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Article

Air cargo transport and economic development in emerging economies: A case study of Brazil with panel data analysis

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Abstract: Air cargo transportation accounts for less than 1% of the global trade volume, yet it represents approximately 35% of the total value of goods transported, highlighting its strategic importance in trade and economic development. This study investigates the relationship between domestic air cargo transport in Brazil and key macroeconomic variables, focusing on how regional economic dynamism, logistical infrastructure, and population density impact the country's development. Using a panel data regression model covering the period from 2000 to 2020, the study analyzes the evolution of air cargo transportation and its role in redistributing economic growth across Brazil's regions. The findings emphasize the key factors influencing the air cargo sector and demonstrate how these factors can be leveraged to optimize public policies and business strategies. This research provides valuable insights into the relevance of air cargo transportation for regional and national development, particularly in emerging economies like Brazil, offering guidance for the formulation of strategies that promote balanced economic growth across regions.

Keywords: air cargo; macroeconomics; economic development; regional disparities; Brazil

1. Introduction

Although air cargo transportation accounts for less than 1% of the global volume of goods transported, it represents approximately 35% of the total value of goods, highlighting its strategic importance for global trade and economic development (Boeing, 2022). Despite this, most of the existing literature on air transport focuses on passenger transport, with little emphasis on cargo transportation, especially in emerging countries like Brazil (Chen and Chou, 2017; Wei and Vaze, 2018). Moreover, studies linking air cargo transportation to regional macroeconomic variables are scarce, creating a knowledge gap in understanding the strategic role of this sector in regional economic development.

This study seeks to fill this gap by investigating how domestic air cargo transportation relates to macroeconomic variables across different regions of Brazil. Using a panel data model and a longitudinal approach, covering the period from 2000 to 2020, this research aims to analyze how economic dynamism, logistical infrastructure, and population density influence the economic development driven by air cargo transportation. Brazil's regions display significant disparities in terms of economic development, and this study seeks to identify how air transport can contribute to greater economic integration and growth across these regions.

The primary research questions addressed by this study include: (1) What are the key factors influencing domestic air cargo transportation in Brazil? (2) How do regional economic variables affect the volume of cargo transported between cities? (3) In what ways can air cargo transportation promote economic development in regions with varying levels of infrastructure and growth? These questions are relevant as air cargo transportation can be a crucial factor for economic development, especially in areas with limited infrastructure, where the fast transport of high-value goods is essential.

The contribution of this study lies in providing an unprecedented analysis of the relationship between air cargo transportation and economic development in Brazil, offering insights for public policy formulation and business strategies. The panel data approach allows for capturing both regional and temporal variations, providing a robust analysis that can be applied to both emerging economies and developed markets. By linking macroeconomic variables with air cargo transportation, this study provides a broader and more detailed understanding of the role of this sector in regional economic growth.

The originality of this article lies in its methodological approach and the use of a panel data model to investigate the relationship between air cargo transportation and economic development, with a specific focus on emerging economies. Although Brazil is used as a case study, the model and insights presented are broadly applicable to other developing countries that face similar challenges, such as regional disparities, insufficient infrastructure, and complex logistical needs. The scientific contribution of this study goes beyond solving a specific case, providing a methodological framework that can be applied to different emerging economies. By employing a longitudinal and panel data approach, this study captures economic and regional variations over time, offering a robust tool for understanding how air cargo transportation can influence economic development in countries with transitional or rapidly growing economies.

This article proposes an analysis that can be replicated in other emerging countries, helping to test hypotheses about the role of air cargo transportation in promoting economic development across different regions. Based on the results from Brazil, which has a vast and unequal economy, testable hypotheses can be generated that apply to other countries with similar characteristics, such as large territories, fragmented logistical infrastructure, and developing industrial sectors. By focusing on variables such as infrastructure, economic dynamism, and population density, this study provides relevant insights for governments, policymakers, and businesses in emerging economies, enabling the creation of growth strategies based on the optimization of air cargo transportation. Therefore, the study has global implications, contributing to the advancement of transportation science and economic development, especially in regions facing logistical and socioeconomic challenges similar to those of Brazil.

2. Materials and methods

2.1. Literature review

The field of air transportation and its relationship with regional economic development has predominantly centered on passenger transport, with a emphasis on

developed countries in Europe, North America, and some developed countries in South Asia. Despite this focus, scholars acknowledge the significance of air cargo as an integral component of the air transport industry and as a crucial catalyst for economic development. Air cargo services offer distinct advantages, particularly in terms of time efficiency, especially for time-sensitive and high-value-added products. While advancements in technology have impacted all modes of transportation, air cargo transportation remains paramount in addressing factors such as perishability, fragility, urgency, and hazardousness. However, limitations arise when dimensions and weights become crucial considerations. Noteworthy goods transported by air include perishable products, high-value-added items, and time-critical deliveries, encompassing commodities such as flowers, fresh fruits, banknotes, electronics, medicines, and spare parts. To support the analytical methodology and data utilized in this study, a set of select research studies was analyzed, considering the availability of relevant statistics in Brazil. This paper aims to build upon existing knowledge and expand the understanding of the relationship between air cargo and regional economic development, particularly within the Brazilian context.

Button et al. (2010) found that small airports in the USA have a significant impact on regional economic development, stimulating growth and acting as catalysts for local investments. This strong positive correlation suggests their relevance in driving economic development.

Mukkala and Tervo (2013) conducted an empirical analysis using annual data from 86 regions in 13 countries in Western Europe to examine the relationship between air traffic and regional economic performance from 1991 to 2010. They employed Granger's non-causality analysis in a panel structure, considering the potential heterogeneity among the regions. The study explored the relationship between passenger air traffic, air cargo volume, employment, and purchasing power in the European market and concluded that air transport activity contributes to regional development.

Kasarda (2005) analyzed data from 63 countries using multiple linear regression modeling to assess the impact of air service liberalization, customs quality, and corruption reduction on economic development and air cargo. The results indicated that all three factors contribute to economic development, as measured by GDP per capita and foreign direct investment. It also recognized that air cargo plays a crucial role in improving regional and national connectivity, serving as an efficient link to global supply chains and urban economic development.

Fung et al. (2006) employed the value-added approach to calculate both the direct benefits of ancillary air transport services and the indirect benefits resulting from commercial services. The aviation industry plays a crucial role in supply chain, generating employment opportunities (both direct and indirect) and positively impacting GDP growth, contributing to global economic growth.

Chang et al. (2007) conducted causality tests to understand the relationship between air cargo expansion and economic growth, revealing a balanced relationship based on the applied tests, and emphasized the need for air cargo companies to adapt to new concepts, demands, products, and stakeholders that drive the new economy.

Button and Yuan (2013) utilized Granger causality models and analyzed data from 35 airports in 32 metropolitan areas in the USA, finding a significant and positive

impact of air cargo transport on local and regional economic development. Cargo airports act as catalysts for economic growth, generating employment and long-term benefits for the region.

Lakew (2015) examined the impact of population size, employment, and income on air traffic, economic development, and air transport. The study investigated passenger and cargo traffic in selected metropolitan areas in the USA from 2003 to 2012, using fixed-effects and city-specific models. For air cargo transport, a positive proportional relationship was identified between metropolitan population and cargo traffic, suggesting that jobs in the industrial sector may induce more air cargo traffic. Moreover, increased wages and a higher share of jobs in high-value sectors like technology and healthcare drive demand for domestic air cargo transport.

