Article

A Regional View of Passenger Air Link Evolution in Brazil

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Abstract: Passenger flows among cities, at both the domestic and international levels and in different countries and regions, have been studied for forecasting purposes. This paper seeks not a forecasting mechanism, but to understand, by analyzing passenger origins and destinations by Brazilian sub-region, how Brazil's domestic air passenger network links have evolved. Using income, population, and fare price as inputs, and seats sold as output, air link performance is examined by data envelopment analysis to discuss the regional link of domestic passenger traffic in Brazil and its dynamics, considering two specific years. The findings indicate that, although the highest passenger flow density is concentrated in Brazil's Southeast region, performance by emerging origins and destinations (O-Ds), such as those connecting the Northeast, display more substantial strength indices and advances (Malmquist analysis). The analysis of specific links was also important, which showed that important Brazilian airports are not necessarily more competent in generating trips. The Catch-Up indicator for innovation reveals the weak point in Brazil's air transport network. Although some airports enjoy strong networkability, they do not correspond in passenger origin or destination strength.

Keywords: domestic air traffic; O-D; DEA; Malmquist; Brazil

1. Introduction

Passenger origin–destination (O-D) flow and its pattern are key components in transport companies' business planning, mainly for airlines and airports. Its analysis is strategic for the best air route design, which can be organized through direct or connected flights. The actual O-D statistics of air passenger transport are not widely held available in the public domain, and as competition hardens, air fares fluctuate considerably. Such constraints make it difficult to formulate highly accurate models. Statistics identifying the reason for travel are also generally not publicly available. Passengers travel from one city to another on business, on holiday, to visit friends or relatives, and so on. Even without knowing the travel purpose, the passenger movement between different destinations can be investigated using a gravity model that examines the aggregate flow between any two cities connected by some common interest. It is interesting how network studies have been evolving, for example, by using mobile phone data [1] and through complex network analysis [2]. These kinds of studies are essential to understanding the role of cities' hierarchy and transport hubs on the development of the territory from different scales of analysis: local, regional, national, and international.

In conceptual terms, gravity modeling uses the flow variable as a function of explanatory variables representing the mass and friction between any two points, and is also widely used to estimate price–income elasticities of demand for forecasting purposes [3].

Considering that the economy is a key driver of air travel demand [4], and that there is a strong correlation between economic development and air passenger demand [5,6], particularly in Brazil [7,8], this paper explores regional passenger flows by considering the O-Ds' population and income, as well as the effectively commercialized fares for a significant sample of air travels in 2011 and 2016. In this matter, this research seeks to respond to the following question: How can we optimize the passengers flow on a given air route, given the income of the cities involved (O-Ds), their populations, and fares? By focusing on how air transport routes are able to induce passenger demand flows under an intra- and inter-regional view, and by highlighting bottlenecks regarding this issue, this research contributes to discussions on sustainable and territorially well-balanced economic development driven by the civil aviation industry, which are elements of development that are straightly related [9]. The analyzed period is justified by the fact that 2011 is the year in which the main airports in Brazil were conceded to private administration, whereas 2016 marks the consolidation of this concession process. This paper discusses the strength among air links, using data envelopment analysis (DEA) and Malmquist indices to show the dynamics of structural change. This kind of analysis is highly important to new Brazilian air transport market entrants endeavoring to establish themselves in Latin America's largest market.

In addition, recently, there has been a radical shift away from a prosperity scenario, where air transport was growing, to a scenario where the economy is seeking avenues to recover from negative growth rates and disruptive phenomena, such as pandemics. Whereas the Brazilian annual geometric gross domestic product growth rate from 2011 to 2014 was 1.80%, from 2014 to 2016, it was −3.42% [10]. In an analogy between world crisis analysis [11] and the Brazilian case, the economic and political crisis observed in Brazil may be categorized as of major proportions, and domestic air passenger transport levels may take up to 36 months to recover. This could take even longer considering the outbreak of the Covid pandemic.

This paper is organized into seven sections. The first is concerned with contextualization and the study object. The second offers a review of selected literature, comprising the publications considered most relevant to the study. The third presents the methodology underpinning the discussion of findings. The fourth describes the data used in the methodology. The fifth briefly describes the Brazilian case. The sixth presents the findings from the analysis and discussion. The seventh and final section states the main conclusions from the analysis, and offers suggestions for future research.

2. Literature Review

Discussions on the origin–destination of air passenger traffic have been attracting researchers' interest for some time now, including Derudder and Witlox [12], Grubesic et al. [13], and O'Connor and Fuellhart [14]. Derudder and Witlox [12], through a review of the literature, argue that future research should develop alternative ways of recording airline data with the aim of building more meaningful analyses, such as identifying the true origins and destinations of passengers, rather than just a specific segment of a trip.

Grubesic et al. [13] examined the emerging global hierarchy of the air transportation network by using the information of around 900 airline carriers from 2006, which considered 4650 origins and destinations. This study identified an increase in the complexity of the air networks in North America, Europe, and Asia. With a global perspective, O'Connor and Fuellhart [14] evaluate the relationship between cities´ hierarchy according to the Global and World City Project of Loughborough and air service characteristics. Results of this research show apparent differences between aircraft, airline size, and mode of operation depending on the city´s hierarchy within the global context.

