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ASSESSING DEMAND AND SUPPLY SUBSTITUTABILITY IN BRAZILIAN INTERNATIONAL AVIATION: A NETWORK THEORY APPROACH FOR ANTITRUST ANALYSIS[1]

Avaliação da substituibilidade de demanda e oferta na aviação internacional brasileira: uma abordagem da teoria das redes para análise antitruste

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STRUCTURED SUMMARY

Context: The definition of the relevant market in the international aviation sector varies among antitrust authorities, with some focusing on origin-destination (O&D) routes and others incorporating broader or narrower criteria. While the European Commission emphasizes the O&D approach and acknowledges the impact of the hub-and-spoke model on supply-side substitutability, debates persist regarding the role of network effects and the substitutability of direct and indirect flights.

Objective: The aim of this article is to contribute to the debate by applying quantitative methods based on network theory to identify the existence of demand and supply subs- titutability between international routes departing from or arriving in Brazil, enabling a more accurate analysis in mergers and acquisitions processes affecting the Brazilian international aviation market.

Method: The adoption of quantitative methods (utilizing network indicators) alongside qualitative approaches to analyze substitutability on both the demand and supply sides within the international aviation sector.

Conclusions: This study demonstrates the importance of adopting a network-based approach to evaluate substitutability in the international aviation sector. By analyzing both demand and supply-side factors, it provides insights into how route connectivity and airline behavior influence market dynamics. The findings underline the necessity of incorporating network dynamics into antitrust evaluations, offering a foundation for further research into the competitive implications of route structures and airline strategies.

Keywords: aviation; network; antitrust; competition; hub-and-spoke; merger.

RESUMO ESTRUTURADO

Contexto: a definição do mercado relevante no setor de aviação internacional varia entre as autoridades antitruste, com algumas focando nas rotas de origem-destino (O&D) e outras incorporando critérios mais amplos ou mais restritos. Enquanto a Comissão Europeia enfatiza a abordagem O&D e reconhece o impacto do modelo *hub-and-spoke* na substitutibilidade pelo lado da oferta, persistem debates sobre o papel dos efeitos de rede e a substitutibilidade entre voos diretos e indiretos.

Objetivo: o objetivo deste artigo é contribuir para o debate aplicando métodos quantita- tivos baseados na teoria de redes para identificar a existência de substitutibilidade pelo lado da demanda e da oferta entre rotas internacionais com origem ou destino no Brasil, possibilitando uma análise mais precisa em processos de fusões e aquisições que impactam o mercado de aviação internacional brasileiro.

Método: a adoção de métodos quantitativos (utilizando indicadores de rede) em conjunto com abordagens qualitativas para analisar a substitutibilidade tanto do lado da demanda quanto do lado da oferta no setor de aviação internacional.

Conclusões: este estudo demonstra a importância de adotar uma abordagem baseada em rede para avaliar a substituibilidade no setor de aviação internacional. Ao analisar tanto os fatores de demanda quanto de oferta, fornece insights sobre como a conectividade de rotas e o comportamento das companhias aéreas influenciam a dinâmica do mercado. Os resultados ressaltam a necessidade de incorporar a dinâmica das redes nas avaliações antitruste, oferecendo uma base para futuras pesquisas sobre as implicações competitivas das estruturas de rotas e das estratégias das companhias aéreas.

Palavras-chave: aviação; rede; antitruste; competição; hub-and-spoke; fusão.

JEL Classification: [L40]

1 INTRODUCTION

The liberalization of international air transport markets and the ongoing consolidation of the sector have brought renewed attention to the challenges of applying antitrust principles in the aviation industry. Regarding the international jurisprudence applied to the aviation sector, the Organisation for Economic Cooperation and Development (OECD)(2014) clarifies that there is no consensus among antitrust authorities worldwide concerning the definition of the relevant market in its geographical dimension. While some jurisdictions maintain the traditional definition based on the origin and destination (O&D) approach, essentially focused on demand-side substitutability, others have adopted broader definitions (including other modes of transportation) or narrower ones considering the evolution of the civil aviation sector. However, there is no consensus on the need to incorporate network effects in the process of competitive market analysis, with Australia considering this factor for relevant market definition purposes (OECD, 2014), while other jurisdictions prefer to incorporate network effects as part of the competitive effects analysis. As, unwittingly, observed by the Directorate-General for Competition in the assessment of the Star Alliance case (European Commission, 2013), a rigid demand-side definition of the relevant market when network industries are in play may be myopic. Accepting out-of-market efficiencies, even to the limited extent that they accrue to the route of concern, in a way extends the boundaries of the relevant market. Ducci (2016), in a paper on out-of market efficiencies, two-sided platforms and consumer welfare, points out the limitations of market definition when the economics of two-sided platforms are not accounted for. Despite these considerations, there is debate over whether the best approach is to define on a case-by-case basis rather than seeking clearer guidance and harmonization (OCDE, 2014). From the perspective of the European Commission, as expressed in the Lufthansa/Austrian Airlines case (Lenoir, 2016), the relevant market definition for passenger air transport services is understood inside O&D approach, meaning that a particular route is seen as a separate market to be analyzed. However, to determine whether a specific route between the origin and destination points should be considered, the European antitrust body examines the various possibilities available.

Nonetheless, the European Commission considers the hub-and-spoke structure as an element that, in practical terms, reduces supply-side substitutability. In theory, it is assumed that an aircraft can be allocated to any route. However, in reality, given that traditional airlines use the hub-and-spoke model to structure their flight operations, this means that traditional airlines decide to fly almost exclusively on routes connected to their respective operating hubs (Lenoir, 2016). This tends to be even more important on long-haul international routes, since this segment is dominated by network air carriers (Lykotrafiti, 2023).

Moreover, according to Nannes (1999, p. 6-7), the antitrust analysis of entry conditions in the commercial aviation sector has become "more sophisticated and substantially more factual" over time. For example, in the 1980s, the Department of Transportation (DOT) approved a series of transactions involving carriers with high market shares of city-pair traffic, based on the reasoning that other carriers could easily enter those routes and discipline fares, without adequately considering whether new entry would be economically feasible given traffic flows and hub economics (Nannes, 1999). In our present context, the delivery of wide-body aircraft by the major global manufacturers (Boeing and Airbus) at a pace insufficient to meet the post-pandemic surge in demand (Singh, 2024) creates additional challenges for contesting the market in cases where incumbents exercise market power on routes with high market concentration.

However, the European Commission's mindset previously presented has been criticized by network air carriers because, from their perspective, the traditional approach fails to consider properly the network effects on demand side derived from the hub-and-spoke model structuring. Several companies have emphasized the need for antitrust analysis to consider all airports that are considered substitutes from the passengers' perspective (European Union General Court, 2015). Regarding substitutability between direct and indirect flights, the Commission found that it depends on the flight duration. That is, the longer the flight duration, the greater the likelihood that indirect flights exert competitive pressure on direct flights (European Union General Court, 2015). As for the jurisprudence of Conselho Administrativo de Defesa Econômica (Cade), the relevant passenger transport market has been geographically defined, like the European Union, based on origin and destination routes[5]. Based on this analytical methodology, for long-haul routes, indirect flights that increase travel time by up to 5 hours should also be considered part of the same relevant market.

