I(0) and I(1), and that no variable is I(2). This mixed integration structure methodologically justifies the application of the ARDL (Autoregressive Distributed Lag). Bound Test approach, which is the most suitable and robust method in the literature for investigating cointegration relationships and long-term dynamics between series.

Preliminary findings from descriptive statistics, VIF, and unit root tests confirmed that the dataset fulfills all econometric prerequisites for the ARDL Bound Test approach. Following these methodological verifications, the estimation phase of the ARDL models designed for passenger (PAX) and cargo (FRE) capacities was initiated to test the primary hypotheses of the study.

Table 4. Passenger Transportation (PAX) Model Analysis Results

Variables	Coefficient	Std. Error	t-Statistic	p-value
MTE	0.0792***	0.015	5.28	0.0000
FDI	-0.1151**	0.0483	-2.38	0.0280
DCREDIT	0.0433***	0.0018	23.3	0.0000
MCAP	0.0297***	0.0062	4.79	0.0000
Shift & Adjustment Parameters				
COVID (Dummy)	-0.9918***	0.1556	-6.37	0.0000
ECT t-1 (Adjustment)	-0.9507***	0.164	-5.8	0.0000
Bound Test Statistics	Value	Significance	Lower I(0)	Upper I(1)
F-statistic	7.387***	1%	5.132	7.282
t-statistic	-5.797***	1%	3.729	5.086
Diagnostic Properties	Statistic		Prob.	
LM Test (Autocorr.)	0.0630		0.8010	
B-P Test (Hetero.)	1.1700		0.2790	
Jarque-Bera	0.1740		0.9160	
Ramsey	2.1050		0.1690	

Note: ***, *, and * signs represent statistical significance levels of 1%, 5%, and 10%, respectively. ARDL model selections were made based on the Akaike Information Criterion (AIC). For all diagnostic tests, the H0 hypothesis is "there is no problem," and p > 0.05 values indicate that the models are robust.

Looking at the ARDL bounds test and long run coefficients for the passenger transport capacity development model, it is observed that the F-bounds test statistic of 7.387 is higher than the upper critical bound of 7.282 at the 1% level of significance proposed by Pesaran et al. (2001) for the long run equilibrium in the case of the passenger transport capacity development model. Moreover, the t-statistic of -5.797 is significant and is in agreement with the F-bounds test statistics that the variables are co-moving in the long run. From the long-run coefficients it is found that the DCREDIT and MCAP coefficients with the positive coefficient at 1% are directly related to the domestic credit liquidity and capital market performance for physical capacity investment. In contrast, the positive coefficient of MTE of 0.0792 is technological in manufacturing and shows that the production of equipment and machinery supports air passenger transport capacity. On the other hand, the negative trajectory of the FDI coefficient (-0.1151) indicates that the foreign direct investment inflows have not yet triggered the volumetric expansion in the aviation landscape. The error correction term (ECT_{t-1}), which is also the dynamic term of our model, strengthens our theory with the negative and very significant coefficient (-0.9507) at the 1% level. This value indicates that the short-run deviation or crisis-induced shocks are rectified very fast in the following period of around 95% and finally we reach long-run equilibrium. The diagnostic properties of the model are also very important to the results of our tests.

The Jarque-Bera normality test gives 0.916 and the residuals are normally distributed and the parameter estimates are correct. The Ramsey RESET test results (F-statistic: 2.105; p-value: 0.1689) indicate that the model is correctly specified and not affected by functional form misspecification or omitted variable bias, since the null hypothesis cannot be rejected at the conventional significance level. The p-values of other diagnostic tests (LM: 0.801; B-P: 0.279) also confirm that the model is free from econometric problems (autocorrelation and heteroscedasticity) and hence the overall reliability for the estimated results is at the highest level.

