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The geographic concentrations of air traffic and economic development: A spatiotemporal analysis of their association and decoupling in Brazil

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ABSTRACT

This paper examines the evolution of the geographic concentration of the Brazilian air transport network with a focus on its determinants and possible detachments from the spatial patterns of socioeconomic activity. We develop an econometric framework employing and contrasting the results of Gini, Herfindahl-Hirschman and Theil indexes, with and without normalisation to account for economic and demographic spatial dynamics. Our results suggest that the spatial dynamics of the air network and that of the country's economy and population are strongly tied for the majority of the considered determinants. However, we find suggestive evidence that the time trend after deregulation has produced some asymmetries in the evolution of these dimensions. As such, our analysis presents some implications for airline network planning and regulators, as it offers additional information to be considered for the understanding of extra-economic and extra-demographic impacts which may be inducive of significant changes in air transport markets.

1. Introduction

Brazil has experienced fast growth in air transportation demand since the mid-2000s, just some years after the economic liberalisation of the sector. The additional demand generated was not only a consequence of existing passengers travelling more frequently but also of new consumers being attracted to the market due to better income distribution and improved credit availability conditions. With new consumers, in the following years, airlines intensified the expansion of fleets and networks, engaging in price wars aimed at increasing their market shares. The effects of such initiatives, combined with the lack of fast transport alternatives throughout the country, led to growth rates of at least 20% per year for the domestic air transport market from 2009 to 2012, a trend illustrated in Fig. 1.

These results created an overload on several major Brazilian airports, well documented in a technical note published by the Brazilian Institute of Applied Economic Research (IPEA) using data from the Brazilian Airport Infrastructure Company (Infraero) (Campos and Souza, 2011). The growth rate of the Brazilian airline industry, including domestic and international sectors, was 11.7% annually, similar to other high-growth emerging economies such as India, China and Russia - respectively 9.0%, 11.6% and 19.5% in the period - and higher than average world growth rates of 8.4% per year (World Bank, 2019a).

The rapid growth of air transport demand in Brazil until the early 2010s, however, was not accompanied by an acceleration in infrastructure investment at major national airports (or alternative transport modes, for that matter). This growth created a situation where, on the one hand, there was urgency in the expansion of the busiest airports to accommodate the requirements of two mega-events, the 2014 FIFA World Cup and the 2016 Olympic Games. However, on the other hand, there was a lack of consensus on the design of the proposed privatisation process of its state-owned airports, which, combined with the growth of demand, produced significant bottlenecks at the hubs. In particular, the metropolitan area of São Paulo, with its three main airports – the major Guarulhos International (GRU) and Congonhas (CGH) airports and a secondary one, Viracopos (VCP), located 58 miles away from São Paulo downtown – was strongly impacted by the rapid growth in passenger movements after the entry of low-cost carriers (LCCs) Gol and Azul in 2001 and 2008, respectively. Severely congested, the CGH and GRU airports began to operate under strict slot restrictions. In 2012, GRU and VCP were eventually privatised through a concession scheme, securing, thus, a source of capital for their much-needed capacity investments. With notable airport bottlenecks in the São Paulo region, the only option left to airlines was to extend their networks elsewhere in the country. Some alternative hubs across Brazil, such as Brasília's (BSB) and Belo Horizonte's Confins (CFN) airports,

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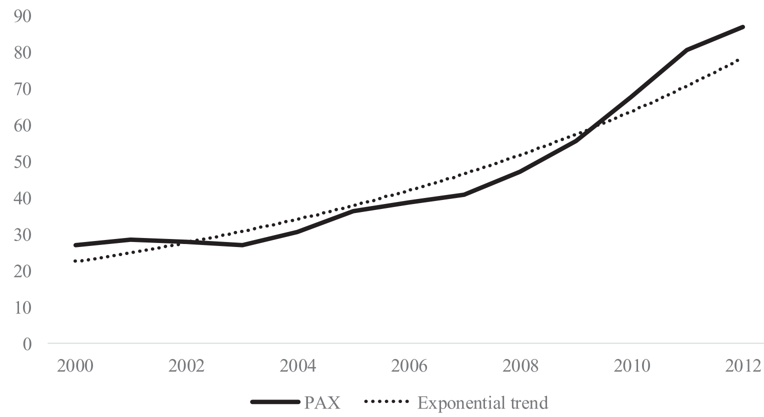

Fig. 1. Number of domestic passengers in Brazil per annum (in millions).
Source: ANAC (2019), with own calculations, 2000–2012.

benefited from the congestion of São Paulo's airports.

Additionally to the major airports' bottlenecks, a notable growth in medium-sized airports across the country was observed, and thus, in principle, contributed to the geographic deconcentration of the late 2000s. Medium-sized cities had higher percentage growth in terms of gross domestic product (GDP) than larger cities, allowing for a better spatial distribution with less pronounced spatial differentials of wealth and income. Fig. 2 depicts such a trend, showing the contributions to the Brazilian GDP of each of the country's mesoregions, while also comparing their values in the years 2000 and 2010. We note that the definition of "mesoregion" follows the one provided by the Brazilian Institute of Geography and Statistics (IBGE), as published in 1990, and refers to a subdivision of Brazilian states, comprising several cities and towns of a geographic area with economic and social similarities, a division in force up until 2017 (IBGE, 1990). Here, one can observe that the economic activity became more dispersed towards the country's hinterlands, with several lower-tier mesoregions rising in ranks in terms of economic contribution and allowing for a more evenly distributed pattern of development throughout the territory.

Regions traditionally conferred with higher economic power - the Southeast and South regions, responsible for more than 70% of the country's GDP - had a growth of 22.2% between 2005 and 2010. In contrast, regions with the lowest share of GDP, the North, the Midwest and the Northeast, grew respectively 34.0%, 30.5% and 28.1% in the same period. This contributed to regional capital cities such as Fortaleza, Recife and Cuiabá gaining considerable attention from airlines, and with some of them going as far as to gain hub status in recent years (namely, Fortaleza becoming a hub for Gol and Recife for Azul). The more significant economic growth of traditionally less developed regions, combined with the slow path of investment in the airports of the major cities of the country and a strong and increasing demand which could not be diverted to alternative transportation modes, seem to have created the incentives for airlines to promote a geographic displacement of part of their operations, fostering a trend of regionalisation of the Brazilian air transportation system. Fig. 3 provides evidence for this assertion, overlaying air traffic values per airport on top of the map of Fig. 2.

In Fig. 3, one observes both the growth of passenger traffic numbers

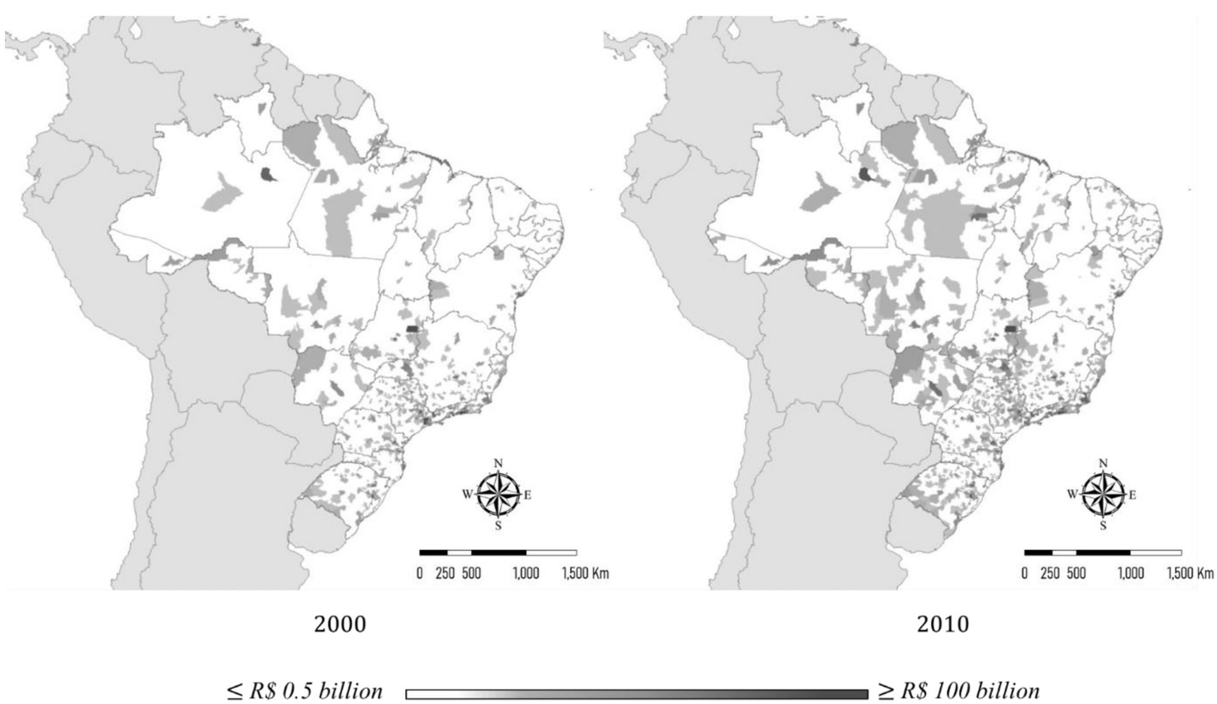

Fig. 2. Evolution of the spatial distribution of the gross domestic product (GDP) in Brazil.
Source: IBGE (2019a), with own calculations, 2000–2010.