Bilotkach (2015) analyzed the relationship between population, average wages, number of companies, total employment, air traffic, airport market concentration, and direct flights in the US market from 1993 to 2009. The results revealed a significant impact of the number of destinations served by direct flights and passenger air traffic on the local economy. Sheard (2019) examined the impact of GDP, employment rate, number of companies, population size, and airport size in the USA from 1991 to 2015 and identified a positive impact of airport size on various economic indicators.

Carbo and Graham (2020) investigated the relationship between per capita GDP, transportation policies, cargo volume, and passenger air traffic. The results demonstrated the positive influence of policies, trade agreements, and airport infrastructure on the economy and cargo volume. Aprigliano et al. (2021) explored the links between air transportation and the GDP of municipalities in the Amazon region through Granger causality tests. The study concluded that aviation plays a crucial role in socio-economic development, particularly in remote areas where air accessibility is vital.

Góes et al. (2018) identified infrastructure bottlenecks as a key obstacle to economic growth in Brazil, affecting productivity and market efficiency, and highlighted the need for governance reforms to improve investment efficiency. Fernandes et al. (2024) analyzed the dynamics of the domestic air passenger market in Brazil and found that, in addition to factors such as income and distance, the level of service on regional routes is crucial in determining demand, changing substantial changes in government policies and airline services. airlines to take advantage of the potential of the domestic market. This paper differentiates itself by focusing on the relationship between domestic air cargo transport and macroeconomic variables in Brazil, using a panel data approach to explore how air cargo can serve as an engine of economic growth, especially in regions with robust infrastructure and high population density.

The literature review presented in this article highlights that longitudinal analysis has been widely used in studies on air cargo transportation and economic growth. This approach is considered appropriate for investigating the long-term relationships between air cargo transportation and macroeconomic variables, providing robust insights into the sector's evolution over time. The analysis of these research studies informed the analytical framework and contributed to the development of a comprehensive understanding of the dynamics and implications of air cargo transportation. This method combined with a context analysis, supported by

descriptive statistics, gives the instruments for an inductive set of arguments to funding the paper discussion and conclusions.

Although the literature on air transport is vast, most research focuses on passenger transport and developed economies. Little attention has been paid to air cargo transportation, especially in emerging markets like Brazil. Second, most previous research has focused on specific aspects of logistics efficiency or transport policy and has failed to systematically link air cargo transport with regional macroeconomic variables and the economic development of emerging countries.

Currently, there is a significant gap in the literature regarding the real role that air cargo transport plays in the economic development of underdeveloped and emerging regions. In this sense, this research contributes to the existing body of literature by focusing on the Brazilian case a country with large territorial extensions and regional disparities where the role of air cargo transport in driving regional economic growth has been little explored. This study aims to fill this gap through a comprehensive analysis of the relationship between air cargo transport and economic development in Brazil, using a panel data model to capture regional dynamics. This is an important study, as it helps to understand the contribution of air cargo transport to the economic growth of emerging regions, considering aspects such as infrastructure, economic dynamism and regional integration. It also proposes a longitudinal analysis with two decades of data, allowing the identification of long-term patterns that are not yet well represented in the literature.

The contribution of this study, therefore, lies in its innovative approach, relating economic and regional variables to the impact that air cargo transport has had on the development of different regions of Brazil. In this sense, by reviewing the prominent role that air cargo transport occupies in the strategy, the study contributes to relevant guidelines on how to formulate public policies and business decisions to optimize transport logistics and regional economic development.

2.2. Methodology and data

Literature shows that panel data analysis is particularly recommended for longitudinal studies, where observations over time are correlated and require appropriate statistical techniques to account for this dependence (Twisk, 2013). Longitudinal data offer notable advantages over purely cross-sectional or time series data, enabling the examination of dynamic relationships over time and the modeling of inter-individual differences (Livres, 2004). To begin the analysis, an exploratory examination of the data was conducted, facilitating an initial understanding of its distribution and properties. Subsequently, a careful assessment of the potential explanatory variables that could be incorporated into the model was undertaken, recognizing that the focus of this study is the discussion of domestic air cargo variable and macroeconomic indicators.

2.2.1. Data

This study uses data from 2000 to 2020 for Brazilian cities, based on information from the Brazilian National Civil Aviation Agency (ANAC, 2022) to analyze paid air cargo volumes, with a focus on Origin-Destination (O-D) data. The real Gross Domestic Product (GDP) for municipalities was derived from nominal data provided

by the Brazilian Institute of Geography and Statistics (IBGE, 2022) and adjusted for inflation using the National Consumer Price Index (IPCA) (IBGE 2023f). The base year for deflation was set as 2020, the most recent year for which municipal GDP data is available. For states without price collection, monthly variations from neighboring states were used. GDPOrig refers to the GDP of the city where the origin airport is located, while GDPDest represents the GDP of the city with the destination airport. This distinction highlights the unique economic dynamics of each city involved in air transport, leading to the creation of an O-D database. For national and regional aggregate analyses, data from IBGE and ANAC extends to 2022, providing insights into broader macroeconomic trends and air cargo data not affected by municipal reporting delays. The econometric analysis focuses on the 2000–2020 period due to delays in the publication of municipal GDP by IBGE and the significant economic disruption caused by the COVID-19 pandemic.

2.2.2. The panel data regression model

The proposed model is designed specifically for Brazil and its regions, considering the limitations of the data availability. Given the absence of a continuous record of data for all cities throughout the period, an unbalanced panel data approach was employed for regression analysis. This methodology allows for the inclusion of cities with available data, forming an unbalanced panel dataset that facilitates the examination of relationships and patterns.

The analytical model employed in this study is built upon the premise that air cargo transportation in Brazil is influenced by three key factors. **Figure 1** shows an diagram of the model. Firstly, the economic dynamism of the origin and destination cities of the transported cargo is a significant driver. This dynamism is captured by variables such as the economic growth rate (GDP) of each city served by the airport, encompassing both the city of origin (GDPOrig) and the city of destination (GDPDest) of the cargo. Additionally, the distance between the cities through which the cargo is transported (Distance) and the number of weekly takeoffs on each connecting route (Flights) further contribute to understanding the economic dynamics of air cargo transportation. Secondly, the model incorporates the commercial evolution process in Brazil over time. This aspect recognizes the intensification of flows of goods, services, and capital that has occurred since the late 20th century, impacting cargo transportation across the country. By considering the temporal dimension, the model accounts for the evolving trade dynamics and their direct influence on air cargo transportation. Finally, the model explores the developmental patterns of air cargo transportation between regions and states within Brazil. It seeks to elucidate the internal dynamics of air cargo transportation within regions, investigating how cargo flows between different regions and states evolve over time. This analysis provides valuable insights into the regional variations and interdependencies that shape the air cargo landscape in Brazil.

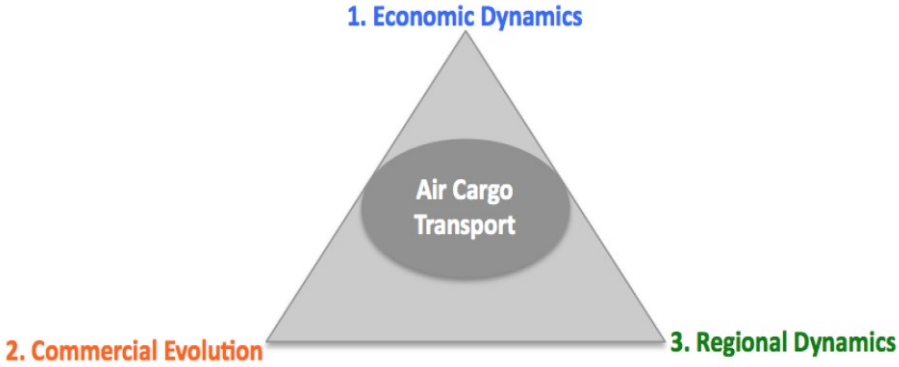

Figure 1. Model of air transportation dynamics.