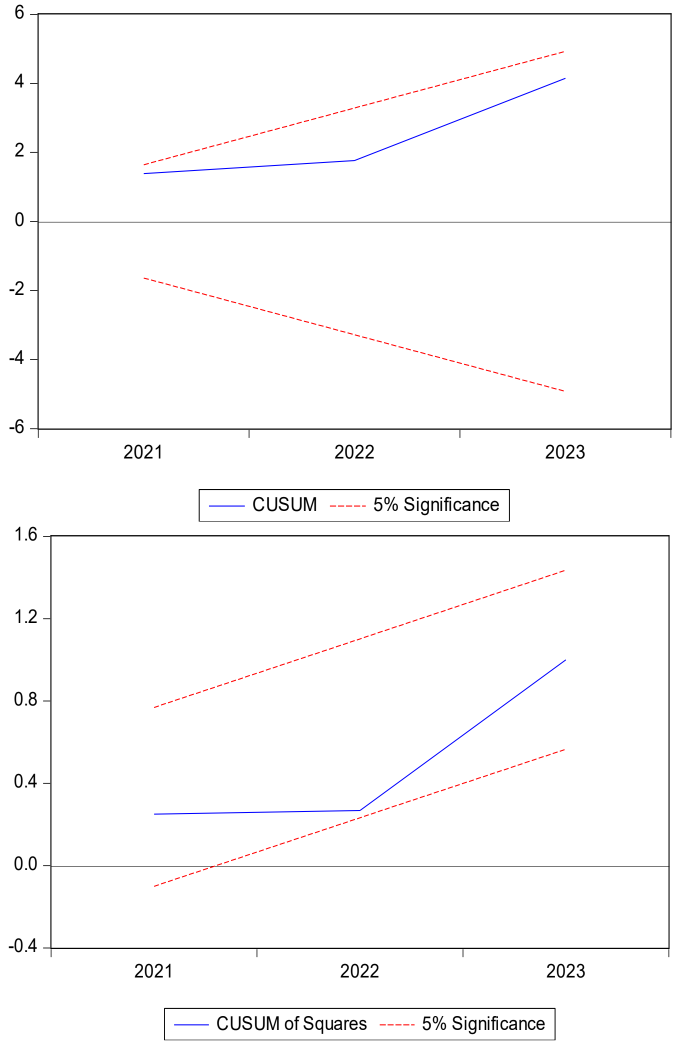

Figure 2. Air Passenger (PAX) Model Parameter Stability Tests (Left: CUSUM, Right: CUSUMSQ)

Furthermore, CUSUM and CUSUMSQ test graphs, which examine the parametric stability of the model, showed that the error terms remained within the 5% significance interval, thus confirming that the estimated coefficients are stable and reliable against structural breaks throughout the analysis period.

In the second model that we covered in this paper, the ARDL bound test results for the air cargo capacity (FRE) model clearly point to the cointegration between logistics and transport infrastructure and macroeconomic variables. Accordingly, the calculated F-statistic (4.772) also revealed that the model has cointegration at the 10% significance level as well as above the upper critical bound values. The negative and significant error correction term (ECT_{t-1}) of the model at the 1% level (-0.3334) confirms the fact that short-term deviations converge to long-term equilibrium in about 3 years. In terms of long-term coefficients, the fact that DCREDIT and MCAP variables were also calculated as significant (0.0607 and 0.0429) in the cargo model suggests that the national financial system is the main driver in expanding the cargo aircraft fleets, cold chain integrations, and the construction of smart cargo terminals.

Table 5. Air Cargo Transportation (FRE) Model Analysis Results

Variables	Coef.	Std. Error	t-Statistic	p-value
DCREDIT	0.0607***	0.0052	11.673	0.0000
MCAP	0.0429***	0.013	3.3	0.0034
FDI	-0.2887***	0.0975	-2.961	0.0073
MTE	0.0675*	0.0385	1.753	0.0939
Dynamic Parameters				
ECTt-1	-0.3334***	0.0628	-5.309	0.0000
Bound Test Statistics	Value	Sign.	Lower I(0)	Upper I(1)
F-statistic	4.772*	10%	2.45	3.52
Diagnostic Properties	Statistic		Prob.	
LM Test	2.157		0.0690	
B-P Test	0.52		0.7490	
Jarque-Bera	1.235		0.5390	
Ramsey	1.731		0.1950	

Note: ***, *, and * signs represent significance levels of 1%, 5%, and 10%, respectively. ARDL model selections followed AIC. All diagnostic test p-values > 0.05 indicate robust models.