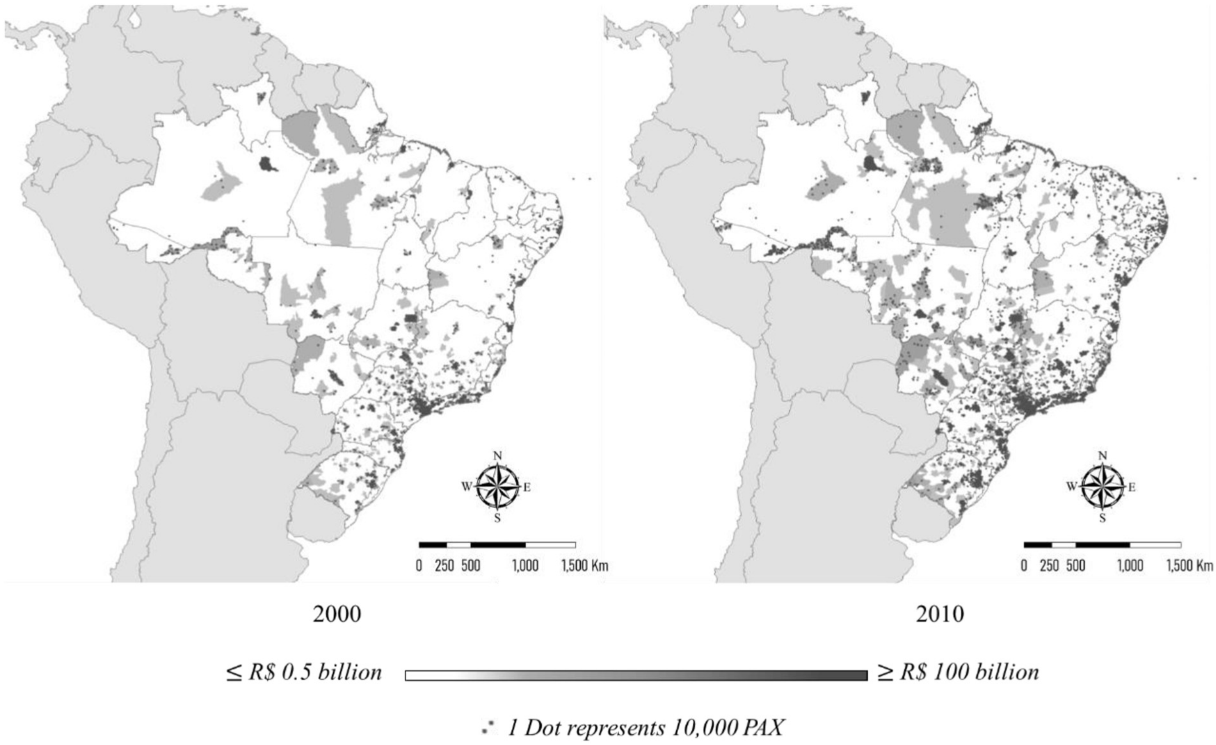

Fig. 3. Evolution of the spatial distribution of GDP and passenger air traffic in Brazil.
Sources: ANAC (2019) and IBGE (2019a), with own calculations, 2000–2010. Red dots mean 10,000 passengers.

in mesoregions already established in the Brazilian air network and the emergence of mesoregions in which air traffic was previously absent, suggesting an increased role of regional airports for the observed traffic numbers. However, by comparing the spatiotemporal distributions of traffic and economic growth in this figure, the development of several focal points of both of these values appear not to have been necessarily mutually engendered, following distinct patterns with regards to their dispersions. Such evidence suggests that, although economic and air traffic growth may have been, to some extent, intertwined, other determinants have been at play in Brazil during that particular period, preventing these measures from becoming completely associated.

With this in mind, we note that some researchers have already scrutinised the geographic-spatial evolution of air transport networks, revealing similar phenomena of deconcentration patterns oftentimes backtracked to the growth of LCCs at small- and medium-sized airports (e.g., Suau-Sanchez and Burghouwt, 2011, in Spain, and Jimenez et al., 2012, in Portugal). On the enumeration of additional grounds for explaining such phenomena, particularly those occurring towards less affluent centres, authors have also commented on the roles of factors such as tourism, new aircraft technology, changing location of economic growth, airport capacity shortfalls and the deregulation of air transportation (e.g., Reynolds-Feighan, 2000; Papatheodorou and Arvanitis, 2009; Bel and Fageda, 2010; Suau-Sanchez et al., 2016). Yet, to the best of our knowledge, an investigation of the effects such determinants may have over observed dissociations in the relationship between air traffic and economic activity still appears to be lacking in the literature.

Within this context, with our empirical framework, we seek to contribute to the existing literature of airline network concentration by devising both (i) economic and demographic normalised concentration indexes and (ii) investigating these through an econometric analysis – a method not too often employed in spatial concentration studies (see, however, Bel and Fageda, 2010, and Oliveira et al., 2016). This framework is pursued to examine more thoroughly the evolution of the Brazilian air transportation network relative to its populational and economic dynamics. In particular, we focus on the period between 1995 and 2012, given considerations of (1) the economic crisis that would take place in Brazil from the mid 2010s, and (2) the number of major capacity-constrained strategic airports that would be granted to the private sector following a series of concession schemes where requirements of capacity investments were in force. These two events would take place from 2012 onwards and would ultimately have a role in inhibiting the dispersion of air traffic. We perform index normalisation by adjusting traditional network concentration measures with equivalent measures of socioeconomic concentration. For this, two macroeconomic metrics are employed, namely, GDP and population at the regional level. By adopting this approach, we aim at inspecting the association and the (possible) decoupling between the geographic concentrations of air traffic and economic development and, more importantly, the drivers of such disengagements. Econometric models having economic and demographic normalised Gini, Herfindahl-Hirschman and Theil indexes as dependent variables are then considered for the isolation of the effects of a series of possible determinants. In the end, we compare these effects with the ones occurring over the traffic concentration alone, as drivers explaining our proposed index and not the associated traffic concentration index will be suggestive of decoupling, i.e., of determining the evolution of traffic concentration only in *relative* terms concerning socioeconomic concentrations but not in absolute terms.

The remainder of this paper unfolds as follows. In Section 2, a review of what has been remarked in a selection of works surrounding airline network developments on suggested traffic dispersal drivers is summarised. This review is accompanied in Section 3 by a brief panorama of Brazil, with some characteristics of its air transportation industry being outlined, along with an analysis of its evolution. Section 4 proceeds to enumerate a series of relevant research dealing with the issue of air traffic concentration and its evaluation, also describing our research methodology for the assessment of geographic network concentration and offering the details of our normalised concentration metrics. In Section 5, we apply our methods to Brazilian data, introducing our econometric models. Estimation results are presented and discussed in Section 6, which is followed by the conclusions in Section 7.

2. Literature review on airline network developments and traffic concentration patterns

Several factors have been referred to in the literature while trying to explain deviations from expected geographic patterns of traffic concentration. Suau-Sanchez et al. (2016), for example, cite the emergence of new aircraft technology (also noted by other authors such as Graham, 1997; O'Connor, 2003; Bowen, 2010), which made (and is expected to still do so in the future) unprofitable routes feasible, enabling an overhaul of airline networks throughout the world over the years. In this sense, one can also identify the role of an airline's operational costs, as lower oil prices, for example, can have a significant impact over the economic viability of ‘lightweight’ routes.

Another critical aspect mentioned by these authors is that of changing airlines business models, as the case of the introduction of the LCC business model, which brought several less-sought second- and third-tier airports to the foreground, providing a means for the economic development of their surrounding regions. Indeed, the literature has already shown much interest in the issue of the loss of absolute traffic figures due to passengers switching over from larger airports to smaller ones due to the operations of an LCC (e.g., Vowles, 2001; Tierney and Kuby, 2008; Graham, 2013). As these airlines often pursue more efficient operations, such as avoiding congestion and flight delays, they tend to focus on airports with easy accessibility, available slots, and cheaper use of infrastructure. The development of networks by Southwest Airlines and other LCCs in a set of Western US cities have been said to have owed much to such factors (Goetz, 2002). However, it is important to emphasise that demand is still a given when making these relocations, as in a free air transport market (with carriers being the sole agents deciding where traffic will ultimately go) such an issue comes down to a matter of where the existing patterns of demand already are.

In addition, Papatheodorou and Arvanitis (2009) mention the influence of tourism on such traffic dispersal patterns, while illustrating the situation in a group of tourist islands in Greece, similarly to what was discussed by Strand (1999), which argued that air travel demand is a result of the combination not only of macro and microeconomic forces but also of the geographic and locational elements that constitute airports catchment areas. Moreover, Bel and Fageda (2010) also touch upon attributes such as a more dispersed economic growth – that eventually has the potential of boosting point-to-point connections - as well as the issue of airport congestion restrained by an inability of making infrastructure expansions (such as urban or environmental concerns) - a point mentioned likewise by Koo and Lohmann (2013).

Finally, the deregulation/liberalisation (and even, in some cases, the re-regulation) of the air transportation market has also been amply cited by a series of authors, although with contrasting consequences being ascribed (especially to the case of deregulation) with regards to traffic concentration. In the case of the US, research such as Reynolds-Feighan (2000, 2001, 2007a) indicate an increased concentration, while results of Lee (2003) suggest a stable evolution of the air traffic distribution for the same geographic scope. To this effect, we note that similar patterns of concentration have also been detected by Koo and Lohmann (2013), in their case, for both the Australian and Brazilian markets. In Europe, Burghouwt et al. (2003) find a stable traffic distribution, while Jimenez et al. (2012) and Suau-Sanchez et al. (2016), for the particular cases of Portugal and Spain, respectively, point to deconcentration. Suau-Sanchez (2013), providing a literature review on this subject, concludes that there seems to be consensus in the obtained results, where intra-continental seat capacity followed a deconcentration path, while inter-continental seat capacity was oriented in the opposite way.

More generally, deregulation has been said to have posed a threat to thin markets (Reynolds-Feighan, 1995) and to have had a direct impact over increased congestion levels, a byproduct of diseconomies of scale in the wake of increased traffic concentrations on a few nodes of airlines' networks, as they turned themselves increasingly more towards a hub-and-spoke network configuration (e.g., Reynolds-Feighan, 2001; Alderighi et al., 2007). However, on the other side, as suggested by Reynolds-Feighan (2000) in the case of the US, deregulation has also provoked changes in the network structures of airlines, with the author finding evidence that the relationship between enplanements and population size was stronger for small and medium hubs when compared with larger ones. The author concludes that there are additional market and industry forces which drive traffic at the major hubs, further hinting at a detachment/causal separation between population, GDP and air transportation provision.

In sum, based on discussions of the previous literature, we have a series of potential factors that could provoke deviations on traffic concentration patterns, namely: aircraft technology, operational costs, changing airline business models, tourism, congestion and deregulation. A question that remains, however, is whether such factors would have a role over observed detachments of air traffic concentration from economic and or demographic activity concentrations, i.e., their role over their *relative* evolution, in lieu of their effects over the air traffic developments alone. Furthermore, in cases where only an effect over the relative evolution is identified, it may be said that a tendency for decoupling between the air transport network and economy/demography is taking place. With such considerations being made, we pose the following hypothesis:

Hypothesis H1. At least one of the following factors: aircraft technology, operational costs, airline business models, tourism, congestion or deregulation presents an effect over the detachment of air traffic concentration relative to socioeconomic development.