By incorporating these three key drivers into the analytical model, this study provides a comprehensive understanding of the factors influencing air cargo transportation in Brazil. The model takes into account the economic dynamism of origin and destination cities, the commercial evolution process, and the intra-regional and inter-state dynamics of air cargo transportation, this is the regional dynamics that represents the developmental patterns of air cargo transportation, contributing to a nuanced examination of the sector's development within the country.

In panel data analysis, it is necessary to consider the presence of fixed or random effects from cross-sections - in this study, specifically the origin-destination of the cargo - as well as the time series nature of the data. In order to determine the most appropriate model, several tests are performed, including the assessment of redundant fixed effects using the Chow test, the examination of omitted random effects through the Breusch-Pagan test, and the evaluation of correlated random effects using the Hausman test.

To examine these three drivers, the study begins by using a set of unbalanced panel data regression analysis with period fixed effects and cross-section fixed effects, with the dependent variable being the volume of domestic paid air cargo transported from the city of origin (i) to the destination city (j) (Cargo), and the selected indicators related to economic and air dynamism in the period from 2000 to 2020 as independent variables (i.e., the set of variables associated with (Driver 1 see **Figure 1**). In the second step, the analysis focuses on the period fixed effects, which indicate the effect of commercial evolution over time (Driver 2, see **Figure 1**) on the evolution of Brazilian domestic air cargo. Considering a different effect for each year is a distinctive aspect of the study, as it is known that we have distinct dynamics over the considered period. The third step involves the discussion of the dynamics of air cargo between and within regions of Brazil (Driver 3, see **Figure 1**), represented by the panel data model of Driver 1. Equation (1) shows the corresponding model used in the analytical framework to estimate the regression parameters. The explanatory variables that did not have coefficients with a significance level greater than or equal to 0.90 were eliminated from the regression (Kim and Choi, 2021).

$$ln(Cargo_{i,j,t}) = \omega_{i,j} + \varphi_t + \gamma ln(GDPOrig_{i,t}) + \omega ln(GDPDest_{j,t}) + \beta ln(Distance_{i,j,t}) + \alpha ln(Flights_{i,j,t}) + \delta lag(ln(Cargo_{i,j,t}), 1) + \varepsilon_{i,j,t} \quad (1)$$

where,

- ln: natural logarithm of the variables;
- $\omega_{i,j}$: cross-section effect;
- φ_t: period effect;
- $Cargo_{i,j,t}$: Payload transported between cities of origin *i* and destination *j* in year t;
- γ, ω, β,α and δ: estimated coefficients in the regression model;
- $GDPOrig_{i,t}$: GDP deflated with base year 2020 of the city of origin *i* in the year t;
- $GDPDest_{j,t}$: GDP deflated with base year 2020 of the destination city *j* in the year *t*;
- $Distance_{i,j,t}$: Distance between the cities of origin *i* and destination j in year *t*;
- $Flights_{i,j,t}$: Departures per week between cities of origin *i* and destination *j* in year *t*;
- $\varepsilon_{i,j,t}$: regression error.

The study assumes that the economic and geographical characteristics of a specific route determine the volume of air cargo in a given year. The first group includes non-economic variables from ANAC: (i) Regular domestic paid cargo (Cargo), indicating the volume of cargo transported between Brazilian cities and serving as the model's dependent variable, distance between cities (Distance), representing the flown distance between the origin and destination airports; weekly departures (Flights) between the origin and destination airports, represented by the number of departures of regular flights, indicating the level of air mobility between cities. The second group consists of economic variables: (ii) Gross domestic product of municipalities (GDP), represented by GDP in real terms, deflated by IPCA based on 2020, indicating the level of development of the origin and destination cities.

2.2.3. Correlations between time fixed effects and macroeconomic variables beyond GDP

After estimating the panel regression model for domestic air cargo, correlation matrices were constructed between the estimated fixed effects over the years and the following variables: (i) Seasonally adjusted fixed-base indexes in December of each year for the nominal revenue of the sectors studied by the Monthly Survey of Services of IBGE (PMS) (IBGE, 2023c); (ii) Seasonally adjusted fixed-base indexes in December of each year for the nominal revenue of sectors from the Monthly Industry Survey of IBGE (PIM-PF) (IBGE, 2023b); (iii) Percentage of online sales per year, estimated from the Annual Commerce Survey of IBGE (PAC) (IBGE, 2023a); (iv) Per capita household income per year, i.e., the total household income divided by the total population of Brazil in each year, estimated from the Continuous National Household Sample Survey (PNAD-continuous) (IBGE, 2023d). Only variables that had absolute correlations of 0.4 or higher with the time fixed effects were considered. In addition to the correlations becoming more significant from 2012, it is important to note that the correlations were calculated from 2011, as this was the year in which the PMS (Monthly Services Survey) began. It should be noted that in 2011, the initial phase of concessions for the private management of major Brazilian airports was completed.

3. Results and discussion

3.1. Case study

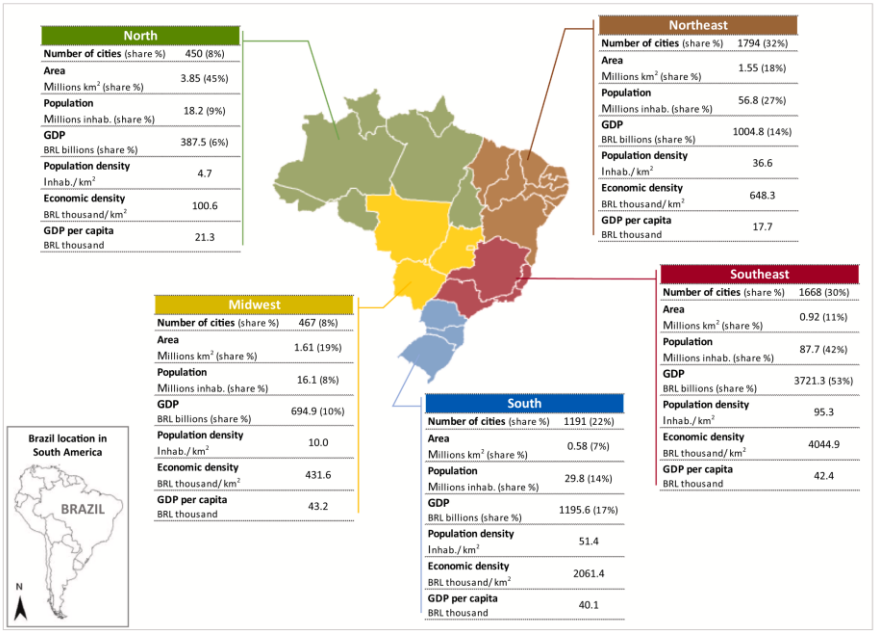

Figure 2. Map with the 5 regions of Brazil, and their socio-economic and demographic indicators.
Source: Ventura et al (2022).