Taking all of this into account, network structures can give rise to two distinct types of effects, each with different implications for competition - effects that might be overlooked in traditional analyses. On one side, a merger can intensify the dominance of a network carrier at key hub airports, particularly those facing congestion. In such cases, the concentration of slots and routes linked to the hub may strengthen the merged entity's market power within the airport's catchment area, reducing consumer choice and harming competition. On the other hand, network effects mean that the outcome of an airline merger goes beyond simply combining their existing routes. In this case, the whole is much greater than the sum of the parts. Incorporating the target airline's routes not only allows the acquiring carrier to operate those services but also opens the possibility of launching new direct or connecting routes. This can enhance the overall network, potentially generating efficiencies that might - though not necessarily - translate into lower prices and improved service quality (Olmedo Peralta, 2020).

The aim of this article is to contribute to the debate by applying quantitative methods based on network theory to identify the existence of demand and supply substitutability between international routes departing from or arriving in Brazil, enabling a more accurate analysis in mergers and acquisitions processes affecting the Brazilian international aviation market. This

5 Case No. 08700.004702/2023-81 (SEI 1377008). **All Cade public proceedings mentioned in this article can be consulted at: https://x.gd/0OMZL**

article is organized as follows: Section 2 presents a literature review, summarizing key studies and theoretical frameworks that underpin the research. Section 3 describes the data, outlining the data collection. Section 4 presents the analysis from the demand side. It is presented the methodology implemented (4.1), the general results (4.2) and then its application is shown with an example (4.3). Section 5 presents a discussion on supply substitutability, incorporating both qualitative aspects (5.1) and quantitative metrics (5.2) applied to understand patterns of network expansion before and after the pandemic crisis. Finally, Section 6 concludes the article, summarizing the contributions and suggesting directions for future research.

2 LITERATURE REVIEW

Our work relates to the use of network to study the Brazilian air transportation sector. Rocha (2009) studies the structural evolution of the Brazilian domestic airport network. Using data from 1996 to 2006, the results suggest that the companies have a tendency to invest in the most profitable routes rather than in new routes, consequently, increasing the number of connections on specific routes. The number of routes together with the number of airports decrease during the period, but the routes are constantly changing and not necessarily within the most connected airports. This dynamic evolution resulted in some airports becoming more central with time, while others become more peripheral. The research in Couto *et al.* (2015) analyzes the main characteristics of the Brazilian air transportation network, using national and international flight data using the complex network approach. The study showed that the Brazilian network has small world characteristics with low average shortest path length and high clustering coefficient and the airport connections follow a power law distribution. According to the authors, the main airports are Viracopos and Guarulhos, and travelers need to go through an average of three connecting flights to reach their destinations. A resilience analysis of the network's robustness also identified that an interruption at Viracopos airport would divide the network into six sub-networks, affecting 10% of passenger demand. Silva *et al.* (2022) investigates how the structure of the air transportation network affects air ticket prices in Brazil. Using microeconometric panel-data estimation, they find that the airports' degree of substitutability (clustering coefficient) and peripheral location (authority score) are associated with lower average airfare prices. In contrast, the convenience of transportation (degree), measured by the number of different cities that an airport serves, and centrality (closeness) are attributes that raise the average price. Also, they find that network's topological characteristics can either amplify or mitigate the relationship between market competition and airline ticket pricing.

Exploring the importance of links in transportation networks has a growing literature, especially in road networks (Jenelius, 2010; Rupi *et al.*, 2015; Li *et al.*, 2020) and metro networks (Yang *et al.*, 2017; Jing; Xu; Pu, 2019). Jing, Xu, and Pu (2019) provides a new dimension of assessing metro network performance—travelers' route redundancy (or route diversity), which is defined as the number of behaviorally effective routes between each origin-destination (O-D) pair in the network. Furthermore, the results of route redundancy are compared with typical measures of topology network performance in terms of measuring connectivity and accessibility of metro networks. Their differences are attributed to the fact that the route redundancy measure considers the travelers' O-D-level route choice beyond the pure network topology and the shortest path considerations of the existing measures.

While existing literature on the application of networks to the aviation sector has made significant strides, most studies do not focus on competition issues. This article, therefore, stands out by applying network metrics to understand the dynamics of flight networks, addressing both demand-side and supply-side substitutability. It offers an innovative perspective for tackling antitrust issues, contributing to the ongoing academic debate by filling this gap and providing analytical tools for antitrust investigations.

3 DATA

The international air travel data utilized in this paper is collected from two different sources: Brazilian National Civil Aviation Agency (Anac) and from the *FlightsFrom*[6] website. The Anac data includes two separate datasets. The first one includes data on airfares of domestic and international flights in Brazil. According to Anac, this accounts for about 50% of the total passenger movement by year once the tickets acquired via frequent flyer programmes and specific agreements between customers and airlines are not part of the database. The international airfare data is also restricted to tickets for trips originating in Brazil and ending abroad (as well as round-trip tickets, as long as the return is from the destination airport of the outward leg) fully operated by the airline that sold them and only for your scheduled flights previously registered with Anac. Both datasets were extracted using the *flightsbr* package in R (Pereira, 2024). Since our interest of study is the international flight network, we only used the origin and destination pairs of the international airfare data. There are 398 unique origin-destination pairs, with 37 unique origins and 60 unique destinations. Only origin and destination pairs that had more than 500 seats sold between 2022 and 2023 were considered.

The second Anac database includes detailed information on every international flight to and from Brazil, as well as domestic flights within the country. The data include flight-level information of airports of origin and destination, flight duration, operating airline, aircraft type, payload, and the number of passengers, and several other variables (Dados [...], 2024) . The flight-level information data identifies the pairs of origin, where the passengers boarded, and destination, where they disembarked, regardless of the existence of intermediate airports, served by a given flight. This dataset is utilized to analyze the evolution of the network from the standpoint of the supply of routes. The data is grouped quarterly and extends from the first quarter of 2017 to the last quarter of 2023. It includes data for the number of take-offs, passengers and seats available for each route and airline.

The second source of data is the *FlightsFrom* website. It encompasses data of flight information for all airports, including all the direct flights leaving the airport and travel time[7]. This becomes necessary as the Anac flight-level database has some limitations, as it does not include the entire itinerary of the passengers, including potential connections, and is restricted to flights that fly from Brazil only. With this data, we can build a larger and more connected network of flights, linking domestic origins to a diversity of final destinations through direct and indirect paths. In this database, we filter for the routes where the destination is either an origin or a destination in our OD pairs database, built with Anac's international airfare data, as said above. Therefore, our network accommodates 100 airports, of which 37 are domestic ones.