As such, an inherent asymmetry in the relationship of air traffic concentration with respect to economic and demographic activity concentrations can be examined, by looking at those determinants having their effects statistically different from zero in the normalised indexes specifications while having their effects statistically equal to zero in the standard indexes specifications.

With hypothesis H1, we intend to offer a more in-depth investigation of the role of the abovementioned drivers in allowing for a more equitable distribution of air traffic in a country. If evidence should indicate such state of affairs, particularly for some of those factors, this could paint a much brighter picture for the future of aviation in Brazil – at least when compared to the case of airlines being forced to move to secondary and regional airports solely based on the inexistence of enough capacity in wealthier markets. This is so since, in this scenario, these airlines may not be able to fill enough seats from regional markets with lower population volume and disposable income potentials. As such, it would mean that it would be more challenging for new entrants to establish themselves in the market. Moreover, the Brazilian air transport network already went through a concentration process, and traffic spills to smaller airports have already been observed, with those, too, becoming congested to some extend – as it was the case of the Viracopos airport. In such an environment, it becomes difficult to generate enough demand relying on regional traffic, creating a situation where not even LCCs may wish to start operations in the country - leaving the market dominated by a handful of carriers. Accordingly, the only opportunities for entry will happen solely when one of those dominant airlines goes bankrupt, in a sort of zero-sum game. Lower prices may, in this way, be the only possible stimulus, heralding, on the contrary, a grim omen for the future of airlines, and the overall competitiveness of the Brazilian market.

3. An overview of the Brazilian economy and air traffic developments in the 2000s

3.1. Air transportation and the Brazilian territory

Brazil enjoys a much favourable geographic position on the Global South, occupying a significant portion of the east coast of South America, receiving a major share of the connections from the Atlantic and serving as the primary gateway for the whole region. Its place as the 9th largest economy in the world (IMF, 2019) alongside its position as the fifth-largest country both in terms of population (approx. 210 million as of 2019) and area (8.5 million km^2), confers the country a leading role in South America. Regarding its population distribution, the cities of São Paulo, Rio de Janeiro, Belo Horizonte, Brasília, Fortaleza and Recife currently occupy the 1st, 3rd, 7th, 8th, 9th and 10th places among the countries in South America. Of these cities, São Paulo and Rio de Janeiro serve as the main gateways for international connections (through the airports of Guarulhos and Galeão, respectively), concentrating more than 80% of the total international passenger traffic of the country in all of the years from 1999 to 2012 (see Pacheco et al., 2015). Of these two airports, Guarulhos holds the central position as the region's largest hub – a fact evidenced by the quick construction of a new international terminal (T3), just after its concession, in 2012. However, it should be noted that Brazil's capital city, Brasília, and the north-eastern cities of Fortaleza and Recife have been playing an increasing role in this respect – with Fortaleza's traffic share being further strengthened following the recent partnership between Gol and Air France/KLM in the region in 2018.

With regards to the airlines operating in the country, as discussed by Lipovich (2014), concerning countries in Latin America, the large territorial extension of Brazil (like Mexico) makes it relatively more difficult for airlines to achieve substantial market centralisation levels, with the country being nearly evenly partitioned between the domestic carriers currently in operation (in 2020), namely, Gol, LATAM and Azul. However, the scope of their networks does not present a similarly symmetric character, with Gol and LATAM having a considerable overlap of their flight networks while Azul operates several monopoly markets of the industry's regional segment. This reflects to some extent their choices of aircraft, as Gol has favoured the use of Boeing aeroplanes, LATAM of Airbus, and Azul of Embraer (along with ATRs following its merger with regional carrier Trip in 2012). Regarding international airline alliances, LATAM is the only carrier currently involved in one (oneworld), while also having 20% of its stake bought by Delta Airlines. Despite having belonged to Star Alliance, we note that Avianca went bankrupt in December 2018.

Considering the country's profile as related to the Global South, an analysis of data made available by the World Bank (2019a, 2019b) on air traffic and population shows how Brazil has kept the lead in absolute terms of per capita number of aggregate (domestic and international) passengers (associated with the airlines registered in each of these countries), among the applicable BRICS countries for every year from 2008 up to 2018 (the most current period available). By 2018, the country has shown a value of about 0.49, a value comparable with the ones of China and South Africa (0.44 and 0.41, respectively) and considerably higher than the one from India (0.12). Nevertheless, its growth was severely slowed down in 2012 and the following years, given the economic crisis that ensued in the country, culminating in a break of its upward trend by 2016. Indeed, Brazil has been surpassed by Russia on this indicator by 2014, and similarly by a set of countries in Latin America, to which we cite Colombia, Peru and Mexico in 2012, 2016 and 2017, respectively.[1]

Turning our attention to a more detached view of Brazil, it is noted that connectivity between large cities is, to a reasonable extent, well covered in the country through airlines responding to market incentives, such as the existence of sufficient demand to break even and of passengers willing to pay for the airlines' set prices. The main challenge, however, is the provision of connectivity between scattered cities, sometimes located far inland. Such a pattern for settlement formation in Brazil - in the sense that cities are mostly coastal, both the ones which were first populated and the ones that are most densely populated as of today - is directly inherited from its colonial history. In addition to such a potential coastal versus inland accessibility asymmetry, there is a strong asymmetry between geographic regions as well, with the country's division into five macroregions (North, Northeast, Southeast, Midwest and South), as devised by the IBGE, aiming at reflecting just that. This division is illustrated in Fig. 4, which reproduces a map made available by the abovementioned institute (with the English translation of the legend being from the authors).

There are accentuated differences among these regions from the perspective of social, economic and geographic attributes. Concerning the social and economic aspects, as an example, a characterisation of the contributions of each of these regions in terms of GDP and population – contrasted with air traffic numbers - for the year of 2010 is depicted in Table 1. We choose this year as it is representative of the period of our analysis–i.e. a combination of quick growth of both the Brazilian economy and the air transport industry.

In addition, from a geographic standpoint, still another evidence of these differences that can be readily identified lies on landforms and the variability of available transportation means between those regions. While counting on large areas of tropical (and dense) forests, wide rivers and the lack of adequate highways and railway services (in some cases, surface transportation is simply not available at all), regional air transportation plays a strategic role for enabling economic activity in more remote and underdeveloped regions - examples being the Amazon and the northern part of the country.

In line with what has been discussed in Section 2, concerning new aircraft technology, we note how significant contributions for allowing accessibility to the remoter regions of the country have been provided by aircraft produced by Embraer, the national aircraft manufacturer founded in 1969, given the requirement for the use of light planes for the operation of many short-haul thin routes. In this regard, the first model developed was the twin-turboprop EMB-110 “Bandeirante,” with its success leading to the development of the EMB-121 “Xingu” and the EMB-120 “Brasília” (for further details, see Dahlman, 1984; Ramamurti, 1985; Sabel et al., 2012).

Besides, Embraer has provided further two generations of aeroplanes - with turboprops giving way to jet aircraft - that have contributed to shaping airline networks in the country. Firstly, in 1997, it was the ERJ family, whose development was primarily focused on substituting turboprops in the regional markets of the US and Europe. Secondly, in 2004, it was E-Jet family's turn, with its models being conceived for the exploration of the (until then) untapped 70–120 seat market. The E-Jet models, which helped to blur the boundaries between regional and mainline aviation, have been extensively employed by Azul Airlines in Brazil and have played a significant role in the shaping of the carrier's flight network.

Fig. 5 provides a spatiotemporal overview of the use of Embraer aircraft in the country. We note that the EMB turboprops increasingly fell out of favour, not being deployed anymore as of today.

Fig. 5 also makes more explicit the spatial domains of operation of each generation of aircraft, with the turboprops dominating the Amazon, part of the Northeast and short-haul routes in the South and Southeast regions, the ERJ family being deployed majorly in a central axis across the country and the E-Jets being seemingly associated with flights having Brasília, São Paulo or, more markedly, Belo Horizonte as one of its endpoints. By 2019, Brazil had a network capacity of more than five hundred public airports (ANAC, 2019). While significant, some historical analysis shows that their number reduced along years:

[1] We note that Chile has demonstrated higher figures with respect to Brazil for this indicator since 1992, presenting, in 2018, a value of about 1.04.

Fig. 4. Macroregions of Brazil as defined by the IBGE.
Source: IBGE (2019c).

Table 1
Contributions of each macroregion to Brazilian air traffic, population and GDP (2010).
Sources: IBGE (2019a, 2019b) and ANAC (2019).

Decomposition	Pax	Population	GDP (R$)
North	4.68%	8.73%	5.45%
Northeast	13.77%	21.40%	11.24%
Southeast	58.20%	46.54%	57.92%
South	8.10%	15.43%	15.83%
Midwest	15.25%	7.90%	9.55%
Total (absolute)	191.09 million	153.22 million	432.5 billion

over the past decades, the number of cities serviced by scheduled flights declined from 400 to little more than a hundred. What is more worrisome, the number of ‘small’ cities (population under 100,000) served by scheduled air transport fell sharply and steadily from 1970 to 2000 (Ribeiro et al., 2010). Despite the public policy efforts put earlier in traction in 1963 (with the launch of the “National Integration Network” program - RIN) and 1976 (with the “Integrated Regional Air Transport System” program - SITAR), territorial coverage of the air transportation system kept being reduced. Reasons for the scenario found in the most recent years (2000- onwards) are varied. Nevertheless, it is worth noticing that airlines usually list the historical lack of investments in the Brazilian transport infrastructure as one of the leading causes for some airports remaining out of the scheduled network or maintaining their air traffic numbers limited.