Brazil, with approximately 4000 airports and airfields and a territorial extension of 8.5 million km² and a population of 203.1 million in 2022, according to estimates by the IBGE, is classified as the fifth largest territorial area and the seventh largest population in the world. Its economy ranks ninth globally and is the largest in Latin America (IMF, 2019). The country is composed of 26 states, with the Federal District as its capital, and a total of 5570 municipalities distributed across 5 macroregions: North, Northeast, South, Southeast, and Midwest (**Figure 2**), each with distinct economic, demographic, environmental, and cultural characteristics. The economic and social diversity of Brazil is reflected in its five distinct regions, each with its own peculiarities and challenges. The North region houses the Amazon Rainforest with its rich biodiversity and natural resources, boasting the largest territorial extension but the lowest population density and economic participation. Its economy is driven by extractive activities, mining, agriculture, and the industrial sector, with a focus on the Manaus Free Trade Zone. The Northeast region has a large population and a diversified economy based on agriculture, industry, commerce, and tourism. It stands out for the production of tropical fruits, sun and beach tourism, as well as the textile and footwear industries. There is potential for growth with investments in infrastructure and renewable energy. The South region, with a predominantly urban population and high socioeconomic indicators, has a diversified economy, with a focus on agribusiness, metallurgy, automotive, and technology industries. Tourism in the mountains, beaches, and vineyards is also significant. The Southeast region is the most populous, urbanized, and developed in the country, housing important economic and

cultural centers, with a strong presence in the industrial, financial, and service sectors. It is known for the automotive industry, mining, technology, commerce, and tourism. The Midwest region is characterized by its strategic geographical location and socioeconomic diversity. Its economy is based on agriculture, mainly grain and meat production. It is also the location of Brasília, an important political and administrative center.

Given the presented data and information, it becomes evident that there are economic and social disparities among the regions of the country, making it essential to conduct research that promotes actions and policies for regional balance and sustainable development across the nation. Brazil's geographical diversity is reflected in its transportation infrastructure, which is not uniform across the territory. In the last two decades, Brazil's GDP has grown from R$2.26 trillion in 2000 to R$9.87 trillion in 2022 (IBGE, 2022). However, this growth has not been homogeneous over the period. Analyzing the past 22 years, we can observe different periods with distinct macroeconomic outcomes and characteristics (**Figure 3**).

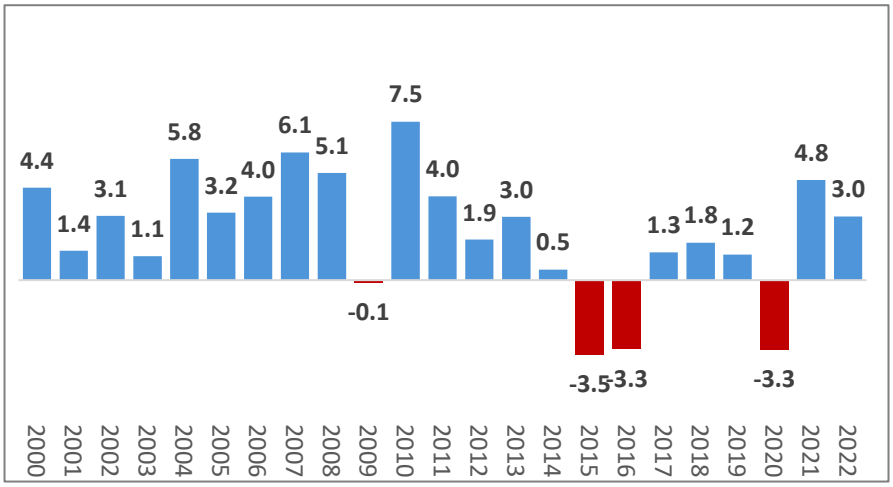

Figure 3. Brazil's annual GDP growth rate (%) from 2000 to 2022.

Between 2000 and 2003, the country faced economic challenges, such as the energy crisis and the currency crisis. From 2004 to 2008, there was strong growth driven by rising commodity prices and solid economic policies, including structural reforms and macroeconomic stability. The global financial crisis of the U.S. subprime market affected Brazil in 2008–2009, leading to reduced international demand, a fall in commodity prices, and credit restrictions, which negatively impacted the Brazilian economy. Between 2010 and 2013, the economy recovered, stimulated by increased government spending, household expenditures, favorable credit market conditions, positive employment indicators, and income growth.

From 2014 to 2016, there was a slowdown due to various factors, including the decline in commodity prices and economic uncertainty. The fiscal and political crisis negatively impacted investor expectations and consumer confidence, culminating in the impeachment of the president in 2016. From 2017 to 2019, Brazil experienced a slow recovery driven by macroeconomic improvements, structural reforms, and renewed investor confidence. The COVID-19 crisis had a significant impact on both

the Brazilian and global economies due to mobility restrictions, resulting in a recession in 2020, followed by a partial recovery in 2021 and 2022.

Between 2014 and 2022, the volume of paid cargo transported in the Brazilian domestic market had an average annual growth of 5%, totaling a 40.2% increase during this period. In 2022, the total volume reached 725.2 thousand tons (ANAC, 2022). This observed growth (**Figure 4**) can be attributed to increased international trade, the growth of the Brazilian economy, and the modernization of airports and air cargo transport companies. However, this growth was not uniform due to events such as the US subprime crisis in 2008, the fiscal and political crisis in 2014, and the COVID-19 pandemic in 2020, which restricted the movement of people and affected global trade.

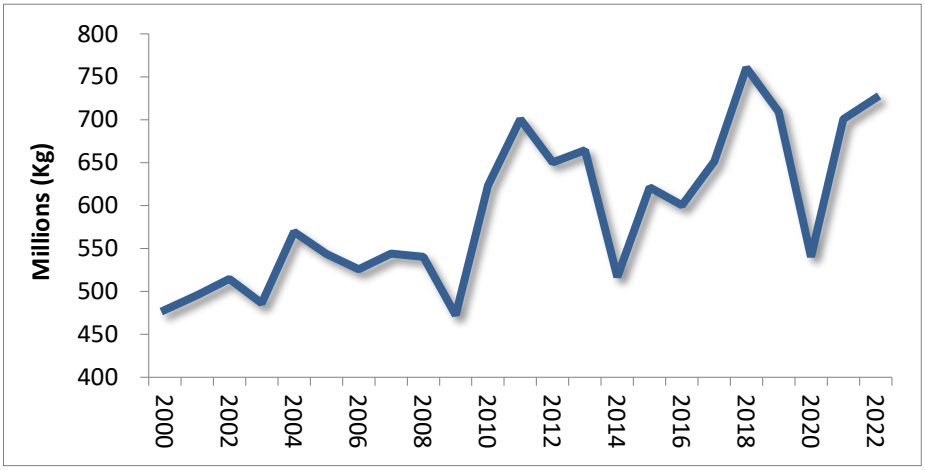

Figure 4. Historical trend of annual paid air cargo volume transported in Brazil (2000–2022)-ANAC data.

The descriptive statistics of the model variables (**Table 1**) indicate that there is greater heterogeneity in the takeoff variable compared to the distance variable. The origin GDP and destination GDP exhibit different behaviors, with the former being less volatile. Additionally, there is greater homogeneity in the distance between cities. Regarding the economic and air transport variables of the regions in Brazil, there are more observations of flows in the Southeast region and fewer in the South and North regions. The volume of air cargo transported between cities is higher when the origin city is in the Southeast and lower in the South and North regions.

Table 1. Descriptive statistics of the model variables.

	$ln\ (Cargo_{i,j,t})$	$ln\ (GDPOrig_{i,t})$	$ln\ (GDPDest_{j,t})$	$ln\ (flights_{i,j,t})$	$ln\ (Distance_{i,j,t})$
Brazil					
Mean	11.89	17.77	17.67	2.76	13.28
Maximum	17.53	20.57	20.57	6.11	16.50
Minimum	8.56	9.55	9.55	0.00	8.17
Std. Dev.	1.77	1.70	1.81	1.07	1.26
Observations	9236	9236	9236	9236	9236

Table 1. (*Continued*).