6 https://www.*flightsfrom*.com/

7 This data can be found at https://github.com/Jonty/airline-route-data.

Although the expansion of the flights' data allows for a better understanding of the network topology and of which paths consumers can take, our dataset still has some limitations that curb the possibilities of analysis. Our dataset lacks information on the flow of passengers on each route, preventing any estimation of node importance or the application of capacity restriction. This happens since Anac's database does not track data at the passenger-level, not accounting for connections. With that, it is not possible to observe which paths the passengers actually take and how they distribute themselves amongst them. Another constraint in our dataset is the lack of data for flight tickets' price, preventing an estimation of elasticities and restraining the possibility to investigate the restrictions to switch routes among consumer and the proper identification of alternative routes. Even though Anac's database has information on prices, the data has some methodological problems that prevent us from realizing a robust analysis. The price data informs the price paid and the number of tickets bought for each month and each route, but it has no information on when the passenger is travelling. This means that the passenger flow database and the price data are not on the same page, therefore it is not possible to know how much the passenger paid for a ticket to travel on a given flight. Given these obstacles, our research focuses on the identification of possible alternatives paths, considering the origins and destinations identified in the international airfare data from Anac, and which links are the most important within this network, as they become important intermediaries in the paths identified.

4 DEMAND SUBSTITUTABILITY

4.1 Methodology

In this section, we present the methodology implemented to assess route redundancy in the aviation network. To do that, an index is built, ranking the routes according to their importance in the O-D network. Based on the work of Jing, Xu, and Pu (2019) and Xu *et al.* (2018) two factors are considered in the construction of the index: efficient path and not-too-long path.

Dial (1971) defined an efficient path as one which does not backtrack. As it progresses from node to node it always gets further from the origin and closer to the destination. A path is efficient if every link in it has its initial node closer to the origin than is its final node and has its final node closer to the destination than is its initial node. All links should satisfy:

$$l_r(head_a) > l_r(tail_a), \forall a \epsilon A$$

where $tail_a$ and $head_a$ are the tail and head of the link **a**; $l_r(tail_a)$ and $l_r(head_a)$ are the cost of the shortest route from the origin r to the tail and head of link a, respectively; A is the set of directed links.

Typically, passengers do not prefer too long routes or are willing to accept a certain amount of extra time when their primary or secondary path alternatives are not available. With that in mind, following Leurent (1997), a length constraint is introduced to ascertain that every link is reasonable enough relative to the shortest path:

$$(1 + \tau^a)\big(l_r(head_a) l_r(tail_a)\big) \geq l_a, \forall a \epsilon A$$

Where l_a is the cost (length of free-flow travel time) of link r is an allowable/acceptable elongation ratio for link a with respect to the origin r. τ_a may be set to 1.6 for inter-urban studies or between 1.3 and 1.5 for urban studies (Tagliacozzo; Pirzio, 1973; Leurent, 1997). By summarizing all links on route k:

$$l_k = \sum_{a\epsilon A}^{X} l_a \leq \sum_{a\epsilon A}^{X}(1 + \tau^a)\big(l_r(head_a)l_r(tail_a)\big)$$
$$\leq \sum_{a\epsilon A}^{X}(1 + \tau_r^{max})\big(l_r(head_a) - l_r(tail_a)\big)$$
$$= \sum_{a\epsilon A}^{X}(1 + \tau_r^{max})\big(l_r(s) - l_r(r)\big)$$

Therefore:

$$l_k = \sum_{a\epsilon A}^{X}(1 + \tau_r^{max})\big(l_r(s) - l_r(r)\big) = (1 + \tau_r^{max}) \min_p l_p$$

where l_k (or l_p) is the cost of the route k (or p); l_r and l_s are the shortest costs from origin r to r and to destination s. This ensures that the cost of the route does not exceed (1 + τ^{max}) times the cost of the shortest path. In our study, the cost of the route is the travel time in minutes. However, in order to account for waiting time in connections, we add an extra 60 minutes for each domestic route and an extra 150 minutes for international routes. In addition, to reduce computational burden, only the 20 shortest paths are calculated for each origin-destination pair.

To build the redundancy index, the following is considered. For each O-D pair, the effective paths are calculated according to the method above. The paths are ordered by their length, and for each link in each effective path is attributed a value. So, for a link i in a O-D pair p and rank r, the links' redundancy index is:

$$RedundancyIndex_{p,r}^{i} = \frac{N_p}{rank_{p,r}}$$

where N_p is the number of passengers recorded in the O-D pair p and $rank_{p,r}$ is the rank of the path p in the path p. In that way, links in the shortest path receive higher values than links in the second shortest path and so forth. So, for each link i in the network, the Redundancy Index is measured as the sum of the redundancy index for all O-D pairs:

$$RedundancyIndex^{i} = \sum_{p\epsilon P}\sum_{r\epsilon R} RedundancyIndex_{p,r}^{i}$$

where P is the set of all O-D pairs and R is the set of the ordered effective paths for each O-D pair.

4.2 Results

To analyze the results, verify which links are more important and identify path alternatives, we run two analyses. In the first one, we estimate the redundancy index for each edge in the network and the number of effective paths for each O-D pair. This way it is possible to identify key routes in the network, considering it is a lane for many pathways and the number of passengers that it probably transports. It is important to point out that the redundancy index value has no direct interpretation, as it is considered only the volume of passengers between the origin and destination of which the edge is part, not the actual volume of travelers on the route. This index also allows for the identification of destinations that are access constrained than others, as they present a lower number of effective paths connecting them. Recognizing points with limited access is also interesting, because any negative impacts in the routes leading to those may result in significant backlashes in passengers' welfare.

Meanwhile, in the second setup, the international routes (the ones where its origin is in Brazil) are removed, one by one, from the network and then the number of alternative paths and travel time are re-estimated for each origin-destination pair. The goal with this is to understand which routes play a crucial role in connecting final destinations or, at least, conducting passengers to out of the country, but also to see the routes that become more important and, therefore, can be seen as alternatives to the removed route. Finding substitute routes can help antitrust analysis when it comes to establishing the geographically relevant market.

In both experiments, the value of τ^{α} is set at 0.3, i.e. passengers are willing to elongate their travel time in 30% compared to the shortest path connecting the origin to the destination. This value is lower than the one observed in urban studies (Leurent, 1997). Although some may think that the willingness to extend the travel could be higher for air transportation, we opt for a more conservative approach. Adding the waiting time for connections supports the use of a lower value for the parameter. Also, since we have no data on flights' frequency outside of Brazil, our estimation of connection time is probably underestimated, making it reasonable to use a smaller value of the parameter. The chosen value would also not extrapolate the travel time extension for indirect flights adopted either by the European Commission[8] or Cade[9], therefore making it a reasonable value.