Bhadra and Kee [15] analyzed the structure and dynamics of the main air transport markets in the United States, using quarterly series for the period between 1995–2006. The analysis focused on the origin–destination of commercial flights on the market segmented by the number of passengers transported per day (pax/day). They discovered that on

thick markets (pax/day > 100), demand was relatively elastic to mean fares, whereas other markets displayed inelastic demand. Their results also showed that passenger trip O-Ds are generally income-inelastic. Pitfield et al. [16] made an empirical analysis of the fit between aircraft size and flight frequency on long-haul routes, considering traffic, airline behavior, and degree of competition. This study used 1990 data for nine routes on the North Atlantic market, where a considerable number of airlines operate in a competitive environment. Pitfield et al. used origin and destination data between European and United States airports, consisting of the number of passengers, flight frequency, and aircraft size. They concluded that, with increased passenger numbers, flight frequency was more likely to increase than aircraft size.

Puller and Taylor [17] examined individual flight ticket transactions for each itinerary on trunk routes of the United States domestic market in 2004. They used detailed data on ticket purchase dates and tariffs, origin and destination, flight number, and service class. Puller and Taylor concluded that airlines charged lower fares for similar flights depending on the day of the week, and that this phenomenon suggested a day-of-purchase price discrimination mechanism. Fageda and Flores-Fillol [18] examined air service provision on thin routes, comparing the United States market with those of the European Union, using origin–destination data between airports and others. Their analyses focused on the impact of two major innovations in the air transport industry: regional jet technology and low-cost airlines. Fageda and Flores-Fillol concluded that regional services provided higher flight frequency at higher fare prices, whereas low-cost services offered cheaper fares at the cost of lower flight frequencies.

Mumbower et al. [19] estimated flight price elasticity using an on-line database and the corresponding aircraft seat maps. These elasticities were estimated considering the number of reservations on the flight and how many days prior to departure the booking was made. Their findings indicated that price elasticity varied with the day of the week when the reservation was made, the time of day of departure, and competitors' promotional sale dates. They showed that airlines could use these detailed price elasticity estimates, among other things, to forecast promotions. Luttmann [20] analyzed the reasons that may lead an airline to charge different one-way and return fares on the same route, depending on the point of origin of the trip, which is a case of directional price discrimination. For that purpose, he used data on airline passenger roundtrip ticket prices and origins and destinations obtained from the US Department of Transportation, as well as regional economic data, the reason for travel, and so on. He found significant evidence of income-related directional price discrimination, that is, airlines charged higher fares to passengers originating in cities with higher mean incomes.

Mohammadian et al. [21] examined the Australian domestic aviation market, using monthly data from 2004 to 2015 for 21 routes connecting eight cities. The aim was to investigate the relationship between demand per flight and capacity variables, such as frequency, aircraft size, load factor, etc. The results suggested that competition led to more flights, smaller aircraft, lower load factors, and more available seats in the markets studied. They also concluded that city socioeconomic parameters, such as population and employment rate, influenced flight demand more strongly on long-haul routes. Oliveira et al. [22] evaluated the effects of a series of determinants on air traffic network concentration and its possible decoupling relative to social and economic activity concentrations. They used air passenger, gross domestic product, and population for defining a concentration decoupling index. Their analysis discussed the relation of the decoupling and concentration indices with air passengers, international tourism, oil cost, slot constraints, airline competition, and socioeconomic events. Urban and Hornung [23], mapping causalities of airline dynamics, identified key elements for long-haul flight competition, which are the generation of transatlantic air transport demand, passenger choice, and airline ticket price and fleet development. Oliveira and Oliveira [24] showed that a Brazilian airline focusing on the regional flights segment conquered many monopoly positions across the country, strengthening its profitability.

The literature concerning airline passenger flows has focused on estimating forecasting models for better operational planning and scheduling by airlines. The studies generally consider the passengers' behavior related to economic and situational variables, considering only the travel segments (instead of the actual origin and destination). This kind of simplification in the analysis opens a research gap, namely the potential profit earned by airlines as the result of changing market conditions. Furthermore, it is important to develop research related to intra- and inter-regional air traffic in order to understand, in terms of performance, the internal dynamics of air traffic in countries with continental dimensions, such as Brazil.

3. Materials and Methods

3.1. Methodology

In emerging economies with continental-sized domestic markets, such as Brazil, China, Russia, and others, the internal passenger traffic between their sub-regions assumes more complex characteristics, requiring a better understanding both of these flows and of the different regional particularities. This study applied a methodology for analyzing regional flows in terms of performance and structural change over a given period. This approach considers a different perspective regarding the elements that make up the independent variables of a forecast function, examining their explanatory power to determine the volume of passengers on a given route. The regional analysis will make it possible to identify the level of performance, in terms of passenger flows, for each region of the country, as well as the interregional interactions.

The methodology comprised three stages. The first involved organizing, describing, and cleaning the available data to suit the study purpose. At this stage, the sample for analysis was defined. The second stage involved calculating and analyzing the efficiency indices of the air links using DEA. In the third, Malmquist indices were calculated, and their variations were examined to reveal a structural change in the links. The analyses covered both the total movement and the intra- and interregional O-Ds.

DEA analysis considered each O-D individually, but overall efficiency indices for the sample of O-Ds were used here, by Brazilian sub-region. That is, these indices were calculated for each region. The overall performance index was expressed by weighted means for individual O-Ds. This result gave cluster means in relation to the efficiency frontier in each year. The result was a number from 0 to 1, where 1 meant that the O-D or cluster was at the efficiency frontier.