On this matter, we note that both Gol and Azul have acted as traffic dispersers, at least at some point of their trajectories. However, Gol eventually directed itself towards increasing its presence on the main airports, while Azul remained focused on regional airports and

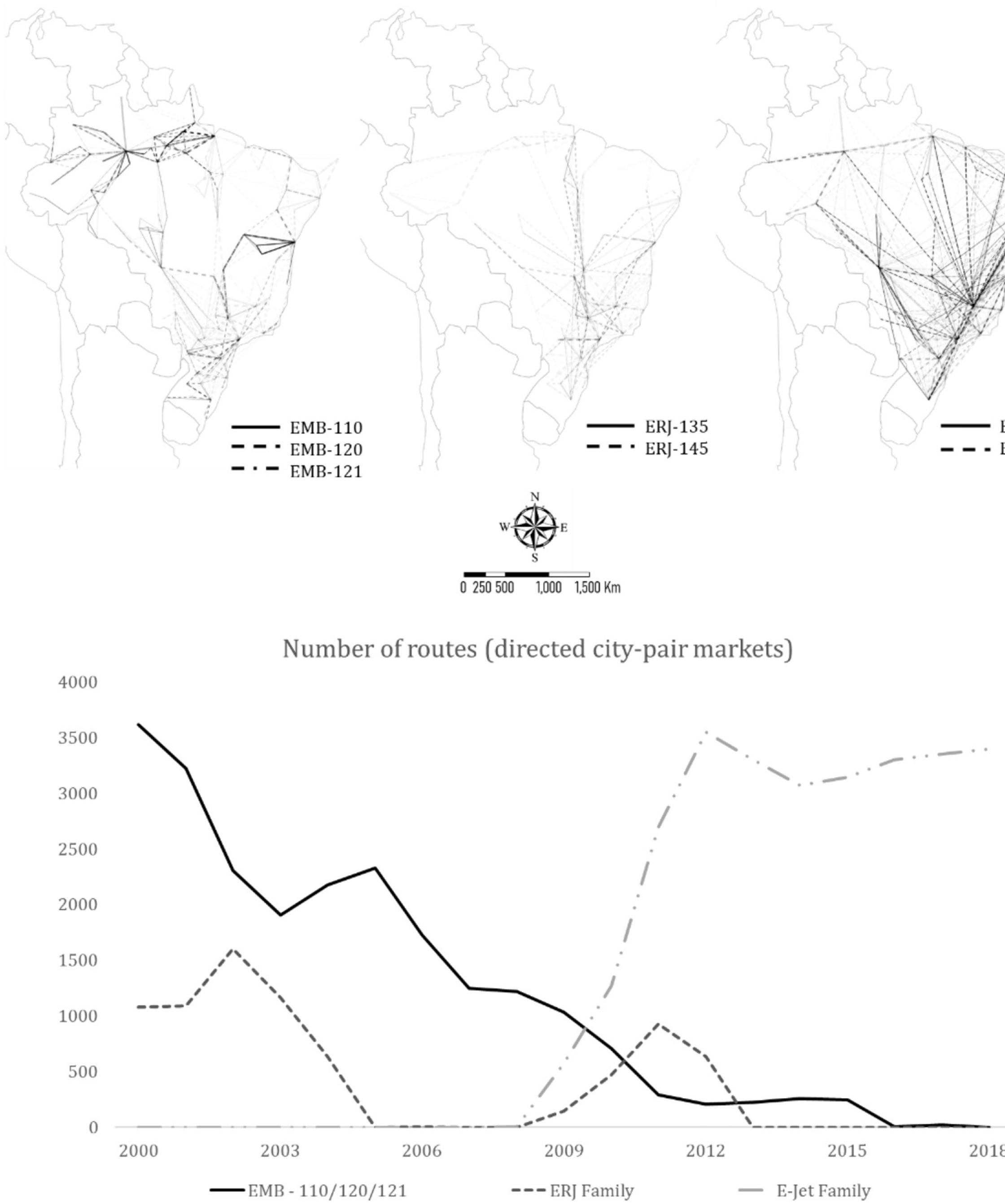

Fig. 5. A spatiotemporal overview of Embraer aircraft utilisation in Brazil (2000–2018).
Source: ANAC (2019), with own calculations, 2000–2019. Notes: Regarding the maps in the upper part of the figure, opacity indicates dominance of a model on a route, while line width indicates longevity of the route (e.g., Belo Horizonte/Recife has 167 months in total).

maintaining its operations from Viracopos. Such reorientations can be attributed to Gol's acquisition of legacy carrier Varig, in 2007, and Azul's merger with regional carrier Trip, in 2012. Notwithstanding, such roles can be observed during the analysed period by the efforts of Gol of boosting connectivity in the country (as Azul would enter the market only in December 2008), as shown in Fig. 6, comparing its network, in December of 2005 and in December of 2010. For illustrative purposes, we also compare the network of Azul, in December of 2010 and in December of 2015, in Fig. 7.

Lastly, we close this section by illustrating how, between the years of 2000 and 2012, shares of traffic have been redistributed between different airport categories. To pursue that, we follow the division of Brazilian airports as employed in Koo and Lohmann (2013) – namely, Group 1 containing the airports of the top three state capital cities (i.e., São Paulo, Rio de Janeiro and Brasília), Group 2 being comprised of those of the other capital cities, and Group 3 encompassing the remaining airports in operation. Table 2 shows that airports in Group 3 have maintained a stable share of domestic traffic (of around 10%), while Group 1 lost about 4% - with that percentage being absorbed by Group 2.

4. Evaluating the spatial concentration of air networks

Given that our aim is the assessment of geographic concentration, and neither hubbing activity nor network configuration of airlines (or of the Brazilian air transport system as a whole), we focus our attention

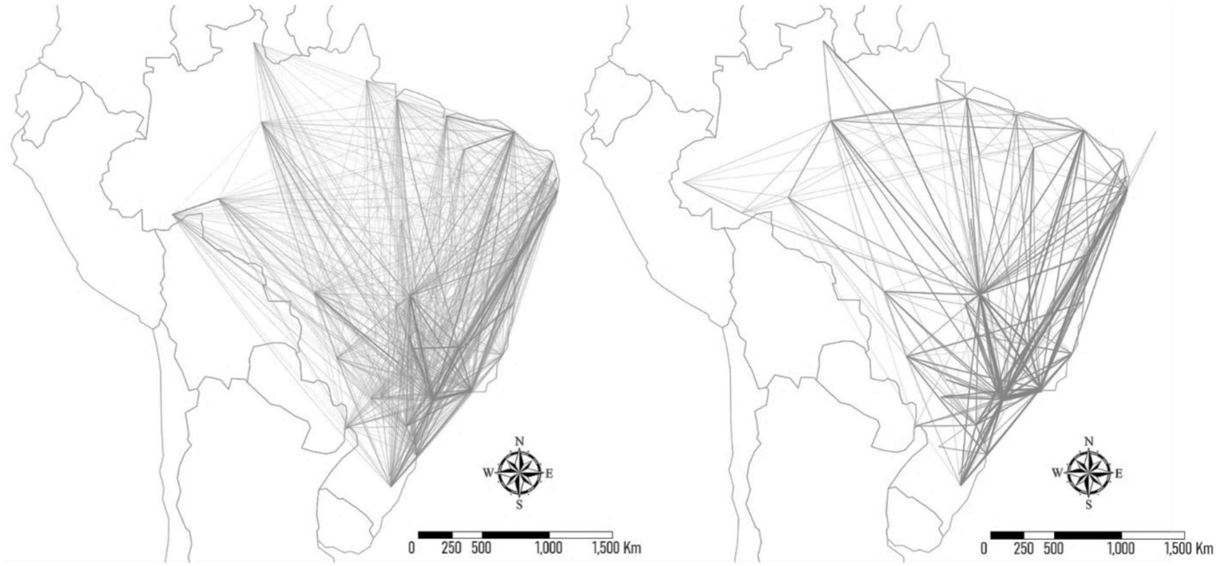

Fig. 6. Gol's network in December of 2005 (left) and in December of 2010 (right).
Source: ANAC (2019). Line width indicates traffic density.

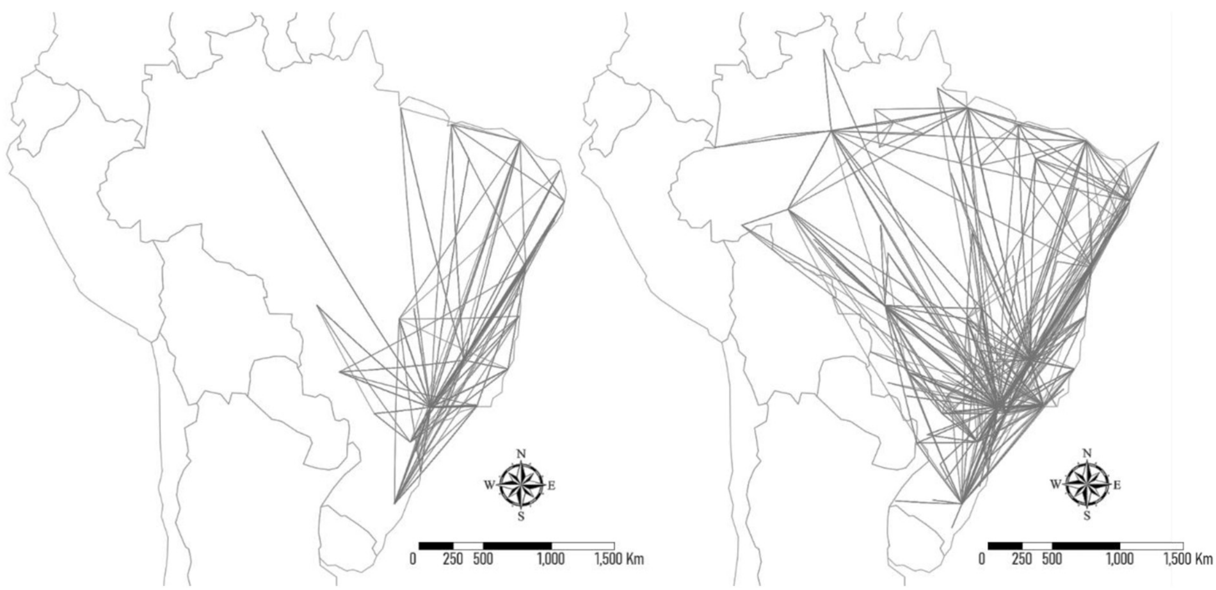

Fig. 7. Azul's network in December of 2010 (left) and in December of 2015 (right).
Source: ANAC (2019). Line width indicates traffic density.

Table 2
Evolution of passenger (PAX) shares for each group of airports.
Source: ANAC (2019). "M" indicates the largest (major) value in the series while "m" the smallest (minor).

Year	Group 1	Group 2	Group 3
2000	51.89%	37.38% (m)	**10.73% (M)**
2001	51.64%	38.58%	9.77%
2002	51.23%	39.79%	8.98%
2003	**52.66% (M)**	38.76%	8.58% (m)
2004	51.23%	39.49%	9.28%
2005	50.58%	39.08%	10.35%
2006	49.03%	41.02%	9.95%
2007	47.35% (m)	42.08%	10.56%
2008	48.29%	41.71%	10.00%
2009	48.37%	42.23%	9.40%
2010	48.51%	**42.55% (M)**	8.95%
2011	47.40%	42.43%	10.17%
2012	47.64%	41.76%	10.60%

in this section on reviewing the literature surrounding concentration measures (instead of connectivity ones). In this regard, the interested reader is referred to the work of Suau-Sanchez (2013), which provides a review of a series of studies considering both concentration and connectivity measures, while also presenting some overarching conclusions.

