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Article

Regular domestic air passenger market dynamics: The Brazilian case

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Abstract: Brazil occupies a prominent position as one of the largest domestic air passenger markets globally. In May 2019, OAG Aviation Worldwide Limited (OAG), a renowned global travel data provider, ranked Brazil as the world's 6th largest domestic market. This study identifies and meticulously analyses statistical trends in how service levels affect passenger demand on domestic air routes in Brazil. To that end, it employs a panel-data gravity model incorporating service as an instrumental variable. The findings confirm the influence of traditional gravity explanatory variables, while also contributing novel insights into the impact of service levels on domestic routes. The analysis reveals that, while factors such as income and distance play a fundamental role in shaping domestic demand, level of service emerges as a crucial determinant on regional connections. Overall, the statistics suggest growing divergences between Brazilian airlines and regional air transport. Accordingly, substantial changes are necessary in both government policies and the services offered by the airline industry in order to harness the full potential of Brazil's domestic air transport passenger market and foster regional development.

Keywords: Brazil; domestic air passenger market; route service level; panel-data gravity model; regional connections; government policy

1. Introduction

Since the early 2000s, Brazil has experienced an increase in air passenger movement, fueling expectations of an improvement in its ranking in world air passenger movement. In May 2019, OAG Aviation Worldwide Limited (OAG), a global travel data provider, ranked Brazil the 6th largest domestic market (OAG, 2022). Meanwhile, according to World Bank Development Indicators, between 1995 and 2019, Brazil moved from 16th to 10th worldwide in air passengers carried (Word Bank, 2022). **Table 1** shows the top ten air transport passenger volumes carried, by country, and related percentage growths from 2002 to 2019. While developed countries showed moderate growth rates, emerging countries returned high growth rates, except for Brazil, which was near the world average. Notably, two borderline Global North countries—Russia, and Turkey—also reported impressive growth and may be considered to have more in common with emerging Global South countries than with the Global North.

Deregulation of Brazil's domestic air transport market began in 1992 and was completed in 2001, resulting in a liberal scenario during the study period. In 2009, its civil aviation agency (Agência Nacional de Aviação Civil, ANAC) initiated a gradual process of international air transport liberalization in Brazil, which is ongoing. Although this had greater impact on Brazilians traveling abroad, international passenger air transport subsequently began to grow more substantially than domestic transport. ANAC data (ANAC, 2020) show that from 2002 to 2019, while domestic passenger traffic grew by 224%, international traffic grew by 244%. As a result, international traffic accounted for 10.91% of total passengers in 2002 and 11.49% in 2019. The measures to liberalize international air transport reversed the previous downward trend in international passenger participation in Brazilian air transport and stimulated international companies' interest in the Brazilian market, shrinking Brazilian airlines' share in this market. **Figure 1** illustrates the composition of passengers embarked and disembarked in Brazilian airports from 2002 to 2019: the percentage of international passengers grew steadily but has not yet regained its 2003 level.

Table 1. World ten largest air transport passenger volumes, by country, 2019.

Country*	2002	2019	% Growth
USA	598,410,415	926,737,000	55
CHN	83,671,798	659,629,070	688
IND	17,633,019	167,499,116	850
GBR	72,381,196	142,392,528	97
JPN	109,037,841	130,233,352	19
RUS	20,892,156	115,482,744	453
TUR	10,686,877	111,028,629	939
DEU	61,889,678	109,633,751	77
BRA	35,889,538	102,917,546	187
World	1,829,359,364	5,268,105,213	188

* USA—United States of America; CHN—China; IND—India; GBR—Great Britain; JPN—Japan; RUS—Russia; TUR—Turkey; DEU—Germany; BRA—Brazil.
Source: adapted from World Bank (2022).

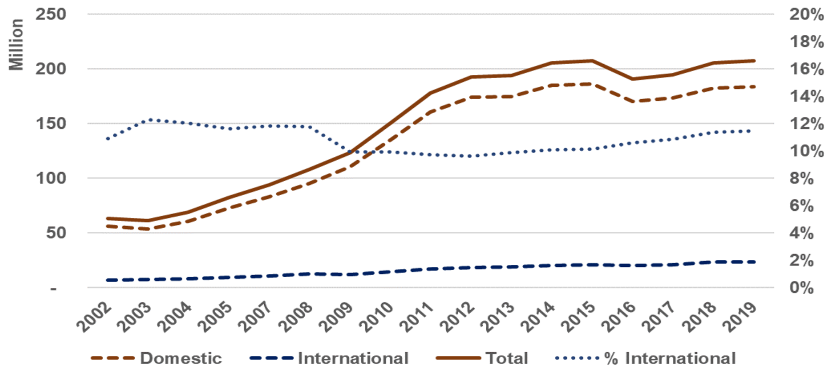

Figure 1. Regular domestic and international passenger movement in Brazil, and percentage international passengers, 2002 to 2019 (Source: ANAC data).

Although Brazilian studies have examined the relationship between changes in air passenger numbers and economic variables, such as gross domestic product (GDP) and yield (Fernandes and Pacheco, 2010; Marazzo et al., 2010), the literature lacks comprehensive studies of movement on intercity air routes, particularly domestic routes, and the impact of service level on demand. One notable exception is the study of Australian domestic air routes, by Lohmann and Vianna (2016). Air routes reflect relationships between cities from business, tourism or personal interests, such as visiting friends and relatives. These passenger flows are fundamental to the airline industry's supply planning and determine expected movement at airports. However, demand also results from endogenous supply factors given by airline planning, such as airline logistics, fleet availability, fare pricing, and other factors. Consequently, trends in demand for air transport between two cities depend on market potential, as expressed by the gravitational model, airline service variables, and factors connected with governmental and airline policies. The way domestic passenger movement has grown in Brazil, with high growth rates and fewer routes served, calls for a discussion of network shrinkage. Despite the full liberalization of the domestic air transport market from 2001 onwards, airlines have shown enormous volatility, with three of them concentrating and supply concentrating on denser routes using larger aircraft. This study constructs a robust model of air passenger flows between airport pairs in Brazil to facilitate discussion of airline and government policies. In doing so, it examines airline supply behavior, fleet evolution, and link stability (here, link and route are used synonymously). The paper addresses observed bottlenecks of Brazilian air transport by utilizing an unbalanced panel data set on air routes in Brazil from 2002 to 2019.