Dynamic performance analysis used the means from the Malmquist analysis. These represented the movement of efficiencies for specific characteristics and changes specific to an O-D or cluster. Malmquist analysis yields indices of change that vary around 1, where values of less than 1 mean the characteristic is deteriorating, a value of 1 means stagnation, and values greater than 1 represent progress. The cluster means from both the DEA and the Malmquist indices were calculated using means weighted by the number of passengers for each O-D in that cluster. This weighting is important, because the O-Ds had differing market shares. As the analysis covered a five-year period, it was important to take growth in demand as a reference point, because small efficiency gains might be insufficient to explain air transport growth. The distinction between intra- and inter-regional passenger flows is strategic for the development of the airline sector, and for the formulation of policies for strengthening and regulating the sector.

Considering the O-Ds' managerial dimensions as inputs, and passengers processed as output, DEA depicted the best performance at each O-D and the overall situation of domestic air transport as a whole. The output maximization approach proved more appropriate to the study problem, because one of airlines' main objectives is to maximize the passenger flow. Moreover, dynamic analysis was conducted using balanced panel data for the two years, 2011 and 2016.

DEA is a non-parametric method designed to measure the performance of a firm, organization, program, etc., i.e., whatever is produced by a decision-making unit (DMU).

Charnes et al. [25] presented the various formulations developed for the DEA approach. In this study, the main issue was the organizations' output potential. Given that the study object comprised O-Ds of differing sizes, the model chosen was the output-oriented approach using a variable return to scale (VRS). The proposed model, known as output-oriented BCC, involved the primal of the linear programming problem in Equation (1).

Output-Oriented BCC Primal
(BCCp-O)

$$\max_{\phi, \lambda, s^+, s^-} Z_0 = \phi + \varepsilon.\vec{1}s^+ + \varepsilon.\vec{1}s^-$$

$$\text{s. t.} \quad \phi Y_0 - Y\lambda + s^+ = 0$$
$$X\lambda + s^- = X_0$$
$$\vec{1}\lambda = 1$$
$$\lambda, s^+, s^- \geq 0$$

(1)

where: X is the vector of inputs used by the DMUs; Y is the vector of quantities produced (outputs) by the DMUs; ε is the infinitesimal non-Archimedean constant that assures that no input or output is assigned zero weight; s^+ and s^- are the slack vectors, respectively, of the outputs and inputs; ϕ is a scalar variable that represents the possible radial increase to be applied to all outputs so as to obtain the values of the projected outputs; and λ is the vector whose optimal values form a combination of units that make up the performance of the DMU under study, thus setting a direction by which to identify the sources of inefficiency in this DMU.

An O-D's efficiency rating at any given moment is a static value. Malmquist analysis was used to reflect the O-D's dynamic behavior in relation to the efficiency frontier from 2011 to 2016. The Malmquist index was used because it allows efficiency change to be decomposed into dimensions that are useful for understanding O-D performance. Authors have used different nomenclatures for these dimensions. The original study by Malmquist [26] decomposed efficiency change into components, as described by Coelli et al. [27], Färe et al. [28], Ray and Desli [29], and others. This study used the Malmquist total factor efficiency index (*MI*) decomposition proposed by Ray and Desli [29] for the VRS output-oriented DEA model. Ray and Desli decomposed the *MI* into three components. Equation (2) shows the *MI* for two years, 2011 and 2016. Its components are catch-up (*CU*) and frontier shift (*FS*) for the VRS, and the scale component (*SEC*).

$$MI\left(x^{2011}, y^{2011}, x^{2016}, y^{2016}\right) = CU \times FS \times SEC$$

(2)

where:

$$CU = \frac{\delta^{2016}\left(\left(x_0, y_0\right)^{2016}\right)}{\delta^{2011}\left(\left(x_0, y_0\right)^{2011}\right)}$$

(3)

$$FS = \sqrt{\frac{\delta^{2011}\left(\left(x_0, y_0\right)^{2011}\right)}{\delta^{2016}\left(\left(x_0, y_0\right)^{2011}\right)} \times \frac{\delta^{2011}\left(\left(x_0, y_0\right)^{2016}\right)}{\delta^{2016}\left(\left(x_0, y_0\right)^{2016}\right)}}$$

(4)

$$SEC = \sqrt{\frac{\sigma^{2011}\left(\left(x_0, y_0\right)^{2016}\right)}{\sigma^{2011}\left(\left(x_0, y_0\right)^{2011}\right)} \times \frac{\sigma^{2016}\left(\left(x_0, y_0\right)^{2016}\right)}{\sigma^{2016}\left(\left(x_0, y_0\right)^{2011}\right)}}$$

(5)

where:

$(x_0, y_0)^t$ represents the position of the O-D considered in period t, by way of its inputs and outputs;

δ^t represents the O-D's efficiency index in period t for the variable return to scale frontier in period t; and

σ^t represents the O-D's scale efficiency in relation to the frontier in period t.

The DEA and Malmquist parameters were weighted by the number of seats sold on the O-D. This weighting was important to prevent trends in the simple means of the country

sub-region efficiency indicators, which might return disproportional measurements when small links had greater indicators than high passenger-density links, and vice versa. The analyses were conducted using mean values at the intra- and interregional levels. Although DEA was conceived to analyze production performance, this paper uses a formulation of a demand function, seeking to show how best O-D socioeconomic conditions and link price result in air transport link demand.