The MTE (Machinery and Transport Equipment Manufacturing Value Added) coefficient (0.0675) was positive and statistically significant at the 10% level. Thus, although domestic credit liquidity (DCREDIT) and market capitalisation (MCAP) are dominant in the long-term growth of the air cargo model, the negative effect of the FDI variable is also an empirical finding that foreign direct investment has not yet led to structural expansion in the air cargo ecosystem.

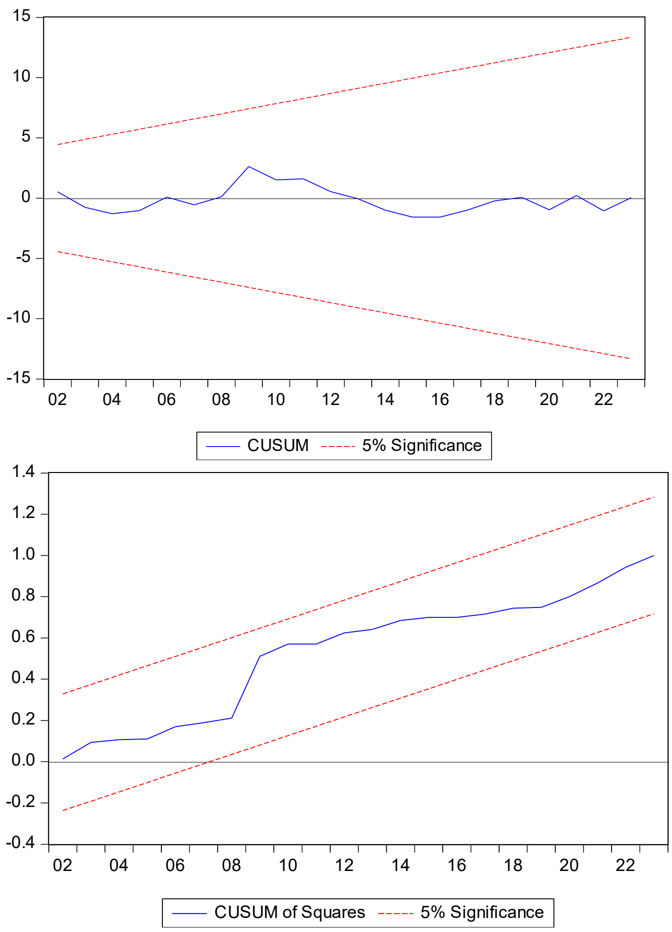

Figure 3. Air Cargo (FRE) Model Parameter Stability Tests (Left: CUSUM, Right: CUSUMSQ)

Finally, the CUSUM and CUSUMSQ tests, which examine the structural stability of the model, remained within the 5% critical boundaries, showing that parameters did not undergo any shocks or structural breaks over time, thus demonstrating that the ARDL estimates are econometrically very robust.

Table 6. Fourier Toda-Yamamoto Causality Test Results

Direction of Causality	Wald Statistic	Asymptotic (p)	Bootstrp (p)	Result
DCREDT => PAX	35.0770***	0.0000	0.0000	Causality Exists
FDI => PAX	0.0560	0.8140	0.8210	No Causality
MTE => PAX	1.9190	0.3830	0.3700	No Causality
MCAP => PAX	0.7640	0.3820	0.3840	No Causality
DCREDT =>FRE	2.0650	0.1510	0.1820	No Causality
FDI => FRE	0.9230	0.3370	0.3480	No Causality
MTE => FRE	0.9670	0.3250	0.3220	No Causality
MCAP => FRE	0.1600	0.6890	0.7140	No Causality

Note: The table presents Fourier Toda-Yamamoto causality test results, taking into account possible smooth structural breaks in the series. The maximum integration degree (dmax) was set to 1, and the VAR(k+dmax) system was estimated by including optimal lag lengths (k) and optimal Fourier frequencies. The null hypothesis (H0) is: The independent variable is not the Granger cause of the dependent variable. Robustness was confirmed with 10,000-repetition Bootstrap p-values based on the MWALD statistic. (*) indicates statistical causality at the 1% significance level ($p < 0.01$).