The paper is organized into seven sections. This introduction sets out the study context and aims. Section 2 gives an overview of research papers on the subject and the grounds for the chosen methodology. Section 3 introduces the analytical instruments supporting the analysis. Section 4 describes the characteristics of the Brazilian domestic passenger market. Section 5 presents the results of the panel data model. Section 6 discusses trends, the panel data model results, and the study's limitations. Ending the paper, section 7 summarizes the authors' conclusions and suggestions.

2. Literature review

In Brazil, several studies have examined transport demand using explanatory variables such as GDP. Fernandes and Pacheco (2010) and Marazzo et al. (2010) investigated global demand, while Bendinelli and Oliveira (2015) focused on specific airports in Brazil. Internationally, Klodt (2004) assessed the effects of borders on passengers embarked on regular flights at Germany's three largest airports. Using the gravity model, the study concluded that the presence of the German border reduced the number of travelers leaving German airports by approximately 22%. Matsumoto (2004) examined international passenger and cargo flows among major cities in Asia, Europe, North America, and Latin America using a gravity model with explanatory variables such as GDP, population, and distance, as well as city dummy variables to assess the extent to which cities were hubs. The analysis indicated that GDP is of decreasing importance in generating air traffic flow. Matsumoto (2007) extended the 2004 study to consider air traffic density at the world's largest cities. The findings revealed that several cities—including Amsterdam, Frankfurt, Hong Kong, London, Miami, New York, Paris, Singapore, and Tokyo—have strengthened their positions as international air transport hubs.

Grosche et al. (2007) estimated passenger volumes between pairs of European cities using two gravity models. One of the models was restricted to pairs of cities where neighboring airports did not pose competition, while the other model covered the entire sample. The models were calibrated with data from flights between Germany and 28 European countries, using geo-economic variables as the primary independent variables. The researchers concluded that the models' good fit indicated that modelling could be applied in the prediction of passenger volumes between city pairs. Bhadra and Kee (2008) employed gravity modelling, focusing on journey origin and destination, to investigate the nature of demand in the air travel market. The analysis examined passenger flows by route density on the domestic US market, finding that the factors of average fare, income and distance exhibited inelasticity across all route types studied. Khadaroo and Seetanah (2008) evaluated the significance of transport infrastructure in determining destinations' attractiveness to tourists, employing gravity modelling to determine bilateral tourist flows among 28 countries. Their findings suggested that, when passengers travelled to destinations in Africa and Asia, transport infrastructure was the most sensitive factor. Hazledine (2009) investigated the border effect on Canadian domestic and international traffic using an econometric specification of the standard gravity model that controlled for factors such as distance, population, and incomes at the origin and destination airports as determinants of air travel. The results showed that Canadian airlines offered more than six times the number of seats on routes interconnecting Canadian airports than on routes linking Canada to the United States or other world destinations.

Inkinen and Pyyhtiä (2013) examined the connectivity and centrality of the geographical airline network in northern Europe and passenger flows on intercontinental flights to Asia and the United States. Using a sample of passenger seat supply per flight during one week in 2009, they measured connectivity using network analysis and formulated a gravity model comprising population, GDP, and distance to explain the geography of air linkages. Their findings indicate that Copenhagen remains the main hub for the region. Zhang and Findlay (2014) constructed aviation policy indices for 19 Asia-Pacific countries to examine the impacts of passenger flows and tourism among these countries. Employing cross-sectional data and gravity modelling, they found that deregulation was significant and positively associated with passenger movement. In another study, Button, Brugnoli, et al. (2015) developed a quantitative framework to link the supply of air connections and major international trade flows in sub-Saharan Africa. Using a gravitational model, they discovered that there was a direct link between airline capacity supply and international trade within the region. In a related study, Button, Martini, et al. (2015) examined the role of former colonizers in the geographical distribution of air transport growth in sub-Saharan Africa between 1998 and 2011. Using seat supply as the dependent variable and a gravitational model, they found evidence of residual linkages between the blocs formed by countries that emerged from former French and British colonies.

Tsui and Fung (2016) studied the passenger network of Hong Kong International Airport from 2001 to 2012. Their findings revealed significant alterations and expansions to new destinations within the network. Utilizing gravity modelling, they identified nine factors, including GDP per capita, that influenced passenger traffic between Hong Kong and its primary destinations. Lohmann and Vianna (2016) examined the conditioning factors that contributed to suspension of air service supply on domestic routes in Australia. Although finding no framework in the literature for analyzing the decision-making process behind the suspension of air routes, they did discover that demand issues, structural costs, and profitability were commonly cited reasons. Díaz Olariaga et al. (2018) employed gravity modelling to analyze the flow of domestic passengers between major airports in Colombia. Their analysis considered various conditions in the Colombian air transport network, such as geography, airport location, and lack of alternatives to air transport. They concluded that passenger flows were significant over distances greater than 200 km, with occasional flows occurring at distances between 100 and 200 km. Matsumoto and Domae (2019) developed a gravity model to assess the competitive status of major cities in Europe and Asia from the perspective of international traffic movements during the period between 2000 and 2012. In addition to traditional variables such as GDP and distance, their model incorporated values for global network connectivity as a measure of business connections. The results confirmed a dynamic change in the hierarchy of cities as regards air transport. Das et al. (2022) used a gravity model to identify demand drivers for air travel on alternative routes, particularly those connecting populations in regional and remote areas of India. Their analysis of pairs of cities revealed that the presence of an educational center at the origin or destination positively affected passenger traffic on regional routes. They also found that flights connecting to major airports have a positive influence on demand. They concluded that air travel offers minimal utility for distances up to 200 km.