	***ln* (*Cargo*$_{i,j,t}$)**	***ln* (*GDPOrig*$_{i,t}$)**	***ln* (*GDPDest*$_{j,t}$)**	***ln* (*flights*$_{i,j,t}$)**	***ln* (*Distance*$_{i,j,t}$)**
Midwest					
Mean	12.13	18.06	17.39	2.76	13.49
Maximum	15.59	19.46	20.57	5.23	15.95
Minimum	8.56	11.94	10.94	0.00	9.77
Std. Dev.	1.73	1.31	1.83	1.03	1.20
Observations	1301	1301	1301	1301	1301
Northeast					
Mean	11.75	16.91	17.95	2.67	13.28
Maximum	16.25	18.19	20.57	5.11	16.50
Minimum	8.57	9.55	9.55	0.00	9.43
Std. Dev.	1.65	1.22	1.77	0.92	1.20
Observations	2124	2124	2124	2124	2124
North					
Mean	11.52	16.32	16.84	2.38	12.94
Maximum	17.53	18.34	20.57	4.18	15.73
Minimum	8.56	11.32	11.27	0.00	8.17
Std. Dev.	1.88	1.52	2.13	0.91	1.29
Observations	1130	1130	1130	1130	1130
Southeast					
Mean	12.14	18.92	17.59	2.90	13.37
Maximum	17.53	20.57	20.57	6.11	16.49
Minimum	8.56	10.98	10.98	0.00	8.31
Std. Dev.	1.81	1.50	1.61	1.19	1.33
Observations	3476	3476	3476	3476	3476
South					
Mean	11.53	17.04	18.50	2.89	13.12
Maximum	15.92	18.57	20.57	5.12	15.78
Minimum	8.56	12.85	12.70	0.02	9.00
Std. Dev.	1.64	1.18	1.65	1.03	1.13
Observations	1205	1205	1205	1205	1205

In the map (**Figure 5)** of state participation in the volume of air cargo dispatched in 2022, a high concentration is observed. The top five states, São Paulo, Amazonas, Rio de Janeiro, Pernambuco, and Distrito Federal, account for 83% of the total dispatched volume, with São Paulo standing out by dispatching 470 thousand tons.

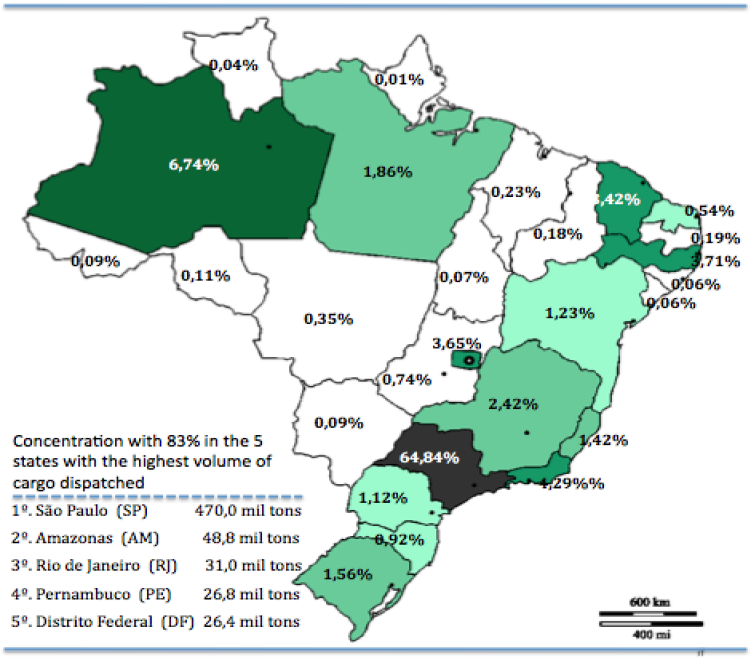

Figure 5. Cargo dispatched by State 2020.
Source: ANAC (2022). Created by the author.

3.2. Results

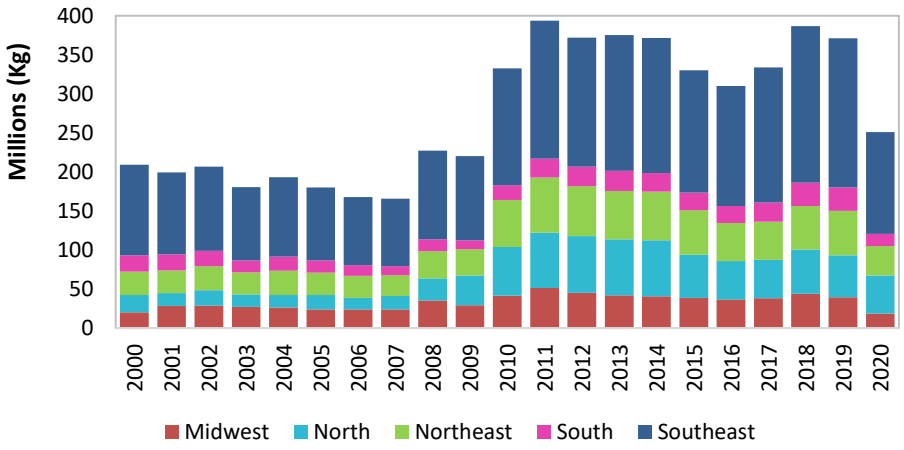

Figure 6. Results of domestic paid cargo by origin region in Brazil 2000 to 2020.

To illustrate the dynamics of air transport within the regions of Brazil, we present **Figure 6**, which depicts the volume of regular domestic air cargo paid transport in different Brazilian regions. The graph reveals a significant growth trend in domestic cargo transport, particularly from 2010 onwards. This increase can be partly attributed to the consolidation of concessions for major Brazilian airports under private management, a process initiated in 2011. Two significant periods of decline in air cargo volumes were observed in 2015 and 2020, correlating with fluctuations in the Brazilian GDP in the air cargo sector. Economic fluctuations and recessions have a noticeable impact on the demand for air cargo services, leading to fluctuations in transported volumes. Among the regions of the country, the Southeast region stands out in air cargo transport. This can be attributed to various factors, including its higher

population density, well-developed infrastructure, and concentration of major economic centers. Throughout the analyzed years, the Southeast region consistently accounted for the largest share of domestic cargo transported across Brazil.

This study applied three key statistical tests for panel data analysis: the Chow test, the Breusch-Pagan Lagrange Multiplier (LM) test, and the Hausman test (Baltagi, 2005). Each test was chosen for its ability to assess specific aspects of model specification, ensuring that the selected model would best represent the data. The Chow test was performed to determine whether fixed effects should be included in the model, evaluating both cross-sectional and period-specific fixed effects. The results, presented in **Table 2**, strongly indicated that fixed effects were necessary, with highly significant statistics (Cross-section F = 212.51, Period F = 6.44, both with *p*-values of 0.00). These findings suggest notable differences across cities and time periods, making a fixed effects model more appropriate for capturing unobserved heterogeneity. The Breusch-Pagan LM test, shown in **Table 3**, assessed whether random effects would be more suitable by testing for random variations across cities and over time. The results (Breusch-Pagan cross-section = 13,933.25; time = 3.83; both = 13,937.08, all with *p*-values of 0.00) indicated the presence of random effects. However, the subsequent Hausman test was crucial for deciding whether a random effects or fixed effects model would be more appropriate. The Hausman test, detailed in **Table 4**, compared the fixed effects and random effects models to ensure that the chosen model would provide consistent and unbiased estimates. The significant results for both cross-sectional and period random effects (Chi-square statistic = 284.86 for cross-section, 36.18 for period, both with *p*-values of 0.00) confirmed that the fixed effects model was superior.