3.2. Case Study

Brazil occupies a geographical area of 8.5 million km^2, making it the country with the fifth-largest territory in the world, after Russia, Canada, China, and the United States. In 2018, it also had the fifth largest population (209 million), according to World Bank figures. Its economy ranked seventh, with a GDP of around 3.388 trillion Int $ (PPP $—international dollar) in 2017 [30]. However, in 2015, Brazil ranked only 74th in per capita GDP (about 8670 Intl $), a long way from the group of countries classified as developed—as was also the case with other countries with large territories and significant GDPs, such as China, India, and Russia. Brazil is a federative republic comprising 26 states and the Federal District (the country's capital), and is organized into five administrative regions: North (N), Southeast (SE), Midwest (MW), Northeast (NE), and South (S). Each Brazilian state has one municipality where the state capital is located. Brazil has 5570 municipalities, of which 309 had populations of more than 100,000 in 2016 [10]. This is a size that can be considered attractive for airline operations, especially when the city is more than 100 km from cities that already have airports. Despite this potential, only 90 cities were found to have airports operating regular flights in both 2011 and 2016. That fact seems to be connected with Brazil's low per capita income combined with the concentration of the total GDP in the Southeast region.

Table 1 shows the distribution of GDP, population (POP), and GDP per capita according to the Brazil's five regions. All monetary values, in Reais (Brazilian currency), presented in this study are in constant 2016 values, corrected by the National Extended Consumer Price Index (IPCA), the country's official inflation rate. Note that, although the SE region's share in GDP declined by 2.24 percentage points (p.p.), the SE continued to predominate quite clearly as the country's economic center, accounting for more than 50% of all income and about 42% of the total population. The MW region, meanwhile, comprising a smaller percentage of the population, returned a higher per capita income than the SE. Two factors account for this situation: the first is that Brazil's export-oriented agricultural and livestock production is concentrated in the MW, and the second is that the nation's capital is located in this region. The NE region performed best in an increased share of GDP (a variation of more than 0.93 p.p.). Fernandes et al. [31] showed that this was the region that prospered most in service GDP, meaning that this region's airports performed best in networkability. However, the NE is the region with the lowest per capita GDP in Brazil. Although the N and MW regions account for large portions of Brazil's total area, they hold a smaller part of the population.

Table 1. GDP, POP, and per capita GDP of Brazil's regions.

Region	GDP (Billion Reais)				POP (Millions)				Per Capita GDP (Reais)	
	2011	%	2016	%	2011	%	2016	%	2011	2016
SE	3452	55.41	3332	53.17	80.98	42.09	86.36	41.91	41,149	38,585
S	1011	16.22	1067	17.02	27.56	14.33	29.44	14.29	38,711	36,243
NE	835	13.4	898	14.33	53.49	27.81	56.91	27.62	16,789	15,781
MW	596	9.57	633	10.1	14.24	7.4	15.66	7.6	44,431	40,412
N	336	5.4	337	5.38	16.1	8.37	17.71	8.59	20,951	19,043
Brazil	6230		6267		192.4		206.1		32,579	30,413

In the nomenclature used in this study, "passengers" (PAX) is synonymous with seats sold. Note, in Table 1, that the SE region's share in all variables declined, although it continued to predominate by a considerable margin as the country's economic powerhouse. The NE region performed best as regards growth in share of PAX.

Among the main economic activities in the NE region, tourism is particularly notable for its recent performance, and for its relevance in terms of income and employment generation. Silva et al. [32] present a hierarchy of 50 Brazilian airports associated with tourism, 38% of which are in the NE region, 20% in the MW, 18% in the N, 12% in the S, and 12% in the SE. Accordingly, the rising gross value of the service sector in the NE region is closely related to the tourism industry, whereas in the MW, the service sector's gain in gross value correlates with growth in the region's agribusiness sector. These data show that tourism plays a significant, but not predominant, role in PAX movement in the MW. The sample used in this study encompasses the main municipalities served by airports. The results for this group of cities better reflect the behavior of air transport in Brazil than the general statistics, since it represents the main economic centers of the country—a source of demand flows for air travel, and historically more sensitive to changes in the economic or political scenario.

3.3. Data

Air transport O-D databases are scarce in the field of air transport research [33–36]. It is thus common practice to use samples in related analyses. The data used in this study originated in microdata from the National Civil Aviation Agency (ANAC) (https://www.anac.gov.br/assuntos/dados-e-estatisticas/microdados-de-tarifas-aereas-comercializadas, accessed on 5 May 2022), which show the volume of tickets purchased on each trip, i.e., from origin to destination, by the price paid and by month. For the purpose of analysis, these data were transformed into annual values of O-D movement and weighted means of prices paid by O-D. According to the ANAC, these data represent about 50% of the total movement, because the database does not include tickets purchased under mileage programs or specific agreements between purchasers and airlines. The data on domestic airfares apply to all tickets sold. The GDP and POP figures for the main municipalities served by the trip origin and destination airports were obtained from Brazilian Institute of Geography and Statistics (IBGE).

The database is directional, i.e., it considers outward and returns tickets separately. Each direction has a specific price. The links considered are those existing in 2011 and 2016, so that Malmquist analysis indices can be calculated. Links with an annual demand of at least 52 tickets were considered, so as not to include occasional ticket purchases as links. The data relate to the 26 state capitals, the national capital, 63 regional cities, and three of the state capitals (Belo Horizonte, Rio de Janeiro, and São Paulo, Brazil) with two airports each, totaling 93 airports that were operating in both 2011 and 2016. Within the specifications of the sample, 3133 O-Ds present in both years were validated. Appendix A contains a map of Brazil's regions (Figure A1), showing the location of the airports covered by the study, and, in Table A1, the ICAO codes for the airports, the cities relating to each airport, and the name and abbreviation of each state.