In this study, finally, the Fourier Toda-Yamamoto causality test was employed, which takes into account possible and unknown smooth-transition structural breaks in time series, therefore producing more robust results compared to standard causality tests. Within the scope of the analysis, the causality of selected independent variables (DCREDIT, FDI, MTE, and MCAP) on two different dependent variables (PAX and FRE) was examined. In this context, when the test results of the model established for the PAX dependent variable are analyzed, a statistically significant relationship was detected only between the DCREDIT variable and PAX. In line with the high obtained MWALD statistic (35.077) and the corresponding p-values at the 1% significance level (Asymptotic p = 0.000; Bootstrap p = 0.000), a strong and unidirectional causality relationship from the DCREDIT variable toward the PAX variable was identified, and the null hypothesis (H0) for this relationship was strongly rejected. On the other hand, since the p-values for the FDI, MTE, and MCAP variables remained above the statistical significance levels (0.05 and 0.10), it was concluded that these variables do not have any causal effect on PAX. When the analysis results for FRE, the other dependent variable, are evaluated, it was observed that none of the independent variables included in the analysis (DCREDIT, FDI, MTE, MCAP) have a statistically significant causal relationship with FRE. Upon examining the asymptotic and bootstrap p-values of the calculated Wald statistics, it was determined that for all variable pairs, these values were well above even the 10% significance level ($p > 0.10$).

Although the long-term coefficients were found to be statistically significant as a result of the ARDL bound test conducted within the study, it is considered that the failure to detect a predictive causality relationship for variables other than DCREDIT (FDI, MTE, MCAP) in the Fourier Toda-Yamamoto causality analysis stems from the distinction in the fundamental philosophies of the two different methodologies used. While the ARDL approach measures the long-term equilibrium relationship and the tendency to move together between series within a static framework (Pesaran et al., 2001); the Granger-based Toda-Yamamoto causality test focuses on the capacity of a variable's past shocks to predict the future values of another variable that is, a dynamic lead-lag mechanism (Granger, 1988; Toda and Yamamoto, 1995). Therefore, although the FDI, MTE, and MCAP variables share a common long-term macroeconomic equilibrium with PAX and FRE, it is thought that relationships other than the dominant one obtained between DCREDIT and PAX could not be detected by the Fourier Toda-Yamamoto causality test in the short and medium term.

5. Conclusion and Evaluation

The aviation sector, as one of the fundamental capillaries of the global economic system, stands out as an industry highly sensitive to financial market fluctuations due to its extraordinary levels of capital intensity and operational costs. Moving from this aspect of the aviation sector, the study was designed to examine the volumetric growth (passenger and freight transportation) in the Turkish aviation sector in relation to deep structural determinants such as foreign direct investment (FDI), domestic sectoral credit volume (DCREDIT), industrial machinery manufacturing capacity (MTE), and the financial ecosystem (MCAP), rather than purely conventional macroeconomic variables like GDP and population frequently encountered in the literature.

While constructing the empirical infrastructure of the study, taking into account the structural and operational differences within the aviation ecosystem itself, two separate and independent econometric models representing passenger demand (PAX) and freight/cargo demand (FRE) were established. Furthermore, the methodological approach preferred in estimating the models is based on the principle of selecting the most appropriate econometric tools for the shocks and long-term equilibrium searches inherent in the nature of the sector. In this regard, the ARDL bound test approach was preferred for testing long-term cointegration relationships due to the fact that variables may have different integration degrees and because it exhibits strong statistical performance especially in small to medium-sized samples. On the other hand, considering that the aviation industry shows significant sensitivity to global economic crises, pandemics, and macro-financial fluctuations, the causal relationships between variables were examined using the Fourier Toda-Yamamoto causality test, which maximizes the robustness of results by modeling unknown and smooth-transition structural breaks.