This literature review indicates that most studies have focused on international passenger traffic, despite the significance of domestic traffic in the air transport industry. These studies primarily examine potential demand and its contribution to national economies, while neglecting airline sustainability. This may be because it is only in large countries, such as the United States, China, India, and Brazil, that domestic traffic exceeds international traffic. Furthermore, these approaches did not consider air service supply constraints. This emphasis on international traffic neglects domestic air transport policy in developing countries, such as Brazil. In Brazil, most investments in air transport have been directed towards expanding and improving passenger terminals and aprons at major existing airports. Policies appear to rely on aggregate demand models and disregard aviation factor constraints, such as those described by Lohmann and Vianna (2016).

3. Methodology

This study used descriptive statistical analysis and a modified gravity model as inductive instruments. For many years, social scientists have used modified versions of the model based on Newton's Law of Gravity (Equation (1)) to forecast movement of people, cargo, communication etc. between cities. The literature review showed several versions used in air transport studies.

$$\text{Flow}_{i,j,t} = \frac{M_{i,t} M_{j,t}}{D_{i,j,t}^2} \tag{1}$$

where:

$\text{Flow}_{i,j,t}$ = Passengers on board between airport origin *i* and destination *j*;

$M_{i,t}$ = Municipal GDP per capita origin airport *i*;

$M_{j,t}$ = Municipal GDP per capita destination airport *j*;

$D_{i,j,t}$ = Average flight distance between airport *i* and *j*;

t = year.

The gravity modelling applied here assumes a relationship between the passengers on board and the two cities' characteristics. In this study, the original gravity model was tailored by combining an unbalanced panel-data regression with level-of-service variables. It thus reflected the masses weighted by service characteristics of the link between two cities. The service variables used in the analysis are given below.

Link service level is represented by $SL_{i,j,t}$. Accordingly, passengers on board ($Flow_{i,j,t}$) is expressed by Equation (2):

$$\text{Flow}_{i,j,t} = f(M_{i,t}, M_{j,t}, D_{i,j,t}, SL_{i,j,t}) \quad (2)$$

The data set was organized in annual unbalanced panel data format. The mass variables ($M_{i,t}$) and ($M_{j,t}$) are represented by the cities GDP, while distance ($D_{i,j,t}$) is represented by the annual average flight distance in km between cities *i* and *j*. Although distance between two cities is not expected to vary with time, the time-index was used in cases where an air route had been altered over the years. The corresponding model used to estimate the regression parameters is shown in Equation (3).

$$\ln \text{Flow}_{i,j,t} = c + a \ln M_{i,t} + b \ln M_{j,t} + d \ln D_{i,j,t} + f \ln SL_{i,j,t} + \varepsilon_{ij,t} \quad (3)$$

where,

c: regressor constant plus cross-section fixed effect;

a, *b*, *d*, *f* and *g*: estimated coefficients of the regression model;

ln: the natural logarithm of the variables;

$SL_{i,j,t}$: annual average load factor;

$\varepsilon_{i,j,t}$: regression error; and all other variables previously defined.

Hsiao (1986) argued that panel data offers advantages over cross-sectional or time series models, in that panel data controls for the occurrence of heterogeneity in the regression. The method for analyzing the panel data model consisted in observing *n* entities for two or more time periods. The Brazilian air transport database provided by the ANAC records data from 2002 to 2019 between pairs of airports, for example, the number of paying passengers on board, aircraft movement on the air route, as well as seat supply, flight distance etc. The figures for Brazilian city GDPs and populations obtained from the official Brazilian Institute of Geography and Statistics, IBGE (IBGE, 2021) are available only for the period from 2002 to 2019, which will delimit the period for estimation in Equation (3). The GDP per capita version was chosen here, because of major income concentration in Brazil, which makes a relative measure more representative of potential demand. The panel data regression model was estimated in order to examine the impacts of the traditional gravity model variables, considering the impact of the service variable on demand. Service levels depend fundamentally on Brazilian airline decisions. A supply variable, such as seat supply, could be a service level variable, which could compromise estimation of the statistical model. Accordingly, given the available data, it was decided to use a variable that correlated better with passenger on board than seats supply, which is an instrumental variable desirable characteristic. Of these, the annual average load factor by link returned a correlation of 0.52 with passenger on board and 0.20 with seat supply. In this paper, service level was considered to be connected with efficient fleet use and, therefore, this variable was chosen to represent service level. To ascertain robustness on routes, the analysis considered airport links that met the conditions: annual average paying passengers per week greater than 10 and annual average seat supply by flight greater than 8 and annual average supply of more than one flight per week. Data were segmented into samples defined by three categories: the first comprising all routes; the second, routes with annual average seat supply of 100 seats or more per flight; and the third, routes with annual average seat supply of fewer than 100 seats per flight.

Aircraft manufacturers consider jets or turboprops with fewer than 90 seats to be regional aircraft (Boeing, 2014). However, constraints on Brazilian airlines result in several regional routes also operating with aircraft with more than 100 seats. This means that lower-density routes operate using medium-sized aircraft, considered here to be aircraft with 100 seats or more and fewer than 150 seats. Routes with average seat supply per flight of fewer than 100 seats were considered regional routes. These routes use mainly smaller aircraft.

4. Case study

ANAC records (ANAC, 2022) show 1637 aerodromes, 1104 of them private and 533 public. ANAC data also give statistical data on domestic connections among airports in Brazil. From 2002 to 2019, 5295 regular domestic air links or routes (ODs is used here to mean direct regular flights between two airports) were found to operate between 329 of these aerodromes. Of total ODs, only 397 were observed continuously during the 18-year span, while 1432 ODs occurred in only one of those years. In 2002, regular domestic flights occurred at 152 aerodromes with 1826 ODs; in 2019, these numbers were 164 aerodromes and 1386 ODs. Airlines operating regular domestic air transport at some point during the study period numbered 49, but only 18 in 2002 and only 10 in 2019. Most of those operating in 2002 were not by 2019. In 2019 three airlines supplied more than 90% of flights. These data show the strong volatility of the domestic regular air transport market and the concentration of market supply in Brazil. On this volatile market, airlines have concentrated their supply in more prosperous ODs. On the more stable links in this study, seat supply averaged fewer than 100 seats on 946 ODs in the course of the 18-year study period, but 262 in 2002 and 183 in 2019. ODs with average seat supply of 100 seats or more totaled 840 overall, but 278 in 2002 and 520 in 2019. As the total sample was 1447 ODs, at least 309 ODs changed category, probably to using aircraft larger than those considered for regional flights. These data show an overall reduction in ODs and in the airline industry's regional fleet, against an increase in ODs with average flight seat supply of 100 seats or more.