Based on these tests, the Ordinary Least Squares (OLS) regression model with fixed effects for both cross-section and period was determined to be the most appropriate for this study. The OLS model is widely used in panel data analysis, especially when capturing individual heterogeneity and time-specific effects is important. By incorporating fixed effects, the model accounts for unobserved factors unique to each city or region, as well as time-specific variations that may influence the relationships between variables.

Table 2. Redundant fixed effects tests (chow test).

Test cross-section and period fixed effects			
Effects test	**Statistic**	**d.f.**	**Prob.**
Cross-section F	21,251	−1.061.872	0.00
Period F	644	−241.872	0.00

Table 3. Lagrange multiplier tests for random effects (Breusch-Pagan LM).

	Test hypothesis		
	Cross-section	**Time**	**Both**
Breusch-Pagan	13,933.25	3.83	13,937.08
p-value	0.00	−0.05	0.00

Table 4. Correlated random Effects-Hausman test.

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	284.86	4	0.00
Period random	36.18	4	0.00

Source: ANAC microdata

Figure 7 visually depicts the dummy variable representing fixed effects in the cross-section within Brazil, arranged in ascending order. The inclusion of this dummy variable accounts for variations in air connection densities among the sampled cities, enabling the model to estimate the true effect on cargo demand. Positive values on the graph indicate routes that are more attractive for air cargo transportation, suggesting higher levels of demand. Similarly, **Figure 8** presents the dummy variable representing fixed effects over time, providing insights into the temporal dimension of air cargo transportation. It reveals the influence of economic growth on air cargo dynamics, with positive values indicating that years characterized by economic expansion have a more favorable impact on the demand for air cargo transportation. This suggests that during periods of economic growth, there is a heightened need for efficient and timely transport of goods via air cargo services. By analyzing these dummy variables, the study gains valuable insights into the factors that drive air cargo transportation in Brazil. The presence of fixed effects in the cross-section captures the heterogeneity in air connection densities among cities, allowing for a more accurate estimation of the effects of income, distance, and flight volume on cargo demand. Likewise, the fixed effects over time enable the examination of the temporal variations in air cargo dynamics and their relationship with economic growth.

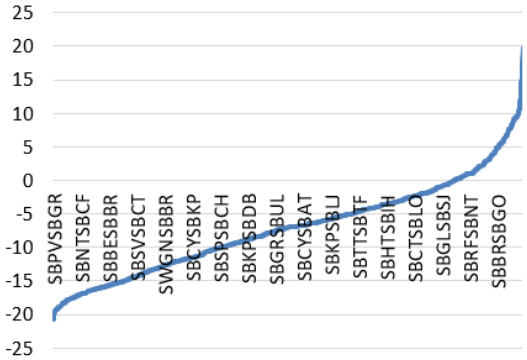

Figure 7. Cross-section and period fixed effects.

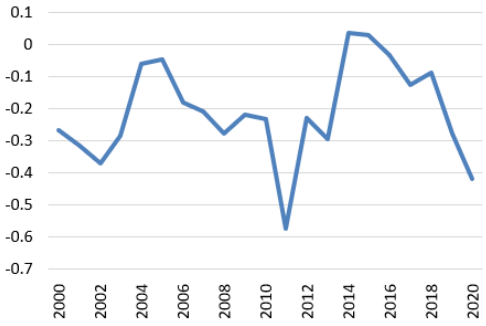

Figure 8. Period fixed effects.

The findings highlight the routes that are most conducive to air cargo demand and underscore the importance of economic growth in shaping the demand for air cargo services. This knowledge provides valuable insights for policymakers, industry stakeholders, and researchers seeking to optimize air cargo operations and leverage the potential of air transportation for economic development.

Figure 9 presents the relationship between the estimated fixed effects per year and two key indicators: the percentage of internet sales and per capita household income. The correlation between these factors demonstrates a negative association, indicating that regions experiencing greater growth in air cargo transportation over the years also exhibited higher per capita household income and a larger proportion of online sales. The significant correlation of −0.54 between the coefficients over time and the percentage of internet sales can be attributed to the increasing consumer demand for expedited and efficient product delivery. These findings underscore the effectiveness of air cargo transportation as a means for companies to swiftly deliver their products across various parts of Brazil, outperforming other transportation modes in terms of speed and efficiency.

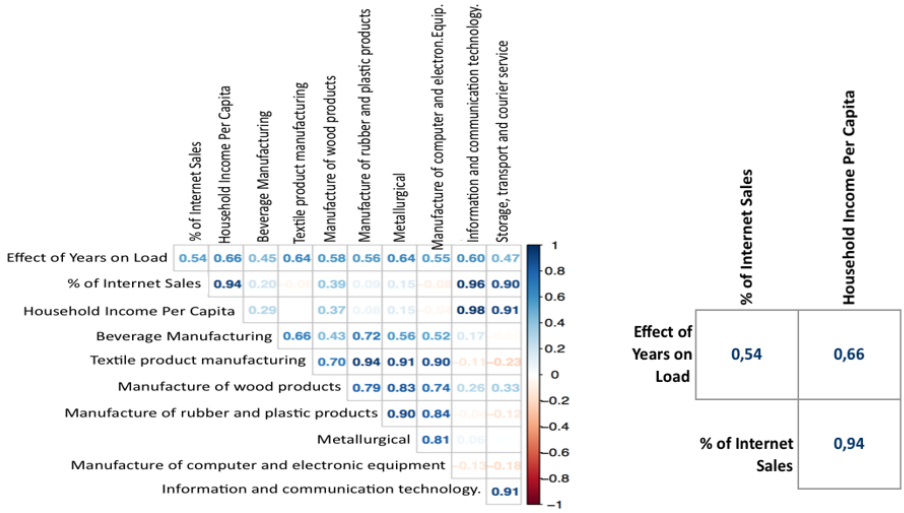

Figure 9. Correlation Matrix-Per capita household income and percentage of internet sales.

Regarding service sectors, there is a notable correlation of 0.47 between the estimated fixed effects per year and the storage, auxiliary services, and transportation to postal services sector. This suggests that the growth of these services may have contributed to the overall increase in domestic air cargo transportation in Brazil between 2012 and 2020. Moreover, information technology-related services also exhibited significant correlations with cargo flows during the same period, indicating their influence on air cargo dynamics. Conversely, services provided to families showed opposite trends, indicating a negative correlation with air cargo growth. These observations highlight the intricate relationship between air cargo transportation and various service sectors. The positive correlation between air cargo growth and storage, auxiliary services, transportation to postal services, and information technology-related services indicates their interdependence and the role they play in driving cargo flows. Conversely, the negative correlation observed with services provided to

families suggests differing dynamics and potential factors influencing air cargo transportation in relation to this sector.

These findings contribute to a deeper understanding of the factors that shape air cargo transportation in Brazil, particularly in relation to service sectors and their impact on cargo flows. They shed light on the pivotal role of air cargo in supporting the rapid delivery of goods and the growth of sectors associated with online sales, storage, auxiliary services, transportation to postal services, and information technology.