On the subject of passenger network spatial concentration and its evaluation, a discussion on the properties of Gini index and other measures has been outlined in Reynolds-Feighan (1998, 2001) (namely, the coefficient of variation and the Herfindahl-Hirschman and Theil indexes), comparing their performance for data of the US air transport network, focusing on different airport categories - as designated by FAA - (1998) and different airline-type networks (2001). In both cases, the author suggests the Gini index as a preferred alternative to be utilised in measuring air traffic concentration, building her analysis upon the seminal work on the measurement of poverty of Sen (1976) to reach this conclusion. Besides, the Gini index has been employed on works such as Huber (2009), comparing the networks of the US and the EU, and Papatheodorou and Arvanitis (2009), which studied the traffic concentration of the Greek airport system together with social and economic activity concentrations. Moreover, for examples of the use of the HHI, the reader is referred to the works of Lee (2003), Suau-Sanchez and Burghouwt (2011) and Pacheco et al. (2015). The latter two also make use of the Lorenz curve in their analyses with Pacheco et al. (2015) additionally employing a normalised version of the HHI.

As a follow-up to her previous research, Reynolds-Feighan employed (and further developed the use of) the Gini index in some subsequent work using decompositions of it. Of these, we cite Reynolds-Feighan (2007a), exploring the spatial (carrier-specific) and industrial (airport-specific) concentrations of air traffic in the US, and Reynolds-Feighan (2007b), presenting a similar purpose while comparing the cases of Europe and the US. Apart from that, Suau-Sanchez et al. (2016), following the methodology presented in Reynolds-Feighan (2007b), offers some insights as to why there has been contrasting results in the associated literature on air traffic concentration surrounding the European market. Interestingly, their results do not support the general view that network carriers tend to increase concentration levels while LCCs promote air traffic dispersion.

Burghouwt et al. (2003) introduced a measure tailored explicitly for the investigation of networks. While being employed on the analysis of the European aviation after deregulation, their 'Network Concentration Gini index' (NC-Gini) was devised to quantify traffic distributions of airline networks as an alternative to the commonly employed Gini index. Its rationale is based on the principle that no airport can command more than half of the total air traffic within an airline network, with the Gini index being unable to reach its theoretical maximum value of '1'. With that in mind, they proposed a normalisation of the traditional index by its maximum attainable value in air transport networks, obtaining, thus, their novel concept. We note that the same index has additionally been employed in the work of Jimenez et al. (2012) - previously discussed in the introduction of this paper.

Moreover, similarly to Burghouwt et al. (2003), Oliveira et al. (2016) proposed the normalisation of a concentration index by its maximum value. In their paper, they focused on both the Gini and the Herfindahl-Hirschman indexes, devoting their attention to the air traffic 'big blackout' that took place in Brazil during the period from 2006 to 2007. These authors employ a regression analysis as well, to further explore some possible determinants of the concentration-dispersion patterns observed. In a similar econometric vein, although working directly with traffic shares (and not with a concentration index), we also mention Bel and Fageda (2010), who focused on concentration patterns as related to the intercontinental long-haul flight market in Europe.

Offering a deviation from these measures - often reliant on some form of normalisation of either the Herfindahl-Hirschman or Gini indexes, we also mention the researches of Derudder and Witlox (2009) and Koo and Lohmann (2013). Derudder and Witlox (2009) develop a series of spatial interaction indexes to measure the degree of hierarchical differentiation in a set of European airline networks, considering - given data availability constraints - two out of three features of hierarchical differentiation, namely, "dominance" and "connectivity" (while leaving "symmetry" out). The authors further normalise their proposed indexes through a comparison with a rank-size distribution. Koo and Lohmann (2013), in turn, employ generalised entropy indexes along with the Gini and (decompositions of) the Theil indexes to investigate and compare traffic distributions in Australia and Brazil, with a focus on the correlation between air transport policy volatility and air traffic spatial concentration.

Finally, we note Martín and Voltes-Dorta's (2008, 2009) proposal of the incorporation of passenger connecting behaviour in the spatial analysis of networks. They stressed the importance of separating the case of airlines concentrating traffic in hub airports from airlines concentrating a high share of their passengers in a single airport with no connections – what Alderighi et al. (2007) designate as a 'technical base,' primarily intended for the offering of direct flights. Martín and Voltes-Dorta (2008) provide the details of their 'Hubbing Concentration Index' (HCI), a measure calculated at the route level and using the HHI for assessing concentration concerning all the possible ways to fly between two cities.

In view of the literature and the relative shortage of investigations aimed at inspecting the detachment between socioeconomic and air traffic patterns of development (to the best of our knowledge, only Papatheodorou and Arvanitis, 2009, pursued an assessment of both measures in this literature) - as well as the use of regression analyses (we, similarly, could only find the works of Bel and Fageda, 2010, and Oliveira et al., 2016), we intend to bridge the associated gap with a methodological procedure of index normalisation followed by the utilisation of an econometric analysis of its spatiotemporal evolution.

4.1. Our proposed concentration index

The details of the standard Herfindahl-Hirschman, the Theil, and the Gini indexes, being already established in the literature, will have their discussion omitted in this research (with the interested reader being referred instead to Reynolds-Feighan, 1998, 2001).

Here, we will only limit ourselves to the presentation of Figs. 8, 9 and 10, depicting, respectively, the Herfindahl-Hirschman, the Theil and the Gini concentration indexes for the variables of air traffic, GDP and population. We note how a general trend of (a slightly) monotonic decrease in concentration can be observed for the socioeconomic activity variables (i.e., GDP and population) for all of the considered

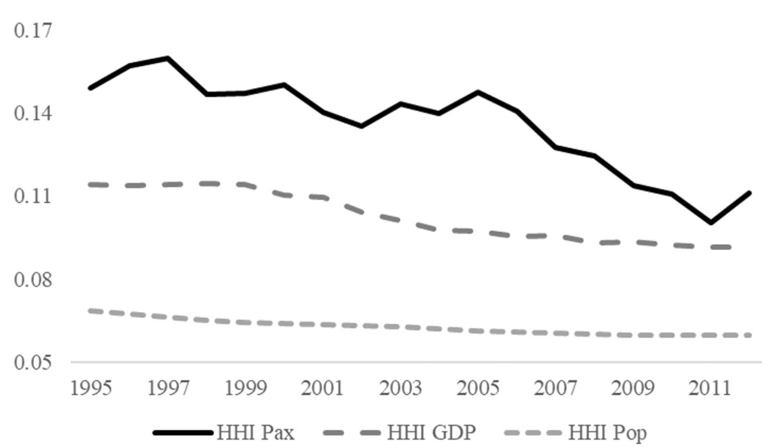

Fig. 8. Evolution of the concentrations of air traffic, GDP and population (HHI).
Source: ANAC (2019), with own calculations, 1995–2012.

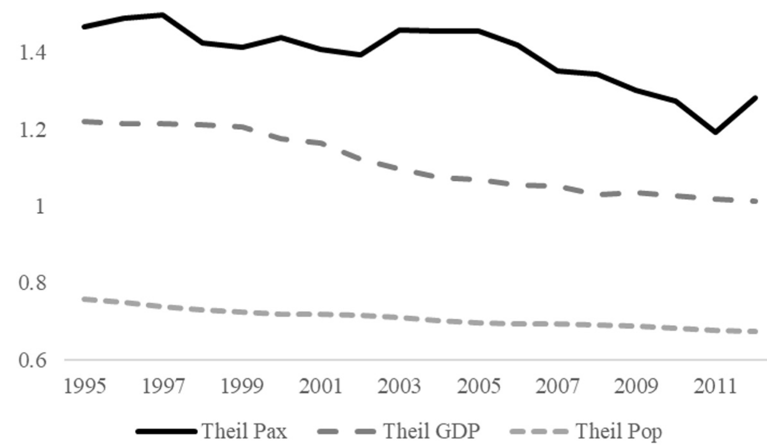

Fig. 9. Evolution of the concentrations of air traffic, GDP and population (Theil).
Source: ANAC (2019), with own calculations, 1995–2012.

indexes.

Moving on, we recall that, in this research, the concentration indexes should account for aggregate changes in the spatial concentration of socioeconomic measures in the country as well. Hence, we propose to normalise our air network concentration indexes by socioeconomic spatial concentration indexes, with this procedure allowing us better to understand causes for any decoupling between these two quantities. Eq. (4) shows the common expression for our concentration decoupling indexes (CD):

$$CD = \frac{\textit{Air traffic spatial concentration}}{\textit{Socioeconomic spatial concentration}} \tag{4}$$

With this, we proceed to experiment with the following versions of this index: using the Herfindahl-Hirschman Index (CD_H), the Theil T index (CD_T) and the Gini index (CD_G).

We use GDP as our primary relative metric, also experimenting with the population concentration as a robustness check. Hence, our CD metrics are as described in Eq. (5),

$$\begin{aligned} CD_G|GDP &= \frac{G(PAX)}{G(GDP)},\ CD_G|Pop = \frac{G(PAX)}{G(Pop)} \\ CD_T|GDP &= \frac{T(PAX)}{T(GDP)},\ CD_T|Pop = \frac{T(PAX)}{T(Pop)} \\ CD_H|GDP &= \frac{H(PAX)}{H(GDP)},\ CD_H|Pop = \frac{H(PAX)}{H(Pop)} \end{aligned} \tag{5}$$

where $G(\cdot)$, $T(\cdot)$, and $H(\cdot)$ designate standard Gini, Theil and Herfindahl-Hirschman indexes. Taking the logarithm of, e.g., $CD_G \mid GDP$ and then finding its differential, we get (6):

$$\frac{dCD_G|GDP}{CD_G|GDP} = \frac{dG(PAX)}{G(PAX)} - \frac{dG(GDP)}{G(GDP)} \tag{6}$$

showing that positive percentage changes in the aggregate traffic concentration over the percentage changes of the aggregate socioeconomic concentration will increase this index, with a similar rationale applying to movements in the opposite direction.