4.2.1 Link's importance and effective paths

Table 1 presents the 10 routes with the highest redundancy index. As can be seen, out of the six first values, five belong to routes leading either to Santiago or to Buenos Aires. This outcome is intuitive since Santiago and Buenos Aires are the main destinations of Brazilian passengers. It is interesting to point out the values obtained for the routes Curitiba (CWB) to Santiago (SCL) and Foz do Iguaçu (IGU) to Santiago (SCL). Even though these pathways don't transport a high volume of passengers, their redundancy index value is prominent, due to the fact that these routes are viable short paths to connect travelers to Santiago. This example may be interpreted from two opposite points of view. First, it could mean that these routes, although not highly traveled, are important to

8 See Case No COMP/M.3280—Air France/KLM, 11.02.2004.

9 See Opinion No. 6/2024/CGAA4/SGA1/SG. Process No. 08700.004702/2023-81 (SEI 1377008), Applicants: International Consolidated Airlines Group and Air Europa Holding, S.L. Brasília: CADE, 2024.

the network, and a traditional approach would miss that. On the other hand, this could be due to the lack of data on passenger flow for each route, which downplays the significance of the airports and exposes one of the limitations of the current study.

Table 1 – Link Importance - Most Important Links

Origin Airport	Origin City	Origin Country	Destination Airport	Destination City	Destination Country	Redundancy Index	Number of Seats Available
GRU	São Paulo	Brazil	SCL	Santiago	Chile	300580.6	1019358
CWB	Curitiba	Brazil	SCL	Santiago	Chile	222818.3	31536
GRU	São Paulo	Brazil	MIA	Miami	USA	192325.8	860656
IGU	Foz do Iguaçu	Brazil	SCL	Santiago	Chile	174838.6	36051
GRU	São Paulo	Brazil	EZE	Buenos Aires	Argentina	158022.7	882914
GRU	São Paulo	Brazil	AEP	Buenos Aires	Argentina	150009.2	1053591
NAT	Natal	Brazil	LIS	Lisbon	Portugal	148660.9	93867
CNF	Confins	Brazil	LIS	Lisbon	Portugal	144665.9	180208
GRU	São Paulo	Brazil	LIS	Lisbon	Portugal	144543.4	734379
VCP	Campinas	Brazil	LIS	Lisbon	Portugal	141940.7	369314

Source: Own Elaboration (2025).

The redundancy index, along with the approximated network built in this study, enables us to speculate which international routes might play an important role in conducting Brazilian passengers abroad. Table 2 consolidates the results for the top 10 international routes, according to their redundancy index.

Table 2 – Link Importance - Most Important Links

Origin Airport	Origin City	Origin Country	Destination Airport	Destination City	Destination Country	Redundancy Index
LIS	Lisbon	Portugal	LHR	London	United Kingdom	30219.27
LIS	Lisbon	Portugal	MXP	Milan	Italy	222818.3
MAD	Madrid	Spain	LHR	London	United Kingdom	21712.71
ZRH	Zurich	Switzerland	MXP	Milan	Italy	21,572.81
LIS	Lisbon	Portugal	ORY	Paris	France	20086.97
SDQ	Santo Domingo	Dominican Republic	JFK	New York	USA	18073.51
MAD	Madrid	Spain	MXP	Milan	Italy	17586.95

CDG	Paris	France	MXP	Milan	Italy	16310.04
ZRH	Zurich	Switzerland	FRA	Frankfurt	Germany	12255.34
BCN	Barcelona	Spain	MXP	Milan	Italy	11026.16

Source: Own Elaboration (2025).

The main finding is the dominance of European routes. The reason for that is twofold. In the first place, destinations in Europe represent 20% of all unique destinations and 34% of all O-D pairs. The second reason is related to distance. Out of the fifteen furthest destinations, on average, only five[10] are not located in Europe. Besides that, the fact that European countries are relatively close to each other makes connections between them more suitable. Additionally, it is fundamental to point out Lisbon's role as a bridge to the rest of Europe. The Portuguese capital has eleven[11] different direct flights from Brazil, offering great access to Europe.

4.2.2 Edge removal

In this section, the goal is to understand how the removal of some routes affects the network, identify which other routes are impacted and which edges become more important in the absence of the removed one. Considering the objective of the current study, we solely remove international routes whose origin is in Brazil. Those come from the flight-level data from Anac, introduced in the *Data* section. We selected the flights from 2022 and 2023 that had more than 50 departures in both years combined. Removing routes that are no longer operational, we have 109 active routes. The idea here is the following: every edge is removed one by one, and, after the removal, the redundancy index is re-estimated for all remaining edges in the network. Given this setup, we can calculate for which edges the redundancy index increased and, consequently, its importance, and estimate an average increase in travel time in all paths that contained the disconnected edges.

Table 3 presents the 10 routes which removal result in the highest traveling time increment. The flight between Belém and Pamaribo leads the way, with a 260% rise in travel time due to its withdrawing. Although the route is not a relatively significant one in terms of volume[12], the exercise shows how its removal has a high impact in the network. We can also see that the flight Panama (PTY) to Pamaribo (PBM) ends being the one which importance increases the most. It also interesting to point out how the extraction of the route São Paulo (GRU) - Johannesburg (JNB) impacts a whole path, augmenting the role of the São Paulo (GRU) - Luanda (LAD) - Johannesburg (JNB) pathway. In some cases, the route that sees its role expand might be a domestic one, given that demand may be redirected to other airport within the domestic network. One example of that is the route Porto Alegre (POA) to Santiago (SCL), where the Porto Alegre (POA) to Curitiba (CWB) ends up being the one with the highest increase in importance.

10 These are Dubai, Doha, Istanbul, Addis Ababa and Los Angeles.

11 Belém, Brasília, Belo Horizonte, Fortaleza, Rio de Janeiro, São Paulo, Natal, Porto Alegre, Recife, Salvador and Campinas.

12 Its 91th out of 172 in terms of seats in 2023.

Table 3 – Routes with the highest increase in travel time due to removal

Origin Airport	Origin City	Destination Airport	Destination City	Time Increase (%)	Benefited Route	Benefited Route Origin	Benefited Route Destination
BEL	Belém	PBM	Pamaribo	260%	PTY → *PBM*	Panama	Pamaribo
GRU	São Paulo	LAD	Luanda	60%	GRU → *JNB*	São Paulo	Johannesburg
GRU	São Paulo	PDP	Pamaribo	56.2%	AEP → *PDP*	Buenos Aires	Punta del Este
MAO	Manaus	PTY	Panama	52.7%	CNF → *PTY*	Belo Horizonte	Panama
GRU	São Paulo	JNB	Johannesburg	48.6%	GRU → *LAD*	São Paulo	Luanda
GRU	São Paulo	JNB	Johannesburg	48.6%	LAD → *JNB*	Luanda	Johannesburg
IGU	Foz do Iguaçu	SCL	Santiago	48.3%	FLN → *SCL*	Florianópolis	Santiago
POA	Porto Alegre	SCL	Santiago	43.3%	POA → *CWB*	Porto Alegre	Curitiba
GRU	São Paulo	VVI	Santa Cruz	40.8%	ASU → *VVI*	Asuncion	Santa Cruz
FLN	Florianópolis	AEP	Buenos Aires	39.65%	CWB → *AEP*	Curitiba	Buenos Aires

Source: Own Elaboration (2025).