The analytical model had five inputs and one output. The output is the number of seats purchased from one origin to a given destination. The inputs are the GDP and POP of the municipality of origin and destination municipality, and average ticket price weighted by tickets sold (TICK) in the years in question. Table 2 shows the correlation between output and inputs of the DEA model considered for analysis. As ticket prices vary inversely with passenger demand, this variable was transformed to its reciprocal, as suggested by Bowlin [37], in order to implement the DEA in such a manner as to guarantee the isotonicity of the variables.

Table 2. Correlation of PAX with the variables.

Variables	PAX	
	2011	**2016**
GDP ORIG	0.293	0.323
GDP DEST	0.291	0.321
POP ORIG	0.300	0.329
POP DEST	0.298	0.327
TICK	−0.302	−0.332

Table 3 shows the descriptive statistics for the variables considered for analysis in this study. From Table 3, it can be seen that the standard deviations of the variables are quite large, revealing a significant variety of situations, ranging from low-density and/or short-haul links to high-density and long-haul links. Distances between airports in Brazil can be greater than 4000 km, as between Cruzeiro do Sul, in AC state, and João Pessoa, in PB state. There are 16 towns in the sample with fewer than 100,000 inhabitants; these are small, isolated localities, of tourist or strategic interest to the country. One example is Fernando de Noronha, an island and protected environment in the east of the NE region, whose economic activity is fundamentally tourism. Another example is Coari, in AM state in the N region, an isolated locality in the Amazon Forest, where there is significant production of natural gas. Data for GDP (in million Reais) and POP (in thousands of the population) relate to the 90 cities in the sample. The statistics used for the remaining variables refer to the 3133 O-Ds.

Table 3. Descriptive statistics by variable.

	Year	PAX	GDP	POP	TICK
Average		15,440	29,904	674	378.41
Standard deviation	2011	52,872	84,294	1421	372.58
Upper value		1,108,434	705,722	11,316	2272.62
Lower value		52	89	3	95.31
Average		12,659	29,137	711	339.19
Standard deviation	2016	40,773	83,060	1487	273.16
Upper value		827,281	687,036	11,896	1637.08
Lower value		52	114	3	107.25
Observations		3133	90	90	3133

4. Results

Table 4 shows the results of the DEA and Malmquist analysis of the intra-regional links. It can be seen that only a small number of O-Ds were at the efficiency frontier—39 and 23, respectively, in 2011 and 2016—of a total of 690. In all, 20 O-Ds were at the efficiency frontier in both years. The regions returned CUs of 0.70 to 0.74, indicating a uniform decline in performance as regards this indicator of innovation. The SE and NE regions displayed FS improvements, the SE's being the most significant (FS = 1.25). SEC remained relatively stagnant in all regions, ranging from 0.97 to 1.01. Overall, intra-regional air transport performance declined, with MI from 0.62 (MW) to 0.88 (SE). Table 4 also shows that from 690 O-Ds, 245 had MIs improved (35.51%); this happens mainly in the SE and NE regions, where FS were 1.25 and 1.07, respectively.

Table 4. Intra-regional DEA and Malmquist indices.

Intra-Region	O-Ds	PAX 2011	PAX 2016	DEA 2011	DEA 2016	CU	FS	SEC	MI	DEA 2011 =100	DEA 2016 =100	MI <1	MI =1	MI >1
SE	257	9991	7147	0.62	0.58	0.70	1.25	1.01	0.88	7	2	167	-	90
S	78	1751	1159	0.80	0.70	0.74	0.97	0.99	0.71	7	5	48	-	30
NE	187	2817	2246	0.55	0.60	0.70	1.07	0.99	0.74	10	8	112	1	74
MW	29	545	344	0.39	0.33	0.73	0.87	0.98	0.62	-	-	24	-	5
N	139	1414	1021	0.63	0.60	0.71	0.96	0.97	0.66	15	8	93	-	46
DEA = 100				39	23									
DEA < 100				651	667									
Index < 1						673	324	402	444					
Index = 1						2	21	13	1					
Index > 1						15	345	275	245					
Total	690	16,519	11,918	690	690	690	690	690	690	39	23	444	1	245

Overall, the analysis showed that in the intra-regional dimension, the indicator for innovation (CU) was most strongly connected with a diminished performance by O-Ds. From 690, 673 O-Ds had CU < 1 (97.54%). Meanwhile, the indicator for scale (SEC) stagnated, reflecting no variations in the regional structures. Although FS did advance in the SE and NE regions, those advances were insufficient to overcome the decline indicated by CU in these regions, leading to MI < 1. In the S and N regions, FS was nearly stagnant, and MI was thus influenced basically by the deterioration in CU. The MW region showed deteriorating FS, which led, in turn, to greater degradation indicated by CU, leaving the region with lower MI. The SE region's performance, because of a good FS result (1.25), was the least affected in total efficiency, represented by MI.