Descriptive statistics of all of our concentration decoupling indexes can be found in Table 3. We note how the HHI-based metrics present the highest variation, while the Gini-based ones, the lowest. As such, we opt to choose the models related to the HHI metric as our main specifications. Moreover, Figs. 11 and 12 illustrate the evolution of our proposed indexes, relative to GDP and population, respectively. Similar trends of deconcentration can be seen in all cases during the period from 2005 to 2011, although only moderately for the case of the Gini measures. This goes in line with what has been depicted in Figs. 8, 9 and 10 for the case of the air traffic concentration indexes alone.

5. Empirical models of concentration decoupling

5.1. Data

For the implementation of our econometric models, we employ data from the *Agência Nacional de Aviação Civil* (ANAC, the Brazilian

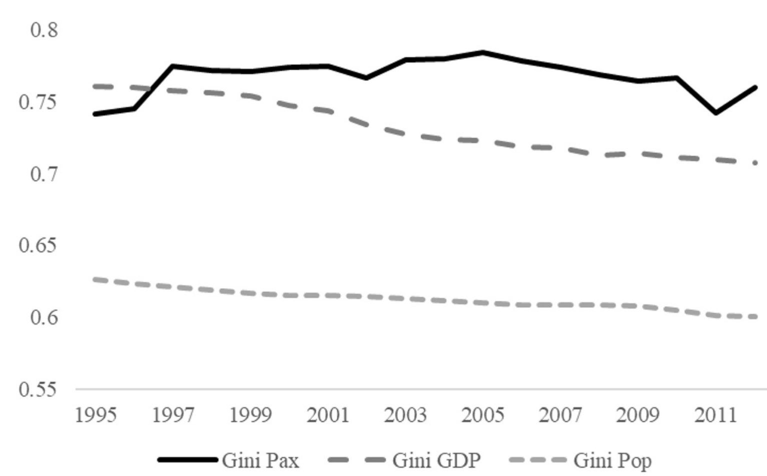

Fig. 10. Evolution of the concentrations of air traffic, GDP and population (Gini).
Source: ANAC (2019), with own calculations, 1995–2012.

Table 3
Descriptive statistics of the concentration decoupling indexes.

Variables		(1)	(2)	(3)	(4)	(5)	(6)
Pearson's correlation							
$CD_G \mid GDP$	(1)	1.0000					
$CD_T \mid GDP$	(2)	0.6982	1.0000				
$CD_H \mid GDP$	(3)	0.1622	0.7371	1.0000			
$CD_G \mid Pop$	(4)	0.9149	0.6425	0.3159	1.0000		
$CD_T \mid Pop$	(5)	0.1479	0.6953	0.9633	0.3563	1.0000	
$CD_H \mid Pop$	(6)	−0.2095	0.3509	0.8799	0.0752	0.9020	1.0000
Univariate statistics							
Mean		1.0490	1.2560	1.3238	1.2532	1.9657	2.1612
Standard deviation		0.0339	0.0650	0.1138	0.0268	0.0857	0.2211
Minimum		0.9650	1.1183	1.0669	1.1710	1.7442	1.6412
Maximum		1.0911	1.3931	1.5624	1.2896	2.1304	2.5353

National Civil Aviation Agency), the *Empresa Brasileira de Infraestrutura Aeroportuária* (Infraero, the Brazilian Airport Infrastructure Company), the *Instituto Brasileiro de Geografia e Estatistica* (IBGE, the Brazilian Institute of Geography and Statistics), the *Instituto de Pesquisa Econômica Aplicada* (IPEA, the Brazilian Institute of Applied Economic Research), and the Energy Information Administration (EIA). The time series of our dataset consists of monthly observations aggregated at the national level, covering the sample period between January 1995 and December 2012.

We utilise data associated with the movement of both inbound and outbound passengers per airport for the construction of our air traffic concentration indexes. For the socioeconomic concentration indexes, we employ the GDP (and population) figures aggregated by the associated airport's catchment area, with the IBGE definition of mesoregion being used for the assessment of their respective boundaries.

5.2. Empirical models

For our empirical framework of the determinants of spatial concentration decoupling, we set $CD_I \mid e$ to account for the relative concentration of air traffic with respect to $e \in \{GDP, Pop\}$ as measured by index $I \in \{H, T, G\}$. Each index is regressed separately, presenting the same specification for its econometric model. These models are given by a linear combination of the following regressors, reflecting the discussions presented in Section 2:

- *PAX* is a variable defined by the total number of paying passengers, aggregated at the national level. It is used to control for the effect of the expansion of the air transportation industry in Brazil during the analysed period. On the one hand, larger values for this variable may trigger a higher concentration of air traffic relative to the economy, in case the national air network presents a much rigid hierarchy of its airports and/or a considerable part of flights operated in the country are provided by airlines associated with the hub-and-spoke network configuration. On the other hand, it may be that capacity constraints - and the ensuing congestion following the increased passenger numbers - contributed to the dispersal of the national air network relative to the economy. This variable is treated as endogenous, with further details being described in Section 5.3, dealing with our estimation strategy (source: Statistical Data Reports of Air Transportation (ANAC), with additional manipulations made by the authors);
- *INT TOURISM* is a variable defined by the share of international paying passengers, aggregated at the national level. It is included to control for any tourism effect over the air network concentration. Its sign is expected to be positive, given that international flights are commonly associated with full-service carriers (FSC), which, in their turn, for the most part, adhere to the hub-and-spoke network configuration. Similarly to the previous variable, it is also treated as endogenous. Further details are also provided in Section 5.3 (source: Statistical Data Reports of Air Transportation (ANAC), with additional manipulations made by the authors);
- *OIL* is a monetary variable calculated as the average monthly crude oil price as given by the Cushing, Oklahoma West Texas International (WTI) spot price (free-on-board (FOB) contract). This is measured in dollars per barrel, converted to BRL and adjusted by the IPCA deflator to a value comparable to December 2012. It is considered in the model given the large share represented by fuel to an airline's total costs. The higher this cost, the greater the number of routes whose profitability may be compromised by it, given the necessary network rationalisation (and prioritisation) initiatives that the airlines may take to keep themselves aloft in such high input costs environment. Such routes will be associated mainly with thin markets. However, given that many of them may be the only connections offered by some airports, their cancellation may severely impact the air traffic concentration values given the disengagement of several airports from the air transportation network (source: EIA and IPEA (for the IPCA values), with additional manipulations made by the authors);
- *SLOT* is a dummy variable assuming the value 1 in the period from October 2007 to March 2008. It is used to control for a connectivity constraint caused by operational restrictions imposed by the civil aviation authority in Brazil (ANAC) to the São Paulo Congonhas

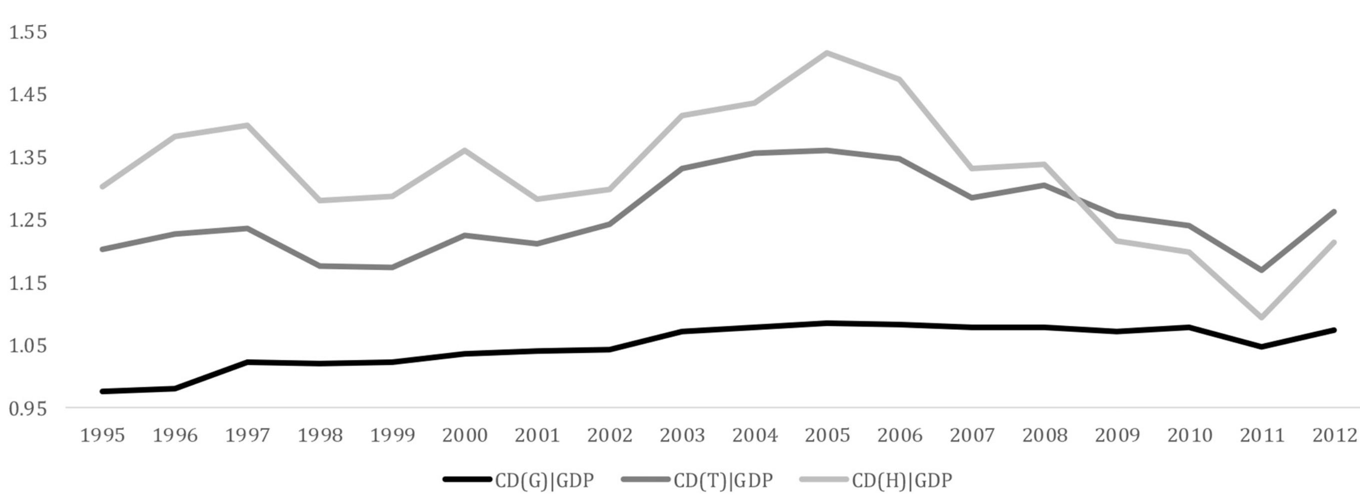

Fig. 11. Evolution of the concentration decoupling indexes of air traffic relative to GDP.
Source: ANAC (2019), with own calculations, 1995–2012.

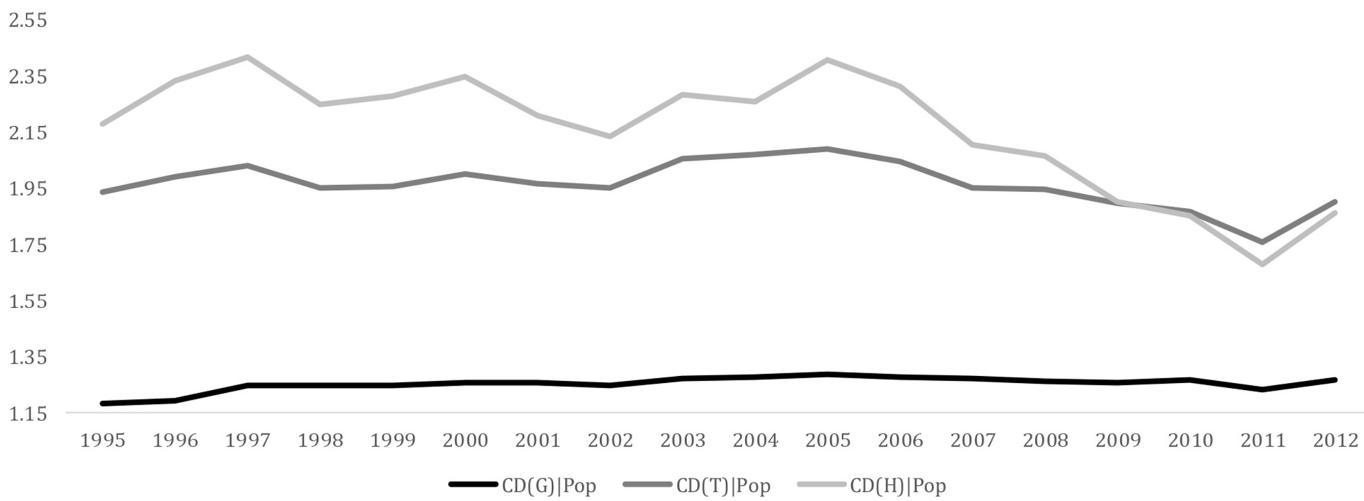

Fig. 12. Evolution of the concentration decoupling indexes of air traffic relative to population.
Source: ANAC (2019), with own calculations, 1995–2012.