This scenario displayed high concentration of passenger movement at the major airports. **Table 2** shows the 150 largest volumes of regular domestic passengers boarded plus disembarked, by airport, in 2019. State capital airports – which accounted for about 72% of total passengers—are shown in bold. Some regional cities recorded larger volumes of movement than Brazil's less-developed state capital airports in the North region (Porto Velho—SBPV, Macapá—SBMQ, Rio Branco—SBRB and Boa Vista—SBBV). SBGR and SBSP serve the metropolitan area of the state capital, São

Paulo, Brazil's most important economic center.

Table 2. Regular domestic air transport passengers, 150 main airports, 2019, see Appendix Table A1 for the identification of the municipality for each ICAO. (Source: ANAC).

ICAO	PAX	ICAO	PAX	ICAO	PAX	ICAO	PAX	ICAO	PAX
SBGR	27,169,212	SBRP	858,942	SBAU	107,012	SBCB	23,393	SWBC	1595
SBSP	21,856,527	SBSR	754,204	SBQV	103,770	SBTD	22,804	SWMW	1147
SBBR	15,629,705	**SBPV**	720,242	SBHT	92,936	SBNM	21,955	SNVS	1035
SBCF	9,781,841	SBMG	703,192	SBJE	88,783	SBUG	19,693	SNCT	1029
SBGL	9,004,714	**SBMQ**	579,657	SBCN	80,570	SBIH	16,712	SBAQ	945
SBKP	8,839,599	SBJV	552,166	SBDO	79,843	SBDB	14,854	SNBA	771
SBRJ	8,755,048	**SBPJ**	548,956	SNBR	74,923	SBPO	14,142	SNJM	760
SBRF	7,803,516	SBIL	454,925	SBUR	73,508	SBPG	12,903	SNMZ	721
SBPA	7,409,784	SBSN	454,616	SBJI	69,172	SBCP	12,891	SBBG	635
SBSV	6,533,102	SBCH	444,543	SBML	64,305	SBBW	12,261	SBJR	538
SBFZ	6,248,783	SBJU	443,760	SBTT	60,916	SBSI	11,948	SBTC	517
SBCT	6,163,844	SBPL	355,339	SBAT	60,554	SBUF	10,850	SSUV	516
SBFL	3,341,151	**SBRB**	338,938	SSKW	59,842	SNVB	10,821	SIMK	493
SBBE	3,271,130	**SBBV**	332,415	SBCZ	57,730	SBUA	9726	SNPD	493
SBVT	3,169,033	SBIZ	308,633	SBRD	51,011	SBTB	9317	SWTS	493
SBGO	3,019,379	SBDN	300,241	SBGV	39,969	SBLE	9185	SNDT	430
SBCY	2,766,450	SBFN	292,396	SBVH	38,139	SBVG	8871	SSZR	406
SBEG	2,671,049	SBMA	269,395	SBSJ	36,882	SWEI	7975	SWHP	396
SBSG	2,089,345	SBCA	219,017	SWGN	35,261	SBPB	7480	SNYA	379
SBFI	2,043,816	SBMK	215,077	SBMS	32,436	**SBBH**	5544	SBMD	341
SBMO	1,876,957	SBCX	201,433	SBSM	32,386	SBFE	5161	SJRG	330
SBNF	1,806,531	SBVC	191,511	SWLC	31,442	SSZW	5004	SNUI	284
SBSL	1,557,468	SBPF	155,483	SNTF	31,133	SWCA	4672	SSGY	255
SBCG	1,444,900	SBZM	147,741	SBPK	30,517	SJTC	4250	SSSB	247
SBPS	1,330,712	SWSI	145,434	SBTG	29,387	SWKO	3803	SWJN	243
SBJP	1,264,356	SBCJ	131,282	SBTF	29,330	SBME	2714	SNVC	239
SBUL	1,113,155	SBJA	128,318	SBSO	27,557	SNTO	2509	SSKM	237
SBTE	1,103,973	SBKG	127,044	SWPI	27,350	SNAT	2370	SSFB	230
SBAR	1,048,069	SBAE	120,531	SBCR	26,760	SWLB	1973	SSVL	207
SBLO	964,087	SBIP	109,507	SBLJ	24,686	SBAX	1792	SNPJ	162

* Total paid regular domestic passengers boarded plus disembarked in 2019 equal to 183,594,880.
International Civil Aviation Organisation (ICAO) four-letter acronyms for Brazilian airports (Annex).

The composition of Brazil's airline fleets is important in determining service level on domestic routes. ANAC gives annual figures for the fleet, by seat category (ANAC, 2020). **Table 3** shows Brazil's airline aircraft fleet, by number of seats installed, in selected years. The number of aircraft changed most in the 151 to 200-seat range. Aircraft with up to 50 seats were being replaced by aircraft with more than 50 and up to 100 seats, whose numbers also tended to decrease. This fleet profile is not suited to providing air services on many low-density routes, as is mostly the case in Brazilian regional air transport. Accordingly, the number of regional routes served by regular domestic air transport can be seen to decline steadily. Airlines managing to stay in the market were those with large aircraft, and concentrated their operations primarily on higher-density routes (Fernandes and Pacheco, 2016). Airlines that devoted themselves exclusively to regional aviation practically disappeared from the market. Today, three airlines operating high-density routes—TAM, GOL and AZUL—dominate practically the whole market. Of these, one single airline, AZUL, operates across nearly the whole Brazilian regional network. This company has been increasing its share in the grid of higher-density routes with larger aircraft and even competing on international market.

Table 3. Brazilian airline aircraft fleet (Source: ANAC).