Table 5 shows the results of the DEA and Malmquist analysis of the interregional O-Ds, where regular domestic air passenger transport flows are largest in Brazil, about 66% of the passenger sample. Although the O-Ds were further from the efficiency frontier than in the intra-regional cases, the indicators of improvement from the Malmquist analysis were much more promising. The considerable number of O-Ds involving the SE region (55% of the total) attests to this region being the main origin or destination of inter-regional passengers. The SE region O-Ds accounted for more than 50% of intra-regional passenger movement (Table 4). As in the intra-regional dimension, only a small number of O-Ds defined the efficiency frontier. Of the 52 O-Ds that were at the frontier in at least one of the study years, 32 were there in 2011, and 35 in 2016. Of these, 15 were at the frontier in both years. All regions had some O-D at the efficiency frontier. The inter-regional O-Ds that moved away from the efficiency frontier least were SE–NE and S–SE, which also comprised the links with the greatest number of passengers. However, total efficiency declined in both, with MI indicators equal to 0.88. The O-Ds with greatest performance improvements (MI > 1) were SE–N, S–NE, and S–N, among which the S region was conspicuous for improvement in total efficiency (MI = 1.15, 1.26, and 1.42). Poor O-D performance, as in the case of intra-regional O-Ds, can be associated primarily with the indicator for innovation, CU, which varied from 0.66 to 0.77. The indicator that displayed most overall improvement was FS. The indicator for scale (SEC) remained largely close to stagnant. Most (56%) of the inter-regional O-Ds returned an MI greater than 1, indicating an endeavor to improve the total efficiency in most of the O-Ds.

From Table 5, it can also be seen that the main improvements observed in the FS indicator did not occur on the highest-density passenger links, which were, in decreasing order of number of passengers, SE–NE, S–SE, and SE–MW.

Table 5. Inter-regional DEA and Malmquist indices.

Inter-Region	O-Ds	PAX 2011	PAX 2016	DEA 2011	DEA 2016	CU	FS	SEC	MI	DEA 2011	DEA 2016	MI		
										=100	=100	<1	=1	>1
MW–NE	139	1927	1787	0.38	0.41	0.66	1.29	0.99	0.85	1	1	53	-	86
N–MW	113	858	635	0.27	0.21	0.70	1.11	0.98	0.76	-	2	73	-	40
N–NE	248	765	713	0.23	0.23	0.66	1.36	1.00	0.90	-	-	116	-	132
SE–MW	191	6015	4735	0.51	0.48	0.73	1.19	0.99	0.86	-	2	103	1	87
SE–NE	479	9424	8261	0.60	0.62	0.68	1.30	1.00	0.88	12	18	206	-	273
SE–N	336	1579	1589	0.20	0.23	0.68	1.41	1.15	1.10	2	2	160	-	176
S–MW	119	1270	1186	0.33	0.34	0.72	1.28	1.03	0.95	1	2	55	-	64
S–NE	285	976	1202	0.16	0.20	0.68	1.76	1.06	1.26	4	2	80	-	205
S–N	197	257	361	0.06	0.10	0.69	1.88	1.10	1.42	2	-	75	-	122
S–SE	336	8784	7272	0.63	0.60	0.77	1.15	1.00	0.88	10	6	160	-	176
DEA = 100				32	35									
DEA < 100				2411	2408									
Index < 1						2399	585	1245	1081					
Index = 1						-	17	16	1					
Index > 1						44	1841	1182	1361					
Total	2443	31,856	27,742	2443	2443	2443	2443	2443	2443	32	35	1081	1	1361

5. Discussion

The intra-regional and inter-regional results obtained seem consistent with the particularities, recent trends, and economic dynamics of each of the Brazilian regions. Taking the discussion presented by Ter Wal and Boschma [38] about the influence of networks on the development of regional economies, together with the intra-regional results given here, we may infer that the SE region offers suitable social and economic conditions for increasing O-D efficiencies, particularly in connections with state capital cities, such as São Paulo, Rio de Janeiro, Belo Horizonte, and Vitoria. These cities have significant GDP, and greater population density and diversity of economic activities, enabling the "social network" to be more resilient [31]. As such, the connections with them, given the variety of economic opportunities available in the region, are better able to withstand regional economic crises. However, the industry does not seem to have made proper use of inter-regional potential. The S region shares a characteristic with the SE region, in that it accounts for the second-largest share of Brazil's GDP [10]. As such, it offers suitable regional economic conditions for improving the MI for certain air links. The opposite effect can be seen in relation to the N region, which has the smallest share of national GDP, which is reflected in lesser diversity and intensity of economic activities and dynamics within the region, as well as in no improvement in the MI for intra-regional air links, whereas better prospects do exist at the inter-regional level, primarily in links with the S and SE regions.

The intra-regional result for the MW region seems to be related to the importance of agri-business to the region [39]. As was observed by Giuliani and Bell [40], with regard to the knowledge and technology network connected with wine production in Chile, which has little connectivity on a local or regional scale, i.e., it is an isolated network concentrated within the wine-producing companies or those that connect with agents outside the "natural" proximity zone (in other regions of Chile), this same process may be occurring with air traffic in the MW region, reflecting the stagnation or degradation of connections in the MW. At the inter-regional level, the O-Ds relating to this region returned the lowest MI values of the set (0.76, 0.85, and 0.86).

After the SE, it is the NE region that has benefited most from domestic tourism [41]. It should also be stressed that Bahia (BA) is the state with the largest GDP in the region [10], especially in the tertiary sector, primarily tourism. Unlike what happens in the MW region, the tourism-related service sector cuts across various other sectors and embodies more significant relations of geographical proximity. This strengthens the production chain of local and regional tourism, which influence factors from everyday leisure activities through to tourism activities in other places within the area of influence of the region's tourism network, particularly the state of BA (where Salvador and Porto Seguro are located), as can be observed in the NE region's intra-regional results. However, although one of the best-performing ODs in terms of total efficiency relates to the NE (S–NE), the set of higher

inter-regional traffic density O-Ds (SE–NE) does not perform satisfactorily and deserves attention from air transport operators.