airport during that period. This limit to capacity growth to one of the most important airports in the country is expected to have contributed to a redistribution of traffic to a larger set of airports, not only composed of the largest ones, thus helping many lower-tier airports to gain prominence. This variable is treated as endogenous, with further details being considered in Section 5.3, dealing with our estimation strategy (source: Statistical Data Reports of Air Transportation (ANAC), with additional manipulations made by the authors);

- *GOL* is a dummy variable accounting for the presence of the airline Gol in the first two years after the beginning of its operations (from January 2001 to December 2002). Its objective is to control for a possible deconcentration effect of the air network associated with the operations of an LCC, given these carriers' preference for choosing secondary, less congested airports – particularly during its early years (source: Statistical Data Reports of Air Transportation (ANAC), with additional manipulations made by the authors);
- *AZUL* is a dummy variable accounting for the presence of the airline Azul in the first two years after it began its operations (from January 2009 to December 2010 – as the company initiated its services on December 15, 2008). It serves the same purpose as the previous variable, although Azul's distinctive use of Embraer E-Jet models may confound its effects over traffic dispersion with those from new aircraft technology making thinner routes cost-efficient (source: Statistical Data Reports of Air Transportation (ANAC), with additional manipulations made by the authors);
- *SLOWDOWN* is a dummy variable assuming the value '1' from January 2012 to the end of our analysed period, December 2012. It is included for isolating the effects of Brazil's economic slowdown in the period. This regressor is expected to have had a positive impact on our variables of interest, i.e., contributing to a disproportionate aggregate concentration of air traffic relative to socioeconomic activity. This would be the case given the air transportation demand's high elasticity relative to income and GDP (source: Statistical Data Reports of Air Transportation (ANAC), with additional manipulations made by the authors);
- *TREND* (*before lib.*) is an increasing discrete linear variable differing from zero from the beginning of our dataset to December 1997. It is utilised to account for any air network concentration trend which could have been present *before* the air transport liberalisation that took place in the country. We do not have any a priori expectations for its sign (source: Statistical Data Reports of Air Transportation (ANAC), with additional manipulations made by the authors);
- *TREND* (*after lib.*) is an increasing discrete linear variable differing from zero from January 1998 to the end of our dataset. Similarly to the previous variable, it is included to account for any air network trend which could have been present *after* Brazil's air transport liberalisation. Considering that after the liberalisation process Brazilian airlines became free for setting airfares and choosing any routes they wanted (to operate or abandon), we expect that this trend would have had a positive effect of concentrating the air traffic in relation to the economy, given the economies of scale effects of the hub-and-spoke network configuration (source: Statistical Data Reports of Air Transportation (ANAC), with additional manipulations made by the authors).

Besides, we also included seasonality terms, as measured by monthly dummy variables, to control for unobserved effects. We conclude this section by presenting the descriptive statistics of all regressors employed in our models. These can be found in Table 4.

5.3. Estimation strategy

For the estimation of our models, we have utilised the two-step feasible efficient generalised method of moments estimator (2SFEGMM), as concerns regarding the presence of heteroscedasticity and autocorrelation required the use of a method able to produce consistent standard error estimates in such settings. Furthermore, in our empirical framework, the variables related to the number of passengers (*PAX* and *INT TOURISM*) were suspected of presenting endogenous relationships concerning the concentration decoupling variable, our regressand, arising from how these variables are defined in terms of one another and the possible bidirectional relationship between GDP and air traffic demand. Likewise, the variable associated with the presence of slots (*SLOT*) is also treated as endogenous, as slot restrictions are dependent on the occurrence of air traffic concentration in the first place (i.e., slot restrictions are enforced in (most often than not, major) airports already experiencing overcapacity - which, by itself, contributes for a higher concentration overall). These compelled us to make use of an instrumental variables approach, with our identification strategy consisting of a set of lagged instruments of the total number (and international share) of passengers and that of slots restrictions being in force. Furthermore, such instruments were tested with respect to their orthogonality and relevance. The Hansen-Sargan J test was considered for examining the validity of the full set of over-identifying conditions associated with our models. For all of our specifications, this test did not reject orthogonality, supporting the exogeneity of our chosen instruments instead. In all models, the set of instruments utilised

Table 4
Descriptive statistics of the regressors of our network concentration models.

Variables		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Pearson's correlation										
PAX	(1)	1.0000								
INT TOURISM	(2)	−0.7087	1.0000							
OIL	(3)	0.6976	−0.7177	1.0000						
SLOT	(4)	0.0599	−0.0681	0.2035	1.0000					
GOL	(5)	−0.2474	−0.0920	0.0552	−0.0904	1.0000				
AZUL	(6)	0.8381	−0.5633	0.3776	−0.0904	−0.2857	1.0000			
SLOWDOWN	(7)	0.6241	−0.2950	0.3274	−0.0410	−0.1296	0.4537	1.0000		
TREND (before ib.)	(8)	−0.3649	0.7246	−0.5127	−0.0644	−0.2036	−0.2036	−0.0924	1.0000	
TREND (after ib.)	(9)	0.8805	−0.8348	0.8629	0.1291	−0.0713	0.6960	0.3811	−0.6004	1.0000
Univariate statistics										
Mean		8.6909	13.7394	147.2413	0.0278	0.2222	0.2222	0.0556	3.0833	105.4167
Standard deviation		3.9158	3.4370	67.2111	0.1647	0.4167	0.4167	0.2296	8.1133	67.0318
Minimum		3.9110	8.8733	31.0148	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum		21.3803	23.7372	290.1918	1.0000	1.0000	1.0000	1.0000	36.0000	216.0000

Table 5
Estimation results of the concentration decoupling (CD) models.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$CD_H \mid GDP$	$CD_H \mid POP$	*H(PAX)*	$CD_T \mid GDP$	$CD_T \mid POP$	*T(PAX)*	$CD_G \mid GDP$	$CD_G \mid POP$	*G(PAX)*
Demand									
PAX (endogenous)	−0.0446***	−0.0539***	−0.0029***	−0.0277***	−0.0320***	−0.0219***	−0.0088***	−0.0052*	−0.0042**
INT TOURISM (endogenous)	0.0161**	0.0377***	0.0022***	0.0324***	0.0430***	0.0289***	0.0035***	0.0062***	0.0032***
Cost									
OIL	0.0008**	0.0006	0.0000	0.0006**	0.0007**	0.0005**	−0.0000	−0.0001**	−0.0001**
Constraint									
SLOT (endogenous)	−0.1840***	−0.2746***	−0.0167***	−0.0599**	−0.0890**	−0.0565**	−0.0189***	−0.0260***	−0.0135***
Competition									
GOL	−0.0362	−0.0636*	−0.0033	0.0249	0.0242	0.0179	0.0062	0.0092	0.0044
AZUL	−0.0985**	−0.2304***	−0.0096**	0.0163	0.0197	0.0199	−0.0232***	−0.0385***	−0.0208***
Events									
SLOWDOWN	0.1952***	0.2734***	0.0170***	0.1181***	0.1767***	0.1226***	0.0320***	0.0276*	0.0186**
TREND (before lib.)	0.0028*	−0.0005	−0.0001	−0.0017	−0.0047	−0.0033	0.0007	−0.0000	0.0000
TREND (after lib.)	0.0022***	0.0023***	−0.0000	0.0023***	0.0017***	0.0004	0.0012***	0.0010***	0.0005***
R^2 Adj.	0.7498	0.8393	0.9168	0.3987	0.5096	0.7745	0.8881	0.6335	0.5177
RMSE	0.0569	0.0887	0.0051	0.0502	0.0599	0.0410	0.0112	0.0159	0.0089
KP (statistic)	10.3984	10.5666	10.3984	6.6710	6.6710	6.6710	10.3984	10.3984	10.3984
KP (p-value)	0.0055	0.0143	0.0055	0.0356	0.0356	0.0356	0.0055	0.0055	0.0055
Weak CD (statistic)	51.7727	51.8110	51.7727	7.2133	7.2133	7.2133	51.7727	51.7727	51.7727
Weak KP (statistic)	22.3001	22.3199	22.3001	2.6953	2.6953	2.6953	22.3001	22.3001	22.3001
J (statistic)	1.1095	2.1811	0.0736	0.0578	0.7983	0.0496	0.0166	0.4862	0.4398
J (p-value)	0.2922	0.3360	0.7862	0.8100	0.3716	0.8237	0.8975	0.4856	0.5072
Nr Observations	215	215	215	215	215	215	215	215	215

Notes: p-value representations: ***p < .01, **p < .05, *p < 010. Regressands are as defined in Section 4.1.

presented one variable over the number of endogenous regressors. Moreover, regarding the relevance of the proposed set of instruments, we made use of the Kleibergen-Paap rk LM under-identification test (KP), which rejected the null hypothesis of under-identification. We also tested weak identification using the Cragg-Donald Wald F statistic and the Kleibergen-Paap rk Wald F statistic (labelled "Weak CD" and "Weak KP" tests). We had evidence for rejecting the hypothesis of weak instruments. Finally, we performed endogeneity tests as well, with all of these tests rejecting the null hypothesis (with a p-value of *at least* less than 0.05), indicating that the specified endogenous regressors cannot be treated as exogenous within our models. The results of all of the tests, together with our estimation results, are reported in Table 5 of Section 6. We note, in advance, that, although the endogeneity tests point to the rejection of the exogeneity of the *PAX*, *INT TOURISM* and *SLOT* regressors, results having them treated as exogenous do not vary significantly from the ones of our main specifications.

6. Results

The estimation results of our main concentration decoupling models, associated with the Herfindahl-Hirschman, are presented in Columns (1) to (3). Columns (1) and (2) show the economic normalised ($CD_H \mid GDP$) and the demographic normalised variants ($CD_H \mid POP$), respectively. Column (3) presents the same regressors of (1) and (2), but with a different regressand, namely, the non-normalised index *H(PAX)* – the numerator of our normalised metrics. This is done to test our Hypothesis H1, by comparing the effects of the proposed determinants over the air traffic concentration alone and its relative evolution with respect to the economic and/or populational concentrations. Further results, to be interpreted as robustness checks, are available in Columns (4) to (6), associated with the Theil index, and Columns (7) to (9), related to the Gini index.