Seats	**2002**	**2011**	**2013**	**2015**	**2019**
Up to 50	130	68	21	15	19
51–100	0	51	75	78	45
101–150	420	157	173	165	120
151–200	24	174	228	211	256
201–250	36	32	39	50	63
251–300	32	2	-	7	10
Over 300	0	4	10	11	18
Total	642	488	546	537	559

Figure 2 shows the number of regular domestic air transport routes from 2002 to 2019, by Size. A route means the leg from one airport to another; the return leg is another route. The total number of domestic air routes rose from 1176 in 2002 to 1217 in 2019. In **Figure 2**, note that routes with annual average aircraft seat size, by link (Size), of less than 100 seats decreased sharply after 2011, and started to recover from 2017, although still well beneath the 2002 figure. That trend is consistent with the decline in the overall fleet (**Table 3**). These figures indicate that Brazil's airline fleet was concentrating in larger aircrafts. The 251 under-100-seat routes that ceased to exist between 2002 and 2019 were regional. The 429 that continued to operate (**Figure 2**) accounted for a very small, steady number of passengers (**Figure 3**). On the other hand, routes in the over-100-seat bracket increased by 292. These figures indicate a certain stability in the routes.

Figure 3 shows domestic passenger volumes on routes, by Size, from 2002 to 2019. Greatest growth occurred on routes with $Size_{i,j,t}$ of 100 seats or more: in 2019, more than 95% of passengers were being transported in this $Size_{i,j,t}$ range. **Table 3** shows that fleet composition is shifting towards larger aircraft, while aircraft with fewer seats account for an ever-smaller share.

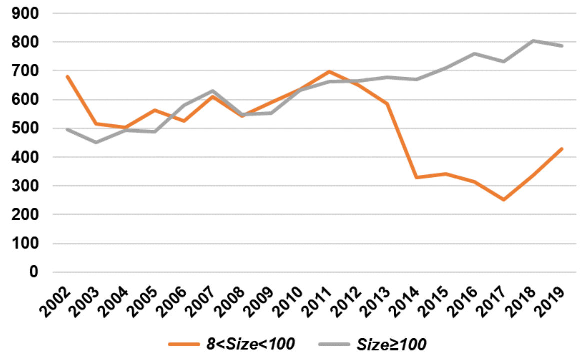

Figure 2. Routes (one-way) by year and Size category (Source: calculations based on ANAC figures).

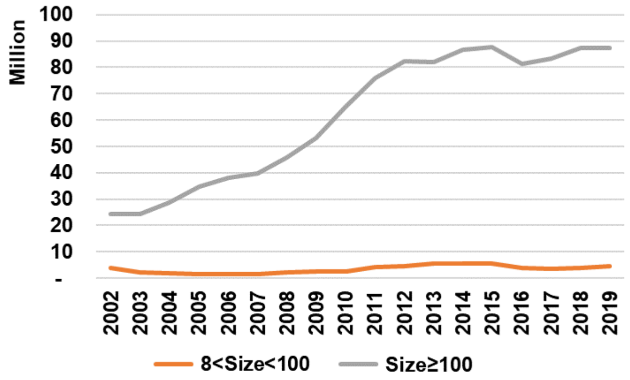

Figure 3. Passengers on routes, by year and Size category (Source: Calculations based on ANAC figures).

Table 4 shows Brazil's 15 main regular domestic air routes (over one million passengers in 2019), by passengers embarked in both directions in 2002 and 2019. The Growth column shows the ratio between the figures for 2019 and 2002. In 2002, the 15 densest routes between airport pairs accounted for around 34% of total passenger movement. In 2019, the 15 airport pairs highlighted accounted for 30% of that total. From 2002 to 2019, this set of routes accounted for a steadily smaller share of total passengers in Brazil. Nonetheless, 14 of these routes still serve São Paulo (SBGR, SBSP) and other capital cities, while only one serves Brasília (SBBR) and Rio de Janeiro (SBRJ) airport.

Domestic air passenger transport statistics show a tendency for traffic density to increase on established air routes. In that respect, airline fleets are concentrating in aircraft with more than 150 seats. From 2002 to 2019, regular air transport aircraft with fewer than 50 seats declined from 130 to 19.

Between 2002 and 2019, the number of routes with $Size_{i,j,t}$ from > 8 to < 100 seats fell from 680 to 429. This decrease reveals a glaring weakness in current regional air transport planning in Brazil as regards the sustainability of routes with low-density passenger traffic. This exclusion of regional connections also affects the air transport system as a whole. However, from 2017 on, some recovery can be seen on regional routes.

Table 4. Brazil's main airport routes, regular domestic paying passengers embarked in both directions (Source: calculations based on ANAC figures).

Route	2002	2019	Growth
SBRJ-SBSP	2,642,601	4,049,864	1.53
SBGR-SBPA	562,111	2,250,659	4.00
SBBR-SBSP	1,100,444	2,052,808	1.87
SBSV-SBGR	634,234	1,901,493	3.00
SBRF-SBGR	508,408	1,908,796	3.75
SBSP-SBPA	694,149	1,885,474	2.72
SBSP-SBCF	4,569*	1,884,349	*
SBFZ-SBGR	299,965	1,777,057	5.92
SBSP-SBCT	1,028,671	1,594,992	1.55
SBCF-SBGR	211,251	1,579,457	7.48
SBGR-SBCT	320,362	1,576,788	4.92
SBBR-SBGR	275,418	1,338,837	4.86
SBFL-SBGR	173,690	1,297,702	7.47
SBGL-SBGR	414,504	1,102,815	2.66
SBBR-SBRJ	658,824	1,081,584	1.64
Total	9,529,201	27,282,675	2.86
Brazil	28,310,245	91,796,600	3.24

*SBCF was operating with restriction, SBBH was Belo Horizonte's main airport in 2002.

5. Results

Analysis of panel-data gravity models for the period from 2002 to 2019 revealed 1477 route pairs (cross-sections), corresponding to 11,367 valid data. In specifying the sample, a variable, $Size_{i,j,t}$, was defined as annual average aircraft size, by link, expressed in number of seats and a variable, $Freq_{i,j,t}$, was defined as annual average week flight supply by link. Routes for which any item of information was lacking were eliminated from the analysis. The model described in Equation 3 was tested for the whole sample, for flights with $Size_{i,j,t} \geq 100$ seats (Trunk routes), and for interregional flights. **Table 5** show descriptive statistics for the variables and **Table 6**, the correlation matrix for the total sample.