When the analysis shifts to routes which removal exercises the lower impact in terms of extension of travel time, a few patterns stand out. Table 4 sums up the results. Excluding the route Brasília (BSB) to Lisbon (LIS), all the remaining ones its origin is in the Southeast region of Brazil. This is due to this region being the one with the more central airports (Couto *et al.*, 2015) and, since these places are somewhat close, alternatives to the removed routes are not time costly. Another point is that São Paulo (GRU) and Rio de Janeiro (GIG) are, most of the time, the closest alternative to each other. The proximity[13] and the fact that these are the largest international airports in the country supports this fact.

13 Its, on average, an one hour flight.

Table 4 – Routes with the lowest increase in travel time due to removal

Origin Airport	Origin City	Destination Airport	Destination City	Time Increase (%)	Benefited Route	Benefited Route Origin	Benefited Route Destination
GIG	Rio de Janeiro	FCO	Rome	4.6%	GRU → *FCO*	São Paulo	Rome
GRU	São Paulo	LHR	London	4.6%	GRU → *LHR*	São Paulo	London
GRU	São Paulo	FRA	Frankfurt	4.6%	GIG → *FRA*	Rio de Janeiro	Frankfurt
VCP	Campinas	MCO	Orlando	4.9%	BSB → *MCO*	Brasília	Orlando
GRU	São Paulo	JFK	New York	5.3%	GIG → *JFK*	Rio de Janeiro	New York
VCP	Campinas	LIS	Lisbon	5.3%	CNF → *LIS*	Belo Horizonte	Lisbon
GIG	Rio de Janeiro	FRA	Frankfurt	5.5%	GRU → *FRA*	São Paulo	Frankfurt
CNF	Belo Horizonte	FLL	Fort Laudardale	5.8%	MAO → *FLL*	Manaus	Fort Lauderdale
BSB	Brasília	LIS	Lisbon	5.9%	NAT → *LIS*	Natal	Lisbon
GRU	São Paulo	CDG	Paris	6%	SSA → *CDG*	Salvador	Paris

Source: Own Elaboration (2025).

Table 5 presents the increase in travel time and the benefited route from the exclusion of the 10 routes with the higher volume of passengers in 2023, considering flight-level data from Anac. This table shows how the methodology here implemented can help in the identification of relevant airports in the network. Although Curitiba (CWB) is not a very important airport[14] it is a significant alternative to passengers traveling to destinations in South America, such as Buenos Aires (EZE, AEP) and Santiago (SCL).

Table 5 – Routes with the highest volume of passengers in 2023

Origin Airport	Origin City	Destination Airport	Destination City	Time Increase (%)	Benefited Route	Benefited Route Origin	Benefited Route Destination
GRU	São Paulo	SCL	Santiago	10.6%	GRU → *CWB*	São Paulo	Curitiba
GRU	São Paulo	AEP	Buenos Aires	16.2%	GRU → *CWB*	São Paulo	Curitiba
GRU	São Paulo	MIA	Miami	7.3%	BSB → *MIA*	Brasília	Miami

14 It was the 13th in terms of volume of passengers in 2023

https://doi.org/10.52896/rdc.v13i1.1932

GRU	São Paulo	EZE	Buenos Aires	26.2%	CWB → *EZE*	Curitiba	Buenos Aires
GRU	São Paulo	LIS	Lisbon	12.8%	GRU → *CNF*	São Paulo	CNF
GIG	Rio de Janeiro	EZE	Buenos Aires	26.8%	FLN → *EZE*	Florianópolis	Buenos Aires
GRU	São Paulo	MAD	Madrid	6.1%	SSA → *MAD*	Salvador	Madrid
GRU	São Paulo	CDG	Paris	6%	SSA → *CDG*	Salvador	Paris
GIG	Rio de Janeiro	SCL	Santiago	21.1%	CWB → *SCL*	Curitiba	Santiago
GRU	São Paulo	PTY	Panama	17.4%	BSB → *PTY*	Brasília	Panama

Source: Own Elaboration (2025).

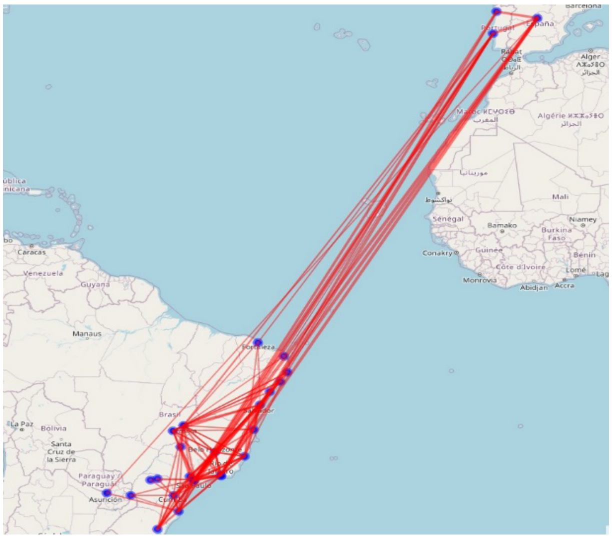
4.3 Practical example

To show the full extension of the methodology presented in Section (4.1), we consider an example based on the failed proposed merger between International Consolidated Airlines Group (IAG) and Air Europa Holding, S.L. (Air Europa)[15]. According to the European Commission and Cade, the transaction could reduce competition on long-haul routes between Madrid and South America, on which both parties offer a direct connection and face competition from only a few other competitors with a nonstop connection. In its analysis, SG/CADE defined the relevant geographical market as the routes: São Paulo/Guarulhos - Madrid/Barajas (GRU-MAD); São Paulo/Guarulhos – Barcelona/El Prat (GRU-BCN); São Paulo/Guarulhos – Londres (GRU-LON); Rio de Janeiro/Galeão – Madrid/Barajas (GIG-MAD); Rio de Janeiro/Galeão – Londres (GIG-LON); Salvador – Madrid/Barajas (SSA-MAD). The routes through London were considered indirect. SG/CADE outlined competitive concerns on the GRU-MAD route. The criteria for the consideration of indirect routes were routes whose travel time would add up to 5 hours. Our methodology differs from this as it considers a time increase compared to the shortest path, not a fixed time increase.

Looking at the flow of passengers between Brazil and Madrid, Figure 1 presents the whole network connecting Brazil to Madrid. For this calculation, only the origin-destination pairs whose final destination was Madrid were used.

15 Case M.11109 in the European Commission and Process No. 08700.004702/2023-81 in Cade.

Figure 1 – Brazil - Madrid network



Source: Own Elaboration (2025).