6. Conclusions

The present research investigates the degree of robustness of the domestic passenger air transport network in Brazil, using a regional analysis of the flow of travelers' origin and destination. The sample selected for analysis comprises the period when the important economic changes experienced by the civil aviation industry in the country became more evident. Furthermore, although not random, the sample analyzed allows us to infer a general profile of the most relevant passenger flows for airline planning purposes.

The intra- and inter-regional analyses show that even though similarities exist, the various O-Ds differ in terms of performance, resilience, and potential. The weighted grouping of intra- and inter-regional indicators for the O-Ds give a more synthetic view of the travel generation efficiency in Brazil. Although the SE region returned better performance indicators at both intra- and inter-regional levels, other regions performed better in a number of other dimensions. Better performance indicators can be connected with major economic differences and population concentration, rather than with improvement in O-Ds. With only three inter-regional exceptions (S–N, S–NE, and SE–N), the MI indicators showed that airlines in Brazil have not managed to take advantage of the demand potential of domestic passenger O-Ds. The domestic airlines' weak point was revealed by the CU indicator, one reason for which may be the lack of secondary airports in Brazilian state capitals, which hinders supply flexibility. Another may be the entry barriers facing new competitors, which are still rather high. Catching up and forging ahead calls for a more innovative attitude on the part of domestic airlines in Brazil.

Brazil's most recent family budget survey, covering the years 2017 and 2018 [10], showed that the share of spending on domestic air transport had almost doubled in Brazilian family budgets, as compared with the previous survey for 2008 and 2009 (from 0.32% to 0.57%). However small this percentage may be, this statistic suggests that Brazilian households, in general, recognize the utility of air transport in their lives. Moreover, this utility tends to be even greater in remote or isolated areas, such as those located in the Brazilian Amazon, situated in the N region. However, the results point out that airlines are still not showing themselves capable of taking advantage of this market opportunity by offering products and services to expand the number of air travels in the country, so that they return satisfactory efficiency indicators. In other words, the contribution of the aviation industry in Brazil to the integration of markets, people, and economic development is still below its potential level. Deepening this analysis and providing new elements for this discussion will be the object of future research, which can be developed based on the findings presented here.
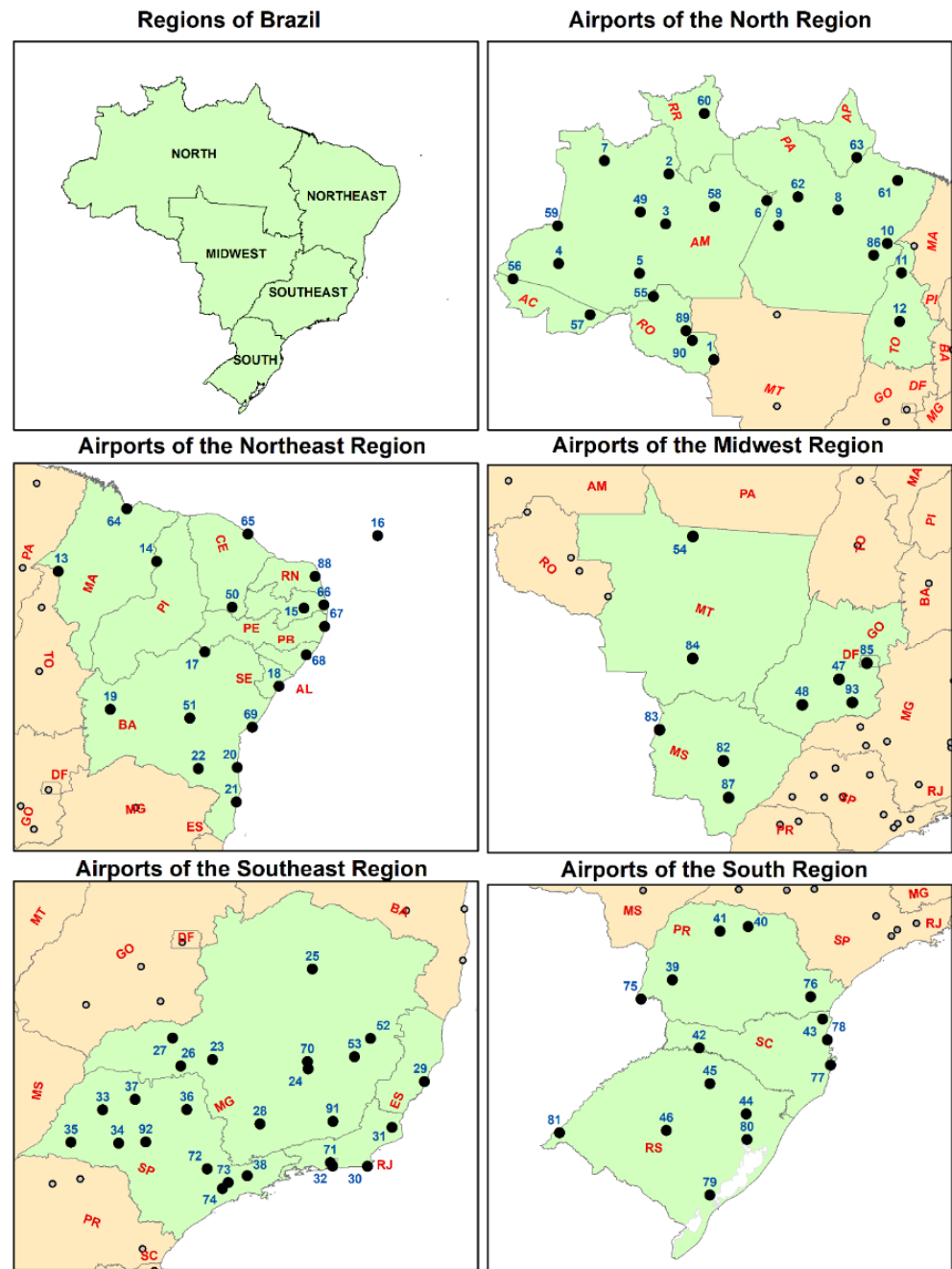
Appendix A