Due to the correlations between explanatory variables observed in **Table 6**, variable inflation factor (VIF) indicators were calculated. The results indicated no multicollinearity.

Table 7 shows the results of applying Equation (3) to the three sets of the sample. All the estimated coefficients returned significant statistical test results and signs consistent with expectations. For the total and trunk samples, cross-section fixed effects were considered to apply, while the regional sample size precluded consideration of panel data effects. The total sample included all ODs with valid data; the trunk sample comprised those ODs with $Size_{i,j,t} \geq 100$ seats; and the regional sample, those where $Size_{i,j,t} < 100$ seats. The coefficients of determination (adjusted R^2) of the three estimated models indicated a significant percentage of explanation; however, the regional sample returned a lower adjusted R^2, because unknown cross-sectional characteristics could not be contemplated by considering fixed effects. The regional routes (8 < $Size_{i,j,t}$ < 100) showed significant changes in explanatory variable coefficients.

Table 5. Descriptive statistics for variables.

	ln($Flow_{i,j,t}$)	**ln($M_{i,t}$)**	**ln($M_{j,t}$)**	**ln($D_{i,j,t}$)**	**ln($SL_{i,j,t}$)**
Mean	10.30	10.60	10.60	6.41	−0.63
Maximum	14.57	12.34	12.34	7.95	−0.01
Minimum	6.26	7.97	7.97	3.33	−4.79
Std. Dev.	1.77	0.57	0.57	0.75	0.61
Observations	11,367	11,367	11,367	11,367	11,367

Source: ANAC—Sample was defined by regular domestic flights, $Flow_{i,j,t}$ > 520 and $Size_{i,j,t}$ > 8 and $Freq_{i,j,t}$ > 1.

Table 6. Variable correlation matrix.

Variables	**ln($Flow_{i,j,t}$)**	**ln($M_{i,t}$)**	**ln($M_{j,t}$)**	**ln($D_{i,j,t}$)**	**ln($SL_{i,j,t}$)**
ln($Flow_{i,j,t}$)	1	0.34	0.34	0.43	0.52
ln($M_{i,t}$)	0.34	1	0.24	0.15	0.26
ln($M_{j,t}$)	0.34	0.24	1	0.15	0.27
ln($D_{i,j,t}$)	0.43	0.15	0.15	1	0.48
ln($SL_{i,j,t}$)	0.52	0.26	0.27	0.49	1

Table 7. Results of the ln($Flow_{i,j,t}$) panel data regression for the three models.

Variable	**Regression coefficients***		
	Total sample	**Trunk sample**	**Regional sample[1]**
ln($M_{i,t}$)	0.67*	0.84*	0.23*
ln($M_{j,t}$)	0.66*	0.84*	0.20*
ln($D_{i,j,t}$)	−6.13***	−8.65**	0.05***
ln($SL_{i,j,t}$)	0.87*	0.77*	1.22*
Regressor Constant	35.89	51.50**	5.02*
Effects Specification: Cross-section fixed (dummy variables)			
Adjusted R-squared	0.91	0.88	0.43

*Regression coefficient, 0.99 significance; ** 0.95 significance; *** 0.90 significance.
[1]This regression does not consider fixed effect.

GDP per capita (the mass variable of the models) showed slightly greater elasticity on trunk and regional ODs. This difference between the coefficients indicates that the income effect is smaller for regional flights. In Brazil, regional route prices are known to be very high and most trips are made for business purposes or by wealthy passengers. Accordingly, the income factor has less impact in relation to regional air trips than to trunk trips, where passenger income levels are more diverse.

The traditional interpretation of the gravity model, where increasing distance means reduced movement, was confirmed in the total and trunk estimations. The level of impact differed: it was lower in the total OD sample, because of the influence from the regional sample. Income and distance proxies were more elastic on trunk ODs, while the effect of distance inverted the sign on regional routes. That result makes sense in that regional air transport is more sought after for long trips. In the North and Mid-west regions, regional air transport becomes almost unavoidable, because other modalities are either lacking or seasonally unworkable. Level of service variables proved to be the most important drivers for passenger demand generally, and especially so for regional trips.

One of the most important issues in Brazilian aviation is the closure of services in regional cities. The statistics shown in **Figure 2** show the substantial reduction in the number of ODs in Brazilian air traffic with regional characteristics ($8 < \text{Size}_{i,j,t} < 100$). This happens either because the link is terminated or because it begins to operate with larger aircraft. The latter situation would be of little concern were there no reduction in the number of localities served. From the airline standpoint, load factor is important to maintaining OD supply, while prices do not appear to be a problem, providing they are kept at reasonable levels. Airlines have to find a breakeven point so as not to close links, which is difficult with a standardized fleet of medium-sized aircraft. **Table 3** shows a steady decrease in fleets of aircraft with fewer than 151 seats.

6. Discussion

The modelling in this study endeavored to provide input to understanding the historical behavior of regular domestic air transport passenger movement in relation to local economic potential and service level on links. This modelling offered a partial but significant picture of the outcomes of government and air transport sector business policies. Also, the descriptive statistics showed that the results of this evolution in air passenger traffic led to a concentration into denser routes and standardization of airline fleets. The present situation took shape after a period of growth up to 2014 and a subsequent period of stagnation lasting until 2019. This scenario displays behavior contrary to what the Civil Aviation Secretariat advocated for Brazilian air transport (SAC, 2015). That is to say that policies in place are not having the desired effect. The relations found in the model reflect the government's investment policy, which is directed to existing state capital airports. These are closed in by dense urban grids and under strong constraints on any increase in numbers of runways. Capacity constraints suppress demand, reduce flight frequency, and increase overall passenger costs (Zou and Hansen, 2012). They also reflect airline policies, which have been straitjacketed by fleet standardization, which is designed to serve trunk links, in addition to favouring product commodification, but hinders any differentiation and customization of supply to suit demand cycles and seasonality. The data presented here revealed major fragility on routes with smaller aircraft. The relative reduction in service supply and stagnation of demand on the passenger market for ODs using aircraft under 100 seats have been reinforced by the changing nature of domestic airline fleets, in which the proportion of smaller aircraft is steadily declining.