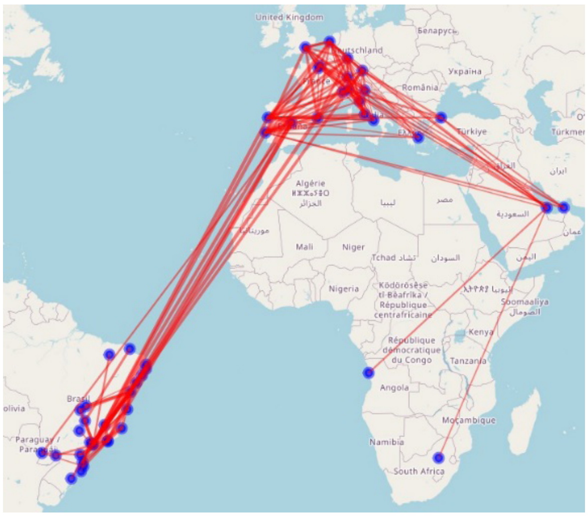
The reason why Salvador is the one with the highest value is its distance from Madrid. While São Paulo and Rio de Janeiro are 8355 and 8124 kilometers away from the Spanish capital, 6915 kilometers separate Salvador from Madrid, resulting in a reduction of travel time of about 100 minutes. Another reason is that Salvador is relatively close to other cities in Brazil, making the city a feasible connection. Although an interesting result, this also highlights a limitation of our methodology, since distance (travel time) is the only factor taken into account.

Additionally, we only observe Portugal (especially Lisbon) as a connection to Madrid within Europe, not also London, as indicated by Cade. First, this could be due to a low selected value for . A higher value could make other cities in Europe, such as London, Paris, and Frankfurt, viable options but at the same time could increase the number of domestic connections, which might not be reasonable. Although Lisbon might present itself as an alternative, the limitation of our study does not allow for any extrapolation of the results. A major factor that is not considered in our analysis is the capacity of the airports, which could curb any deviation in demand.

Expanding the analysis, we can observe the impact of the route when we consider the full network, not only the one leading to Madrid. For that, we simulate the removal of the GRU-MAD route and then recalculate the redundancy index.

https://doi.org/10.52896/rdc.v13i1.1932

Figure 2 – GRU-MAD impact network



Source: Own Elaboration (2025).

As can be seen from Figure 2, the removal of the GRU-MAD route has a worldwide impact. 157 routes available in our dataset suffer an increase in their redundancy index. At the same time, 39 routes are negatively affected, most of which Madrid is the origin. This simple exercise exemplifies how the adoption of a network approach can enhance the analysis in the aviation sector and how a traditional analysis might not paint the full picture as it misses the direct and indirect network effects. Taking the example above, an increase in concentration on the selected route could have a negative impact on many other routes and, consequently, passengers. Domestic routes, which play an important role in feeding international routes, could see higher prices due to the deviation in demand from passengers. This simple example shows how a traditional analysis might miss some of the ripple effects of a change in conditions in a route. Companies which operate on important routes may have a higher dominant position than what is captured by their market share, in such a way that an O&D approach would underestimate the merger effects. On the other hand, if the company operates on a limited network, its position might be reduced, even though it has a high market share in a route. This goes for the analysis of a merger's efficiencies as well. Increasing returns due to network effects (Arthur, 1994) could justify an operation, as the airline may become better positioned to optimize its network.

Once more, it is important to stress the limitations of the results. The goal here is to implement network theory as an alternative to discussions involving the aviation industry. The absence of prices in our analysis curtails any stricter interpretation of alternative routes or paths as actual substitutes. It can only show paths the passenger would be willing to take, say the price was the same for all routes. Therefore, with detailed price data for each route, the analysis could be expanded to account for a more realistic passenger behavior and to understand substitution not only as a factor of the time of travel, but as the price as well. In this case, the metric would cover not only the amount of time that passengers would be willing to elongate their travel time, but also how much they would be willing to spend on a longer flight.

5 SUPPLY SUBSTITUTABILITY

In the antitrust context, the ability of dominant players to exercise market power on routes under their control should not be analyzed solely from the demand perspective. This is because, even if consumers consider alternative routes unfeasible — leading to significant and non-transitory increases in air ticket prices on the route under review — there would still be the possibility, from the supply side, that competing airlines might start operating on the route in question due to the increased profitability initially generated by this fare increase. Thus, this section aims to analyze the substitutability of the supply of airline seats in the post-pandemic context from two distinct yet complementary perspectives: one qualitative and the other quantitative.

In the qualitative analysis, evidence is presented regarding the challenges airlines face in increasing capacity in the post-pandemic scenario, highlighting the implications for the sector's competitive dynamics. As discussed in the next subsection, the contraction in demand for new aircraft during the pandemic crisis - due both to uncertainties about sector recovery and to the substantial increase in airlines' leverage - combined with the difficulties faced by major global wide-body aircraft manufacturers (Boeing and Airbus) in meeting backlogged orders, has brought this issue to the forefront of antitrust authorities' attention.

The quantitative analysis employs empirical exercises based on a route network construction methodology to illustrate recent patterns of network expansion in the post-pandemic period and assess their potential impact on the competitive dynamics of the sector.

5.1 Qualitative analysis

From a supply perspective, antitrust authorities and academics in their analysis of merger cases and or competition analysis involving commercial airline sector have historically focused their analysis on airport infrastructure availability and regulatory mechanisms for slot allocation at coordinated airports – the approach taken in Bilotkach and Lakew's work (2014) – without adequately considering whether new entry would be economically feasible given traffic flows and hub economics (Nannes, 1999).

However, the fact that the European Commission's ex-post assessment concluded that the divestiture of slots alone has not been sufficient to remedy competitive harm (Richen, 2024; Ibitoye, 2023) has shed light on the need for additional antitrust remedies that take into account network effects and, implicitly, the availability of the assets necessary to ensure the timely and effective entry of a new competitor on the routes under antitrust scrutiny. According to Chen (2024, p. 331), "[...] if there is not enough perfect transfer network and passenger flow, even if some slots are released, other airlines will not take over, but in a short time, the choice of passengers will be reduced, and the fare will not be lower." Following this new guidance, in the case of the merger between Lufthansa and ITA, approved by the European Commission on July 3, 2024, the Commission imposed as one of the conditions for the approval of the transaction that the parties must make available to one or two rival airlines the necessary assets to enable them to start non-stop flights between Rome and Milan and certain airports in Central Europe (European Commission, 2024). Similarly, in the merger between Korean Air and Asiana Airlines concluded in 2024, the European Commission imposed remedies extending beyond traditional slot divestitures. These included the sale of Asiana's cargo division to Air Incheon and the transfer of five Airbus A330 aircraft along with approximately 100 pilots to T'way Air, a South Korean low-cost carrier. This support enabled T'way to commence direct flights between Seoul and key European cities such as Paris, Rome, Frankfurt, and Barcelona, thereby preserving competition on these routes (Min-Hyung, 2023).

In Brazil, the most recent and emblematic case analyzed by antitrust authority Cade was Gol-Webjet merger case[16], in which has been imposed for the applicants a performance commitment agreement (TCD) for a four-year period establishing a requirement to maintain 85% efficiency in the use of slots at Santos Dumont Airport in Rio de Janeiro (SDU). This aimed to prevent slot idleness granted to the company by Anac[17].