For a comprehensive analysis and comparative examination, the same regression model was applied to assess air cargo transportation across all cities in Brazil, encompassing diverse characteristics such as proximity, economic size, and cargo transportation between macro-regions (Inter-Regions) as well as within macro-regions (Intra-Regions). **Table 5** presents the results obtained for Brazil, Inter-Regions, and Intra-Regions, based on a dataset comprising 1033 valid data links spanning from 2000 to 2020. The model's estimations demonstrate a commendable level of explanation, as indicated by the adjusted R-squared, capturing the flow of air cargo on the examined routes. The coefficients offer insights into the anticipated demand behavior in response to potential variations in both the GDP of the origin and destination cities and the influence of distance between cities on air cargo transportation. The findings align with expectations, reflecting the expected sensitivities of cargo demand to changes in these factors. Notably, the descriptive statistics highlight greater diversity in the Flights variable compared to the Distance variable. This diversity indicates substantial variation in flight frequencies between cities, underscoring the diverse demand patterns and air connectivity throughout the country. Contrary to expectations, the analysis reveals that the distance between cities does not have a significant influence on the demand for air cargo transportation. This suggests that air cargo transportation is consistently utilized even for shorter routes. So, air cargo is recognized as a reliable, efficient, and appropriate mode of transportation for various route lengths. Statistical tests provide support for the explanatory power of city income in cargo demand, with both the GDPOrig and GDPDest proving to be significant factors in both the Brazil-wide and inter-regional analyses. These variables consistently exhibited significance across all geographical and temporal sub-samples investigated. In instances where the GDP of the municipalities involved in the air routes did not demonstrate statistical or economic significance, those variables were subsequently removed from the model. This was the case for routes within regions (Intra-Regions). The estimated coefficients for the explanatory variables of air cargo transportation have been statistically validated with a confidence level of 95%. These findings provide valuable insights into the factors shaping air cargo transportation in different geographic contexts and over time, offering a robust foundation for understanding and analyzing cargo flows within Brazil.

Table 5. Panel data regression results (ln ($Cargo_{i,j,t}$)).

Variables	Model		
	inter-Regions	**intra-Regions**	**Brazil**
C	−60.034*	7.948*	−47.756*
ln ($GDPDest_{j,t}$)	0.457*		0.221*
ln ($GDPOrig_{i,t}$)	0.403*		0.237*
ln ($Flights_{i,j,t}$)	0.606*	0.783*	0.686*
ln ($Distance_{i,j,t}$)	7.586*		8.961*
Adjusted R-squared	0.877	0.827	0.861
Cross-sections	548	485	1033
Periods	21	21	21

Level of significance: *0.95.

Table 1 reveals that the GDPOrig demonstrates lower volatility compared to the GDPDest, indicating greater economic stability in the regions from which air cargo flows originate. This disparity can be attributed to factors such as regional demand patterns, dominant economic sectors, and the availability of airport infrastructure, which vary across different regions. When examining the statistics of economic and air transport variables by region in Brazil, it becomes evident that the Southeast region has the highest number of observed flow instances, whereas the South and North regions exhibit a lower quantity. This discrepancy can be attributed to the higher population density and more favorable macroeconomic conditions in the Southeast, driving the demand for air cargo transport. Furthermore, the volume of air cargo transported between cities is notably higher when the city of origin is located in the Southeast, while it is comparatively lower in the South and North regions. These regional variations in cargo distribution can be attributed to the concentration of economic and industrial activities in the Southeast, as well as disparities in infrastructure and economic development across different regions of the country. Understanding these regional logistics dynamics and challenges is crucial for comprehending the complexities of air cargo transport in Brazil.

4. Discussion

Temporal analysis indicates a significant increase in domestic air cargo transport starting from 2010, which was followed by a sharp decline in 2020. The growth in air cargo transport during this period can be attributed to factors such as the privatization of major airports, investments in airport infrastructure, and increasing product demand. However, the outbreak of the pandemic disrupted this upward trend, leading to a steep decline in air cargo transport demand.

The panel data regression model corroborates the importance of fixed effects and the relationship between economic growth and air cargo transport. The Chow test, Breusch-Pagan LM test, and Hausman test confirm that periods of economic expansion have a more favorable impact on air cargo transportation. The identified correlations demonstrate that regions experiencing increased air cargo transport also exhibit higher per capita household incomes and a higher percentage of internet sales. This indicates a connection between air cargo transport demand, economic

development, and shifts in consumption patterns. The growth in transported cargo is linked to economic expansion, the purchasing power of the population, and changes in consumer behavior, particularly the emphasis on speed and efficiency in product delivery, particularly in the context of e-commerce.

In sectors related to auxiliary services, storage, transportation to postal services, and information technology, there is a positive correlation with the growth of domestic air cargo transport in Brazil. This suggests that the expansion of these sectors may drive the demand for air cargo transport due to the significance of fast and efficient product delivery, as well as the increasing prominence of e-commerce. Conversely, services provided to families exhibit the opposite trend, indicating differing dynamics and potential factors influencing air cargo transport within this sector.

Study limitations

This study considers some limitations that must be considered. The availability and quality of air transport and macroeconomic data between 2000 and 2020 presented challenges, especially in the more remote regions of Brazil, which may have affected the accuracy of the estimates. Furthermore, the analysis focuses on Brazil, limiting the generalization of results to other countries, due to cultural, political contexts and economic variations between emerging nations. The focus on macroeconomic variables such as GDP and infrastructure excludes important qualitative factors such as regional transport policies and technological changes in the sector. Finally, a methodology used, based on panel data and OLS regression, assumes linearity in the variables, meaning that future studies can explore non-linear or dynamic modeling to verify the robustness of the results.

5. Conclusion

This paper provides inductive evidence of a positive causal relationship between air cargo transportation and regional economic development in Brazil. The findings highlight various factors that influence the air cargo sector, including economic growth, per capita income, takeoffs, population density, e-commerce, and sectors related to transportation and information technology. Economic growth serves as a key driver of air cargo demand, while per capita income reflects consumers' ability to utilize these services. E-commerce plays a significant role in driving the demand for fast and efficient deliveries. Interestingly, factors such as the distance between origin and destination cities demonstrate low significance in influencing air cargo transportation. Specific sectors such as storage, transportation, and information technology are found to have a positive influence, as efficient logistical infrastructure is crucial for ensuring speed and reliability in air cargo transportation, while information technology plays a crucial role in cargo tracking and management.

The demand for air cargo transportation is closely linked to the economic and commercial activity of cities and regions. Cities with higher levels of commercial and industrial activity, as well as better infrastructure, exhibit a greater demand for air cargo transportation. Additionally, the proximity of major urban centers and regions with ports also influences the demand for air cargo transportation. However, the distribution of air cargo remains highly concentrated in five major cities, indicating a

need for broader regional integration. The study highlights several challenges facing air cargo transportation in Brazil, including limited infrastructure at many airports, few flights, and inadequate capacity to accommodate large aircraft. These challenges discourage companies from utilizing air transportation, thereby limiting the flow of goods. The results of the sample analysis reveal a high sensitivity and dependence of the GDP on air cargo, indicating a strong impact on the Brazilian market. This relationship becomes particularly evident during periods of internal and external crises, as demonstrated by the crises of 2008 (Subprime USA), 2015 (Fiscal and Political), and 2020 (Covid-19).