The findings of the ARDL bound test prove that there is a long-term, stable cointegration relationship between the financial and structural variables included in the analysis and the passenger (PAX) and freight (FRE) demands of the aviation sector. This finding confirms, from a long-term perspective, the hypothesis emphasized in the introduction that "the sustainability of aviation investments is directly linked to financial integration and industrial infrastructure."

However, according to the Fourier Toda-Yamamoto causality test results; despite the long-term equilibrium in the system, it was determined that the causality relationship occurs only unidirectionally from the DCREDIT variable toward the PAX variable. Although the fact that foreign direct investments (FDI), market capitalization (MCAP), and industrial capacity (MTE) do not create a statistically significant causality on passenger demand seems to contradict the long-term findings at first glance, it is evaluated that this situation arises from the theoretical distinction between long-term cointegration and the dynamic lead-lag relationship based on Granger philosophy (Granger, 1988; Pesaran et al., 2001).

In this context, according to the Fourier Toda-Yamamoto causality test results which maximize the robustness of the findings by modeling smooth structural breaks the findings suggest that domestic credit expansion (DCREDIT) acts as a primary and highly responsive catalyst for the growth of passenger air transportation.

Within the scope of the findings obtained for the FRE model representing freight transportation, the role played by the structure of the aviation sector can be observed. It was determined that none of the structural and financial variables (DCREDIT, FDI, MCAP, MTE) included in the analysis have causality over FRE. This situation is directly related to the structural rigidity inherent in the nature of the general aviation sector and the long maturation periods of sectoral investments. In this regard, investments such as expanding cargo logistics networks, integrating new-generation cargo aircraft into fleets, or constructing cargo terminals involve time-consuming processes. Therefore, expansions in credit volume (DCREDIT), foreign direct investments (FDI) entering the country, or increases in machinery equipment capacity (MTE) spread their impact over the long term through a lagged transmission mechanism rather than creating an instantaneous capacity increase in the sector. Indeed, while the long-term cointegration relationship identified in the ARDL analysis proves that these variables move together in the final equilibrium, the failure of the Toda-Yamamoto causality test to detect this relationship in the short term aligns with the aforementioned heavy investment infrastructure of the sector.

When the long-term cointegration and asymmetric causality findings obtained from the study are synthesized; the following policy recommendations are offered to decision-makers, financial authorities, and market actors in order to correctly direct capacity investments in the Turkish aviation sector and to maintain sectoral growth in harmony with financial dynamics.

Empirical findings prove that sectoral credit expansion (DCREDIT) is the single and strongest predictive parameter for passenger demand (PAX) in the short and medium term within the scope of this study. Therefore, it is recommended that airline companies consider domestic credit volume trends as a primary signal when making operational capacity decisions such as fleet leasing, opening new routes, or increasing flight frequencies. Additionally, it is considered that when policy makers feel the need to stimulate passenger transportation in the short term, they should prioritize policies that rationalize direct sectoral credit channels and financing costs.

The fact that foreign direct investment (FDI) and industrial machinery-equipment (MTE) capacity have no short-term causality on the sector but are effective only in the long term (ARDL findings) is a critical planning detail. In this context, decision-makers should look for FDI and infrastructure investments not as short-term sectoral incentive mechanisms but instead use them to finance strategic goals with long-term maturation (e.g. mega-airport or regional maintenance and repair centres) and not just for the short term.

In conclusion, the current study fills a major empirical gap in the literature by taking the volumetric growth of the Turkish aviation sector beyond traditional transportation parameters and modeling it as an ecosystem directly integrated with macro-financial liquidity, foreign capital, and industrial infrastructure. In future work, exploring the possible asymmetric effects of expansions and contractions in sectoral credit volume (positive and negative changes) on passenger demand with non-linear approaches will reveal the reaction mechanism exhibited by the aviation industry against financial fluctuations in a much deeper way.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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