Figure A1. Location of airports in Brazil, by state and region.

Table A1. Airports in each city, state, and region (IDs relate to Figure A1).

ID	ICAO	CITY	STATE	REGION
85	SBBR	Brasília	Distrito Federal (DF)	MIDWEST (MW)
47	SBGO	Goiânia	Goiás (GO)	
48	SWLC	Rio Verde		
93	SBCN	Caldas Novas		
82	SBCG	Campo Grande	Mato Grosso do Sul (MS)	
83	SBCR	Corumbá		
87	SBDO	Dourados		
54	SBAT	Alta Floresta	Mato Grosso (MT)	
84	SBCY	Várzea Grande		
68	SBMO	Maceió	Alagoas (AL)	NORTHEAST (NE)
19	SNBR	Barreiras	Bahia (BA)	
20	SBIL	Ilhéus		
21	SBPS	Porto Seguro		
22	SBQV	Vitória da Conquista		
51	SBLE	Lencóis		
69	SBSV	Salvador		
50	SBJU	Juazeiro do Norte	Ceará (CE)	
65	SBFZ	Fortaleza		
13	SBIZ	Imperatriz	Maranhão (MA)	
64	SBSL	São Luís		
15	SBKG	Campina Grande	Paraíba (PB)	
66	SBJP	Santa Rita		
16	SBFN	Fernando de Noronha	Pernambuco (PE)	
17	SBPL	Petrolina		
67	SBRF	Recife		
14	SBTE	Teresina	Piauí (PI)	
88	SBSG	Natal	Rio Grande do Norte (RN)	
18	SBAR	Aracaju	Sergipe (SE)	
56	SBCZ	Cruzeiro do Sul	Acre (AC)	NORTH (N)
57	SBRB	Rio Branco		
2	SWBC	Barcelos	Amazonas (AM)	
3	SWKO	Coari		
4	SWEI	Eirunepé		
5	SWLB	Lábrea		
6	SWPI	Parintins		
7	SBUA	São Gabriel da Cachoeira		
49	SBTF	Tefé		
58	SBEG	Manaus		
59	SBTT	Tabatinga		
63	SBMQ	Macapá	Amapá (AP)	

Table A1. *Cont.*

ID	ICAO	CITY	STATE	REGION
8	SBHT	Altamira		
9	SBIH	Itaituba		
10	SBMA	Marabá	Pará (PA)	
61	SBBE	Belém		
62	SBSN	Santarém		
86	SBCJ	Parauapebas		
1	SBVH	Vilhena		
55	SBPV	Porto Velho	Rondônia (RO)	
89	SBJI	Ji-Paraná		
90	SSKW	Cacoal		
60	SBBV	Boa Vista	Roraima (RR)	
11	SWGN	Araguaína	Tocantins (TO)	
12	SBPJ	Palmas		
29	SBVT	Vitória	Espírito Santo (ES)	
23	SBAX	Araxá		
24	SBBH	Belo Horizonte		
25	SBMK	Montes Claros		
26	SBUR	Uberaba		
27	SBUL	Uberlândia	Minas Gerais (MG)	
28	SBVG	Varginha		
52	SBGV	Governador Valadares		
53	SBIP	Santana do Paraíso		
70	SBCF	Confins		
91	SBZM	Juiz de Fora		SOUTHEAST (SE)
30	SBCB	Cabo Frio		
31	SBCP	Campos dos Goitacazes		
32	SBRJ	Rio de Janeiro	Rio de Janeiro (RJ)	
71	SBGL	Rio de Janeiro		
33	SBAU	Araçatuba		
34	SBML	Marília		
35	SBDN	Presidente Prudente		
36	SBRP	Ribeirão Preto		
37	SBSR	São José do Rio Preto	São Paulo (SP)	
38	SBSJ	São José dos Campos		
72	SBKP	Campinas		
73	SBGR	Guarulhos		
74	SBSP	São Paulo		
92	SBAE	Bauru		

Table A1. *Cont.*

ID	ICAO	CITY	STATE	REGION
39	SBCA	Cascavel		
40	SBLO	Londrina		
41	SBMG	Maringá	Paraná (PR)	
75	SBFI	Foz do Iguaçu		
76	SBCT	São José dos Pinhais		
44	SBCX	Caxias do Sul		
45	SBPF	Passo Fundo		
46	SBSM	Santa Maria		SOUTH (S)
79	SBPK	Pelotas	Rio Grande do Sul (RS)	
80	SBPA	Porto Alegre		
81	SBUG	Uruguaiana		
42	SBCH	Chapecó		
43	SBJV	Joinville		
77	SBFL	Florianópolis	Santa Catarina (SC)	
78	SBNF	Navegantes		

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