Although air cargo transportation in Brazil lags behind passenger transportation and other modes of cargo transportation, its development has the potential to drive industrial modernization in the country, supporting the transformation of the industrial chain into high-value-added products. To achieve this, it is crucial for local governments to formulate public policies aimed at incentivizing sector growth, investing in logistical infrastructure, stimulating digitalization, and facilitating collaboration among stakeholders. Similarly, businesses should adapt their strategies to align with consumer preferences and e-commerce trends, investing in technology and innovation to improve operational efficiency. These conclusions offer valuable insights and have important implications for the development and enhancement of air cargo transportation in Brazil. Understanding the economic, geographic, and sectoral factors that influence air cargo demand is crucial for the formulation of effective strategies by local governments and companies alike. The goal is to drive the sector's growth, add value to the local industry, promote economic dynamism, and contribute to the overall development of the country.

For future research, it is recommended to evaluate how policies can drive sector growth and promote economic development in different regions of the country. Additionally, exploring the relationship between air cargo transportation and aircraft idle capacity, with a focus on sustainability, would be a valuable area of investigation.

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References

ANAC. (2022). National Civil Aviation Agency of Brazil. Available online: http://www.anac.gov.br/assuntos/dados-e-estatisticas/microdados-de-tarifas-aereas-comercializadas (accessed on 02 June 2024).

Baltagi, B. H. (2005). Econometric Analysis of Panel Data. John Wiley and Sons. https://doi.org/10.1002/9781118725293

Bilotkach, V. (2015). Are Airports Engines of Economic Development? A Dynamic Panel Data Approach. Urban Studies, 52(9), 1577–1593. https://doi.org/10.1177/0042098015576869

Boeing. (2022). World Air Cargo Forecast 2020–2039. Available online: https://www.boeing.com/resources/boeingdotcom/market/assets/downloads/Boeing_World_Air_Cargo_Forecast_2022.pdf (accessed on 15 July 2024).

Button, K. J., Yuan, J., Doh, S. (2010). The role of small airports in economic development. Airport Management, 4(2), 1–12.

Button, K., Yuan, J. (2013). Airfreight transport and economic development: An examination of causality. Urban Studies, 50(2), 329–340. https://doi.org/10.1177/0042098012446999

Carbo, J. M.; Graham, D. J. (2020). Quantifying the Impacts of Air Transportation on Economic Productivity: A Quasi-Experimental Causal Analysis. Economics of Transportation, 24, 100195. https://doi.org/10.1016/j.ecotra.2020.100195

Chang, Y.-H., Yeh, C.-H., Wang, S.-Y. (2007). A survey and optimization-based evaluation of development strategies for the air cargo industry. International Journal of Production Economics, 106(2), 550–562. https://doi.org/10.1016/j.ijpe.2006.06.016

Chen, C.-H., Chou, J.-H. (2017). Multiobjective optimization of airline crew roster recovery problems under disruption conditions, IEEE Transactions on Systems, Man. Cybern, 47(1), 133–144. https://doi.org/10.1109/TSMC.2016.2560130

Fernandes, A. V., Pacheco, R. R.; Fernandes, E., et al. (2021). Air Transportation, Economy and Causality: Remote Towns in Brazil's Amazon Region. Sustainability, 13, 627. https://do i.org/ 10.3390/su13020627

Fernandes, E., Pacheco, R. R., Guedes, E. P., Aprigliano, V. (2024). Regular domestic air passenger market dynamics: The Brazilian case. Journal of Infrastructure, Policy and Development, 8(6), 4908. https://doi.org/10.24294/jipd.v8i6.4908

Fung, M. K. Y, Law, J. S., Ng, L. W. K. (2006). Economic Contribution to Hong Kong of the Aviation Sector: A Value-Added Approach, Chinese Economy. Taylor and Francis Journals, 39(6), 19–38. https://doi.org/10.2753/CES1097-1475390602

Góes, C., Garcia-Escribano, M., Karpowicz, I. (2018). Filling the Gap: Infrastructure Investment in Brazil. Journal of Infrastructure Policy and Development, 4(1), 100–123. https://doi.org/10.24294/jipd.v4i1.1234

IATA. (2024a). Air cargo capacity crunch: demand plummets but capacity disappears even faster, 2020. Available online: https://www.iata.org/en/pressroom/pr/2020-06-02-01/ (accessed on 20 July 2024).

IATA. (2024b). IATA Cargo Strategy, International Air Transport Association, 2021. Available online: https://www.iata.org/en/programs/cargo/ (accessed on 20 July 2024).

IBGE. (2022). Estimates of the resident population for municipalities and federative units (Portuguese). Available online: https://censo2022.ibge.gov.br/panorama/(accessed on 20 June 2023).

IBGE. (2023a). Annual Trade Survey: Gross resale revenue by marketing methods (Portuguese). Available online: https://www.ibge.gov.br/estatisticas/economicas/comercio/9075-pesquisa-anual-de-comercio.html?=&t=resultados (accessed on 15 March 2023).

IBGE. (2023b). Monthly Industrial Survey-Physical Production: Seasonally adjusted index number (Portuguese). Available online: https://sidra.ibge.gov.br/home/pimpfbr (accessed on 01 March 2023).

IBGE. (2023c). Monthly Survey of Services: Seasonally adjusted index number (Portuguese). Available online: https://sidra.ibge.gov.br/home/pms (accessed on 01 March 2023).

IBGE. (2023d). Continuous National Household Sample Survey: Per Capita Household Income (Portuguese). Available online: https://sidra.ibge.gov.br/home/pnadct (accessed on 01 March 2023).

IBGE. (2023f). Sistema de Contas Nacionais Brasil: 2022. Available online: https://www.ibge.gov.br/explica/pib.php (accessed on 20 June 2023).

IMF. (2019). World Economic Outlook: Global Manufacturing Downturn, Rising Trade Barriers. IMF.

Kasarda, J. D., Green, J. D. (2005). Air cargo as an economic development engine: A note on opportunities and constraints. Journal of Air Transport Management, 11, 459–462. https://doi.org/10.1016/j.jairtraman.2005.06.002

Kim, J. H., Choi, I. (2021). Choosing the Level of Significance: A Decision-theoretic Approach. Abacus, 57, 27–71. https://doi.org/10.1111/abac.12172vv

Kupfer, F, Meersman, H., Onghena, E., Van de Voorde, E. (2017). The underlying drivers and future develop-ment of air cargo. Journal Air Transport Management, 61, 6–14. https://doi.org/10.1016/j.jairtraman.2016. 07.002

Lakew, P. A. (2015). Airport traffic and metropolitan economies: Determinants of passenger and cargo traffic. Transportation Research Record: Journal the Transportation Research Board, 2471,58–72.

Livres. (2004). Longitudinal and Panel Data: Analysis and Applications in Social Sciences (Portuguese). Cambridge University Press.

Mukkala, K., Tervo, H. (2013). Air Transportation and Regional Growth: Which Way Does the Causality Run? Environment and Planning A: Economy and Space, 45, 1508–1520. https://doi.org/10.1068/a45298

Sheard, N. (2019). Airport Size and Urban Growth. Economica, 86, 300–335.

Twisk, J. W. (2013). Applied longitudinal data analysis for epidemiology: a practical guide. Cambridge University Press.

Ventura, R. V., Cabo, M., Caixeta, R., et al. (2022). Consumer behaviour analysis based on income and price elasticities: The case of the air transportation in Brazil. Case Studies on Transport Policy.

Wang, F.; Zhuo, X.; Niu, B. (2017). Strategic entry to regional air cargo market under joint competition of demand and promised delivery time. Transportation Research Part B Methodological, 104, 317–336. https://doi.org/10.1016/j.trb.2017.08.002

Wei, K., Vaze, V. (2018). Modeling crew itineraries and delays in the national air transportation system. Transportation Science, 52, (5), 1035–1296. https://doi.org/10.1287/trsc.2018.0834