However, the current post-pandemic period indicates that there is no shortage of slots at Western airports, and according to (Transforming [...], 2023), this overall situation is not expected to change until 2030. Therefore, it can be stated that the scarcity of airport infrastructure does not currently represent a significant obstacle to competition, which means that the mandatory allocation of slots would most likely be an ineffective antitrust remedy to promote competition

The recovery of the international aviation sector starting in 2023 has led airlines to face substantial challenges in expanding their routes (as networks links) or increasing flight frequencies (corresponding to an increase in the intensity of existing routes) due to a limited supply of new aircraft. This supply crisis is mainly due to a combination of two factors: (i) a decrease in demand for new aircraft during the pandemic crisis, driven by uncertainties about the sector's recovery and a substantial increase in airlines' leverage; and (ii) difficulties faced by major global wide-body aircraft manufacturers (Boeing and Airbus) in meeting backlogged orders.

Regarding factor (ii), it is worth highlighting the specific challenges faced by each aircraft manufacturer. In the case of Boeing, the American company has been experiencing an internal crisis since 2018, both reputational and operational, caused by the accidents involving the Boeing 737 Max, which have impacted its production and delivery rates even before the pandemic. The crisis resurfaced in early 2024 when an emergency door on a Boeing 737 Max 9 jet detached during takeoff on a flight operated by Alaska Airlines (Relatório [...], 2024). Following the incident, the Federal Aviation Administration (FAA), the U.S. aviation regulatory agency, opened an investigation into the case and set a monthly production limit of 38 new aircraft for the model, below the delivery rate of 45 units reached before the latest incident (in November 2023) and the target of 57 aircraft set by Boeing for July 2025 (Crumley, 2024). Given this situation, the average delivery time for Boeing aircraft reached 16.9 years in the first quarter of 2024, almost double the average time of seven years observed in 2018.

The crisis at the American manufacturer, combined with the post-pandemic recovery of the aviation sector, has benefited competitor Airbus. However, the manufacturer is encountering difficulties in meeting aircraft delivery targets and reducing the average order lead time. In the first quarter of 2024, the company had an order backlog of 8,626 aircraft, with annualized deliveries of

16 Process No. 08012.008378/2011-95.

17 Similarly, in the LATAM-IAG Merger Case (Process No. 08700.004211/2016-10), Cade held that various remedies should be imposed on the applicants to ensure competition on relevant international routes and pass any operational efficiencies on to passengers. As a structural remedy, the ACC (Merger Control Agreement) required applicants to make slots available, free of charge, to a potential market entrant at a London airport of the entrant's choice for a period of 10 years, for use in daily nonstop f lights departing from Guarulhos Airport in São Paulo.

568 during the period, resulting in an estimated average delivery time of 15.2 years (Faury; Toepfer, 2024), compared to an average of 8.7 years observed in 2018. Since the delivery pace was weaker at the beginning of 2024, if the target of delivering 800 aircraft is met this year (and without considering the addition of new orders), the indicator would drop from 11.7 recorded in 2023 to 10.8 in 2024, still above the level observed before Boeing's crisis.

Given the scenario presented, the main concern from an antitrust perspective is that new competitors' entry into air routes could be hampered by the scarcity of new aircraft, not only due to the backlog and delays in deliveries by major manufacturers but also due to the increased bargaining power of leasing companies, which tend to raise leasing contract costs. This has asymmetric impacts on potential new entrants, which typically have a smaller scale of operations.

Evidence suggests that aircraft delivery delays have already compromised the expansion of the aviation sector. At the end of October 2024, Lufthansa announced the suspension of its São Paulo-Munich route, which was set to start in December 2024, due to a lack of aircraft (Pólo Júnior, 2024)[18].

Far from being isolated cases, capacity saturation can be observed through the seat occupancy rate of flights operated in the Brazilian market. According to Anac's 2023 Annual Report, annual load factor (RPK/ASK) reached 85.4% last year, the highest level at least since 2005. According to a BNDES study (Gomes; Fonseca, 2014, p. 135), a rate above 85% indicates that '[...] as this indicator is an average, the company will already be leaving people on the ground or losing passengers to the competition (saturation point, spill)'.

This is thus a case of 'expansion under scarcity', which should serve as a warning to antitrust authorities regarding the timeliness of increasing seat supply on evaluated routes, even by incumbents themselves. Although this indicator above 80% was observed in several years in the last decade, the long waiting list for aircraft delivery from major global manufacturers should be considered, indicating that this saturation cannot be resolved in the short term.

5.2 Quantitative analysis

At first glance, one might say that airlines have full flexibility in managing their respective fleets, since, unlike most capital goods, aircraft can be moved to different airports in a matter of hours to achieve higher returns on more profitable routes. However, this theoretical possibility does not take into account various operational, regulatory, and strategic constraints that significantly reduce this flexibility in practice.

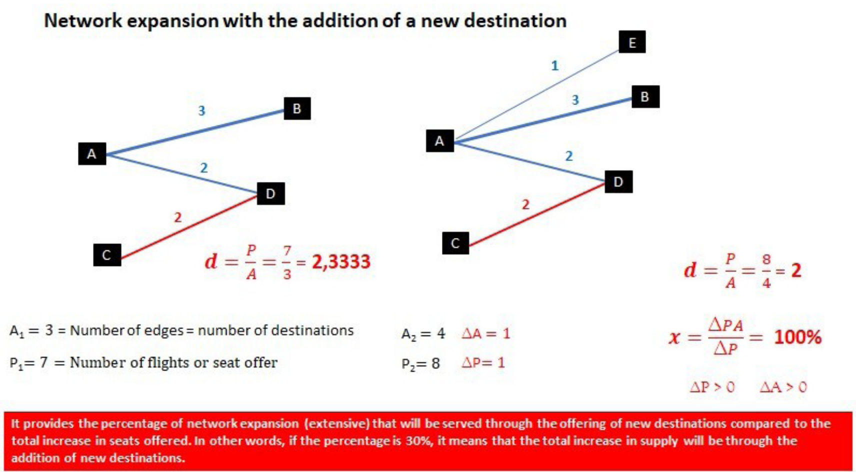
Given the practical difficulty of obtaining profitability levels per route for each airline - and thus identifying the effects on aircraft reallocation - the issue was reformulated from a network perspective, aiming to understand the extent to which airlines reallocate their flights intensively (through the reallocation of the existing fleet) and extensively (through the addition of new aircraft), regardless of the underlying motivations. The initial hypothesis of this study is that, for various reasons, airlines do not tend to substantially change their fleet in response to short-term changes; therefore, new destinations would largely be added through the introduction of new aircraft.

18 American Airlines, in turn, announced at the end of June this year that it decided to pause hiring new pilots until the end of 2024 due to delayed aircraft deliveries by Boeing (American [...], 2024). Similar announcements had been made months earlier by Delta Air Lines and United Airlines (Schlangenstein; Beene, 2024).