Between 2002 and 2019, regular domestic air passenger transport operations were observed at 329 Brazilian aerodromes, 30 of them serving the 27 state capitals. In that period, a number of regional towns entered and left the regular domestic passenger air transport grid. In 2002 there were 122 aerodromes with regular domestic flights serving regional towns, while in 2019 there were 134. The challenge is the great volatility of regional aerodrome operations. The grid changes every year, with a tendency for the number of ODs to decrease (**Figure 2**).

Figure 4 shows the geographical distribution of Brazilian aerodromes with regular domestic air transport services between 2002 and 2019. It shows also that the 27 state capitals, with 30 aerodromes, saw passenger movement throughout the study period. It gives the distribution of the 165 regional towns with passenger movement between 2002 and 2018 and no further service in 2019, and the 134 regional aerodromes with passenger movement in 2019. **Figure 4** shows comprehensive availability of Brazilian aerodromes to operate regular air transport. This volatility in operation suggests that regional air transport policy lacked a stable airline business plan.

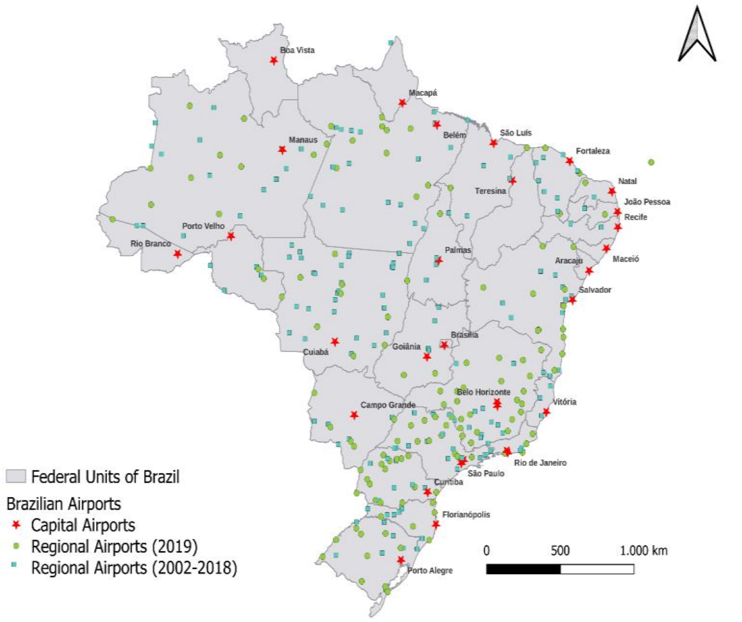

Figure 4. Geographical distribution of cities with regular domestic air passenger transport, 2002 to 2019 (Source: Based on ANAC data).

The airlines' fleet strategy of using aircraft with larger seating capacities may result from the small number of runways at state capital airports, which makes it more difficult to secure slots at peak demand times. This empirical observation of the trend in regular domestic air passenger transport in Brazil is at odds with the regional aviation development program launched in 2012 (SAC, 2015). The percentage of aircraft on domestic routes with $Size_{i,j,t} < 100$ seats fell from 20% in 2002 to 11% in 2019, due to the dwindling number of regional links in the grid and the airlines' policy of standardizing their fleets with larger aircraft. Thus, the only routes that remain economically viable are those where larger aircraft can be operated all year round, which has limited-service supply on routes with lower passenger density or seasonal fluctuation with long low-density periods.

This concentration of passenger movement on routes with larger *Size* was ongoing even before the heavy investments made since 2010 in Brazilian airport concessions for management by private enterprise. That fact is reflected in airline fleet composition and the declining number of ODs between 2002 and 2019. The concentration has produced results at odds with public policies designed to broaden the scope of regional aviation operations in Brazil. By way of example, **Table 8** shows the number of domestic and international connections with the main São Paulo airports (SBGR and SBSP). Some of these connections are not active year-round. Although São Paulo is the economic center of Brazil, the table shows few connections with $8 < Size_{i,j,t} < 100$, making the city hard to access directly by regular domestic flights. This sets up a vicious circle leading to a lack of regional air transport services. Airlines may have used simple aggregate demand models and focused on the numbers of passengers transported, basing their calculations on income and price elasticity parameters alone. This possible interpretation may have led airlines to adopt fleet and price policies unsuited to Brazil's air transport network.

Table 8. Connections at São Paulo airports, by year.

Year	SBGR		SBSP	SBGR	SBSP
	Domestic	International	Domestic	*B**	*B**
2002	69	70	90	15	23
2003	72	69	83	10	26
2004	69	65	83	10	22
2005	70	66	78	13	18
2006	76	78	81	7	16
2007	80	63	72	10	14
2008	69	71	58	7	8
2009	65	67	52	12	4
2010	76	79	49	18	4
2011	73	78	45	23	0
2012	72	76	44	18	0
2013	73	80	42	17	0
2014	71	97	46	12	0
2015	71	91	49	10	0
2016	67	91	51	7	0
2017	68	85	51	5	0
2018	63	93	48	3	0
2019	65	85	55	3	11

*B** = regular domestic, $8 < Size_{i,j,t}\ t < 100$ and $Flow_{i,j,t} > 520$ and $Freq_{i,j,t} > 1$.

Prominent among the limitations to this study are data constraints. Real passenger origins and destinations are not available, only passengers on board flights. Accordingly, passengers on board depends on airlines' network strategy, which is unknown. Passengers in transit are numerous only at hub airports, which will have little effect on the estimations, because this situation occurs at the few cities with large volumes of origin and destination passenger movement. Although information on air transportation in Brazil is among the best, detailed demand studies are rather lacking. These results are thus not precise and should not be taken as precise demand forecast models; rather, they indicate directions.