We begin by noting how, for most of the regressors, the sign of the coefficients and their statistical significance are consistent throughout the specifications, although magnitudes do vary to some considerable degree. Besides, such magnitudes are, to a large extent, diluted in specifications having the air traffic concentration as the dependent variable when compared with specifications having the associated normalised CD indexes. We note, however, that the variable *TREND (after lib.)*, loses statistical significance overall in Columns (3) and (6), associated with the Herfindahl-Hirschman and Theil specifications. This may be said to indicate a tendency for decoupling between air transport network and socioeconomic activity, as a trend can be noticed for their relative evolution but not for the air traffic concentration alone. With the non-normalised index unable to capture such an effect, we believe this to be suggestive evidence of a possibly decoupled relation between those dimensions, which may have been triggered by the air transport deregulation in the country. However, we note that we can only talk about rudimentary evidence given these results, as such conclusions cannot be drawn from the Gini specifications (Column (9)). In sum, we can see from Table 5 that economic/demographic normalisation allows us to infer that economy and air transportation walk closely, even being matched, with the major portion of regressors that explained one of these metrics also explaining the other. Nevertheless, in the presence of only limited evidence, we find instructive to reject H_1, as we cannot infer much from the *TREND (after lib.)* dissociation results, and we rather recommend further enquiry on this issue in future studies.

Moving on to the analysis of the determinants over our proposed measures and the standard indexes alone, we turn ourselves to the examination of the results from our demand variables. Regarding the *PAX* variable, all our specifications have shown an adverse effect of the number of passengers over the concentration decoupling of air traffic relative to socioeconomic measures. This goes in line with the hypothesis that capacity constraints at the major airports in the country, incapable of processing the growing demand of passenger air travel, may have contributed to deconcentration of air traffic, mainly when analysed in conjunction with the results of our infrastructure constraint variable, *SLOT*. We suggest that traffic spill from major hubs could have diverted part of the carriers' networks to other airports, especially in other Brazilian state capital cities. Moreover, the variable *INT TOURISM*, on the other hand, has provided the opposite effect of increasing the concentration. We note, nevertheless, that the share of international passengers has presented a descending trend since February 1997. Pacheco et al. (2015), in fact, point out that the share of international passengers has declined, from 14.5% in 1999 to just over 9.8% in 2012 (the analysed period in their dataset), with this trend offering, thus, a net effect of deconcentration.

Concerning our cost variable (oil price), its effect as measured by the variable *OIL*, however, did not obtain consensus across specifications. Both the HHI and Theil metrics consistently implied a positive effect of concentration of air traffic over economic activity, and, in the case of Theil, over population as well. As previously discussed, this result was expected given necessary network rationalisations of airline operations on denser routes. The Gini index, nevertheless, suggested a negative impact over concentration relative to population, which may indicate that firms took precedence of routes with an associated high GDP over routes with large populations on its endpoints. We believe that, under higher fuel costs, smaller turboprop aircraft such as the ATR-45 and the ATR-72 became relatively more competitive when compared to larger jets, which may have provided some incentives for regional airlines to enhance their services across the country. An example of that is the rapid expansion across the Brazilian territory of the regional carrier Trip Airlines, one of the most successful carriers in terms of network growth during that period. That effect, however, would depend significantly on the network structure of the airline in question. Results of Dresner et al. (2002), concerning the use of regional jet in the US, for example, indicate that these models were being used to add longer stage length routes and to supplement (and not replace) turboprop operations. Still, they were being deployed mainly to connect destinations to the airlines' hubs, most likely contributing to air traffic concentration, as the hubs gained a more prominent role in their networks. As far as we are concerned, an understanding of the link between air traffic dispersal and aircraft size and type remains an open avenue for research. We note that all of the above findings - related to the *PAX, INT TOURISM* and *OIL* variables - are broadly consistent with the ones found previously in Oliveira et al. (2016), when analysing, instead, a logit transformation of the traffic concentration (our numerator) as the dependent variable.

With respect to our airline competition variables, the presence of the LCC Gol (*GOL*) does not seem to have affected the air traffic concentration in the domestic market. This is in contrast to Azul's presence (*AZUL*) results, which are, in most cases, suggestive of having stimulated network deconcentration. This evidence is in line with the fact that Azul has had substantial operations on less congested and secondary airports - such as Viracopos, its main base. Moreover, the use of Embraer aircraft, in stark contrast with all of its competitors, may have given the company an edge on the operation of a variety of regional routes having low-ranking airports in (at least) one of its endpoints. Its deconcentration effects, still, could not be adequately captured by the Theil index, as indicated by the lack of statistical significance of Azul's presence. Given the overrepresentation of airports with small shares of traffic in the composition of the value of this index (Derudder and Witlox, 2009), this is suggestive of Azul avoiding operations in this particular low-tier set.

Lastly, regarding our event variables, *SLOWDOWN* has consistently shown the expected sign in all specifications. This goes in line with our conjecture that, given the high-income elasticity of air transportation demand relative to the Brazilian economy, the economic slowdown experienced since 2012 would generate a disproportionate concentration of air traffic relative to the economic activity. Moreover, the variables *TREND (before lib.)* and *TREND (after lib.)* have also shown robustness across specifications. These suggest that, before liberalisation, no clear trend with regards to concentration could be observed. However, things appear to have changed after the liberalisation event, with movements towards higher relative concentration, a result already indicated in Koo and Lohmann (2013).

We conclude this subsection by observing that our main results were robust to the use of alternative metrics for economic concentration and different indexes. Moreover, these results do not appear to have been sensitive to change of specification of the left-hand variable, such as a logarithmic transformation as well.

7. Discussion and conclusion

This paper aimed at contributing to the literature on air transport spatial concentration dynamics by proposing a methodology for the evaluation of the effects of a series of determinants on air traffic network concentration and its possible decoupling relative to social and economic activity concentrations. We proposed an index to pinpoint the determinants of such potential dissociation. We, nonetheless, provided comparisons of the effects of these determinants with those over the standard air traffic concentrations alone, to investigate further our proposal. We note that for most of the regressors, the main conclusions were unchanged whether we considered our proposed indexes or standard concentration indexes, as their sign and statistical significance were consistent throughout specifications of normalised and non-normalised indexes. However, for the case of a variable associated with a time trend occurring after the liberalisation of the Brazilian air transport sector, we found rudimentary evidence that this is somewhat differently considered by our indexes, presenting a higher statistical significance. As vestigial as this result may be, we believe that it merits additional discussion, and we recommend further investigation into this issue.

More broadly, we found evidence that significant demand shocks, such as the economic slowdown of the early 2010s, played a critical role in increasing the observed network concentration. We do not find, nevertheless, evidence of network concentration adjustments following oil price hikes. Also, our results suggest that the notable decrease in spatial network concentration that occurred in Brazil during the late 2000s was influenced by the accelerated growth of its rapidly-increasing domestic demand. This provides evidence to the hypothesis that the resulting congestion, following from the lack of sufficient infrastructure at the major airports, actually caused a notable traffic spill from São Paulo airports to alternative airports within the country's territory. Finally, in contrast to the entry of LCC Gol Airlines in the early 2000s, the more recent LCC entry episode of Azul Airlines (2008) seems to have triggered airline competition towards system-wide market share building, ultimately contributing to overall network deconcentration. This, however, could have been confounded with the particular aircraft technology used by this carrier alone.

As policy implications, we argue that our proposed metrics can be further developed to present an important tool for airline network planning as they constitute an additional element to be considered with relation to the understanding of extra-economic and extra-demographic impacts which may induce significant changes in the market. If we reach the conclusion that events such as a post-liberalisation trend have the capacity of generating asymmetry in the air traffic/socioeconomic activity concentrations, then airlines must be aware of this to be able to take the cues from the market. Implications for governments are at hand as well, since, as authorities must make investments in airports, they must keep in mind that the state of affairs doesn't always allow air traffic and economic/populational dynamics to be perfectly associated.

7.1. Limitations

As limitations, we find instructive to add that our purpose in this research was to analyse the dissociations between air traffic and economic activity concentrations on an aggregate level. However, we are aware that at a much aggregate level, the sensitivity of the model to changes in the air transportation network may not be as significant as warranted. As our index was constructed, it cannot distinguish if the concentration of traffic is happening at a different place in the country than that of economic concentration, only being able to capture differences in relative concentration comparing two final concentration scalars instead of first comparing the quantities for each airport and summarising this difference as a final index.

Furthermore, concerning the endogenous relationship between slot restrictions and air traffic concentration, although our use of the slot variable with a lag of one period (a month) could be said to provide some correction for the incurred bias, interpretation of the results and the variable is, nonetheless, difficult within such a setting, as it offers little economic meaning. In this sense, the use of a structural economic model in future works could be more suitable for appropriately accounting for its constraining effect.

From a data availability point of view, moreover, similarly to Papatheodorou and Arvanitis (2009), with their use of NUT2 and NUT3 regions for the case of Greece, our use of mesoregions has the potential of making our results sensitive to the spatial scale of analysis, as these mesoregions are not all of similar sizes. Analogously to their case, unfortunately, no better option was found here as well.

Additionally, we note that the specificity of our results to the Brazilian experience, where a lack of high-speed trains and ferries as alternatives within a broader transport network may have had a role in the observed air traffic deconcentration trends. Additionally, the overall shortage of airport capacity in the period is undoubtedly distinctive and may not be observed in many other realities. Further investigation gathering evidence from other air transport systems is unquestionably needed to provide a more precise inspection of the crucial interrelations between the local economic activity and the dynamics of airline network design in the modern air transport industry.

We conclude by stressing that our focus was on a period of rapid growth in which the expansion of air traffic put considerable pressure on airport infrastructure–certainly a suitable setting for the analysis of the occurrence of possible decouplings. However, concerning the implications of using this time window, we note that the estimation results related to the nineties to the early 2010s may not be appropriate for the present moment, in particular in these difficult times of Covid-19. For policy-making, we believe our analysis may be useful in attempts of future scenarios development, knowing that a quick return to normal after the pandemic may not be a realistic case for air travel across the world.

Declaration of Competing Interest

All authors participated in all steps of the research.

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