7. Conclusions

The empirical analysis reported in this paper indicates that airline service supply in Brazil is concentrating increasingly on high-density passenger routes and deploying larger-capacity aircraft to meet demand. However, this trend has led to a decline in regional air transport and poses challenges for airlines seeking profitability on less-dense routes. However, panel data regression analysis shows the important effect of level of service on passenger demand considerations. The overall body of information assembled here indicates that Brazilian airlines are continuously distancing themselves from regional air transport and unsuccessfully seeking profitability on less passenger-dense links. The contradictions brought out by the model and by the descriptive results as regards government investments, fleet trends and airlines' economic results recommend rethinking present policies.

In Brazil, the government's policy of investing in hub airports has reduced the space in these for regional aviation. The modelling indicates that the present trend is leading to the commodification of air passenger services and a consequent tendency towards oligopoly in the industry, with profitability sought through tax claims, input price reductions, and cost cutting by standardizing fleets or even limiting service supply to high-demand routes. The present trend towards commodifying domestic passenger air transport points to economies of scale as the only path to profitability. The issue seems to lie in the industry's own supply policies or rather in its policies for exploiting the market, which are strongly induced by government policies. The key problem to be worked through, on the part of both government and airlines, seems to be how to arrive at policy tailored to the characteristics of Brazil's economy.

One of the main challenges facing air transport is having somewhere to offer its services at reasonable cost. Secondary airports in Brazil's major urban centers would offer opportunities to supply differentiated services, such as those offered by low-cost airlines. They would also make room for regional aviation during peak hours and encourage the development of airlines with more diversified or more specialized fleets. As a result, Brazil's existing regional airports would be reactivated in the natural course of events, without the need for any policy of subsidies.

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Appendix

Table A1. ICAO acronyms of Brazilian airports with regular domestic flights, by Municipality (Source: ANAC).

ICAO	Municipality	ICAO	Municipality	ICAO	Municipality	ICAO	Municipality	ICAO	Municipality
SBGR	Guarulhos	SBRP	Ribeirão Preto	SBAU	Araçatuba	SBCB	Cabo Frio	SWBC	Barcelos
SBSP	São Paulo	SBSR	São José do Rio Preto	SBQV	Vitória da Conquista	SBTD	Toledo	SWMW	Maués
SBBR	Brasília	**SBPV**	Porto Velho	SBHT	Altamira	SBNM	Santo Ângelo	SNVS	Breves
SBCF	Confins	SBMG	Maringá	SBJE	Jijoca de Jericoacoara	SBUG	Uruguaiana	SNCT	Caratinga
SBGL	Rio de Janeiro	**SBMQ**	Macapá	SBCN	Caldas Novas	SBIH	Itaituba	SBAQ	Araraquara
SBKP	Campinas	SBJV	Joinville	SBDO	Dourados	SBDB	Bonito	SNBA	Barretos
SBRJ	Rio de Janeiro	SBPJ	Palmas	SNBR	Barreiras	SBPO	Pato Branco	SNJM	Manhuaçu
SBRF	Recife	SBIL	Ilhéus	SBUR	Uberaba	SBPG	Ponta Grossa	SNMZ	Porto de Moz
SBPA	Porto Alegre	SBSN	Santarém	SBJI	Ji-Paraná	SBCP	Campos dos Goytacazes	SBBG	Bagé
SBSV	Salvador	SBCH	Chapecó	SBML	Marília	SBBW	Barra do Garças	SBJR	Rio de Janeiro
SBFZ	Fortaleza	SBJU	Juazeiro do Norte	SBTT	Tabatinga	SBSI	Sinop	SBTC	Una
SBCT	Curitiba	SBPL	Petrolina	SBAT	Alta Floresta	SBUF	Paulo Afonso	SSUV	União da Vitória
SBFL	Florianópolis	**SBRB**	Rio Branco	SSKW	Cacoal	SNVB	Valença	SIMK	Franca
SBBE	Belém	**SBBV**	Boa Vista	SBCZ	Cruzeiro do Sul	SBUA	São Gabriel da Cachoeira	SNPD	Patos de Minas
SBVT	Vitória	SBIZ	Imperatriz	SBRD	Rondonópolis	SBTB	Oriximiná	SWTS	Tangará Da Serra
SBGO	Goiânia	SBDN	Presidente Prudente	SBGV	Governador Valadares	SBLE	Lençóis	SNDT	Diamantina
SBCY	Cuiabá	SBFN	Fernando de Noronha	SBVH	Vilhena	SBVG	Varginha	SSZR	Santa Rosa
SBEG	Manaus	SBMA	Marabá	SBSJ	São José dos Campos	SWEI	Eirunepé	SWHP	Água Boa
SBSG	São Gonçalo do Amarante	SBCA	Cascavel	SWGN	Araguaína	SBPB	Parnaíba	SNYA	Almeirim
SBFI	Foz do Iguaçu	SBMK	Montes Claros	SBMS	Mossoró	**SBBH**	Belo Horizonte	SBMD	Monte Dourado
SBMO	Maceió	SBCX	Caxias do Sul	SBSM	Santa Maria	SBFE	Feira de Santana	SJRG	Rio Grande
SBNF	Navegantes	SBVC	Vitória da Conquista	SWLC	Rio Verde	SSZW	Ponta Grossa	SNUI	Aracuai
SBSL	São Luís	SBPF	Passo Fundo	SNTF	Teixeira de Freitas	SWCA	Karauari	SSGY	Guaíra
SBCG	Campo Grande	SBZM	Juiz de Fora	SBPK	Pelotas	SJTC	Bauru	SSSB	São Borja
SBPS	Porto Seguro	SWSI	Sinop	SBTG	Três Lagoas	SWKO	Coari	SWJN	Juína
SBJP	João Pessoa	SBCJ	Parauapebas	SBTF	Tefé	SBME	Macaé	SNVC	Viçosa
SBUL	Uberlândia	SBJA	Santa Catarina	SBSO	Sorriso	SNTO	Teofilu Otoni	SSKM	Campo Mourao
SBTE	Teresina	SBKG	Campina Grande	SWPI	Parintins	SNAT	Aracati	SSFB	Francisco Beltrão
SBAR	Aracaju	SBAE	Bauru	SBCR	Corumbá	SWLB	Labrea	SSVL	Telêmaco Borba
SBLO	Londrina	SBIP	Ipatinga	SBLJ	Lages	SBAX	Araxá	SNPJ	Patrocínio