From a conceptual standpoint, in this case, the network is formed by the connection (routes) between origin and destination airports (network nodes), with edges represented by A and the weight P, which reflects the strength or importance of the connection between network nodes, represented by the number of flights or the quantity of seats offered. Based on these measures, it is possible to derive network evolution indicators.

The first indicator pertains to the variation in the number of edges (ΔA), which consists of the absolute expansion of the network in an extensive manner. The variation in the number of edges weighted by seat offer gives (ΔPA). The weight variation (ΔP) represents the change in the total weight of the network's edges. Based on these metrics, it is possible to construct indicators to verify the network's evolution pattern. Figure 1 shows a hypothetical case of extensive network expansion, with the addition of destination E with weight 1.

Figure 3 – Network expansion with an inclusion of new destination



Source: Own Elaboration (2025).

As can be seen, the addition of the new destination to the network results in $\Delta A = \Delta PA = 1$ and $\Delta P = 1$. With this, the extensive network expansion indicator (x) can be obtained, calculated by the following algebraic expression:

$$x = \frac{\sum_{i=1}^{z} A_i^N(t+1)P_i^N(t+1) \; - \sum_{j=1}^{g} A_j^S(t+1)P_j^S(t+1)}{\sum_{k=1}^{n} P_k(t+1) \; - \; \sum_{k=1}^{n} P_k(t)}$$

$$x = \frac{\sum_{i=1}^{z} P_i^N(t+1) \; - \sum_{j=1}^{g} P_j^S(t+1)}{\sum_{k=1}^{n} P_k(t+1) \; - \; \sum_{k=1}^{n} P_k(t)} = \frac{PA}{\Delta P}$$

On the condition that the denominator is not equal to zero:

$$\sum_{k=1}^{n} P_k(t+1) \; - \; \sum_{k=1}^{n} P_k(t) \; = \; \Delta P \; \neq 0$$

where A_i^N is the i-th added edge; A_j^S is the j-th removed edge; P_i^N represents the i-th weight of the added edge i; P_j^S represents the j-th weight of the removed edge j; P_k represents the weight of the edge k; PA represents the contribution of the weights of the new edges (net) to the network flow; z is the number of edges added to the network in period t + 1; g is the number of edges removed from the network in period t + 1; n is the total number of edges (or weights) in the network and t is the initial or reference period.

In this way, it is possible to determine the extent of a network expansion in a selected period through the allocation of flows (weights) between the new edges (in net terms) and the pre-existing ones.

It should be noted, therefore, that the weights of the new edges are considered to explain extensive expansion, not just the absolute variation of the edges. This means that the emergence of a new route, which from the beginning has a higher frequency of flights during the evaluation period (t), is classified by indicator x as extensive growth. Any subsequent intensification of the new route's usage in a following period (t + 1), thus, is considered intensive expansion. This differentiation is justified because, in most cases, there is a minimum efficient scale for operating a given route, depending on the commercial strategy and passenger demand profile. For example, on a route with a predominantly business-travel profile, it is assumed that there is a higher preference for airlines with a higher flight frequency, since in the event of a flight cancellation, there are greater chances of reallocating passengers to another flight with the least possible delay. Another scenario occurs with an airline offering a particular destination as a connection from a longer route, with the decision on the number of flights to be offered being conditioned to the latter.

In practical terms, the indicator x for the hypothetical case in Figure 3 is calculated as follows:

$$x = \frac{1 \cdot 1 - 0}{1} = 1$$

This means that the entirety of the new flow (route or seat availability) has been allocated to the new edge (in net terms). If the new route were to emerge with a weight of 2, the same value for the indicator x would be obtained:

$$x = \frac{1 \cdot 2 - 0}{2} = 1$$

Additionally, another way to assess the network's evolution pattern is related to the network density variation indicator (d), obtained through the following algebraic expression:

$$\Delta d = \frac{\sum_{k=1}^{n} P_k(t+1)}{\sum_{k=1}^{n} A_k(t+1)} - \frac{\sum_{k=1}^{n} P_k(t)}{\sum_{k=1}^{n} A_k(t)} = \frac{\sum_{k=1}^{n} P_k(t+1)}{\sum_{k=1}^{n} A_k(t+1)}$$

Taking the example listed in Figure 1, we obtain that:

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$$\Delta d = \frac{8}{4} - \frac{7}{3} = 2 - 2{,}333 = -0{,}333$$

Based on the Anac database, it was possible to perform the calculations of the presented metrics. To reduce the chances of $\Delta P = 0$, which would make the relative extensive network expansion indicator (x) unsolvable, the seat offer of the routes was considered as the weight variable for the network edge, rather than the flight frequency on each route.

Regarding the time frame, due to the limitation of information on fleet size and type, as well as the use of aircraft during the COVID-19 pandemic period for the restoration of supply, the analysis considered the 2022-23 biennium and the isolated year of 2023 for this purpose.

Based on the Figure 4, changes in the evolution of the air traffic network during the period from 2017 to 2023 can be observed. In the second quarter of 2020, the first period under the full impact of the crisis in the aviation sector caused by the COVID-19 pandemic, it is observed that all metrics were negative (and significantly, based on absolute values), indicating a contraction in both the number of destinations and/or origins (ΔA) and the additional seat offer (PA), as well as the total seat offer (ΔP), which constitute the weights of each network edge. In this case, there was a decrease in network density, given the disproportionate reduction in the total seat offer relative to the number of edges. Similarly, during the recovery periods (2020-Q2 and Q3; and 2021-Q4 to 2022-Q1), all metrics displayed positive values, reflecting both extensive expansions, marked by the addition of new edges to the network, and intensive expansion, characterized by an increase in network density.

Figure 4 – Results of the variation in selected international flight network metrics – quarterly variation compared to the immediately preceding period (2017 to 2023)

		Δd	ΔA	ΔP	ΔPA
2017	T2	✓	●	●	●
	T3	✓	✓	✓	✓
	T4	●	✓	✓	●
2018	T1	●	✓	✓	✓
	T2	●	●	●	●
	T3	✓	✓	✓	✓
	T4	●	✓	●	✓
2019	T1	✓	✓	✓	✓
	T2	●	●	●	●
	T3	✓	●	✓	✓
	T4	●	✓	●	●
2020	T1	●	✓	●	✓
	T2	●	●	●	●
	T3	✓	✓	✓	✓
	T4	✓	✓	✓	✓
2021	T1	●	✓	✓	●
	T2	●	●	●	●
	T3	✓	●	✓	✓
	T4	✓	✓	✓	✓
2022	T1	✓	✓	✓	✓
	T2	●	✓	✓	●
	T3	✓	✓	✓	✓
	T4	●	✓	✓	✓
2023	T1	✓	✓	✓	✓
	T2	●	●	●	●
	T3	✓	✓	✓	✓
	T4	●	✓	✓	✓

Source: Own Elaboration (2025).

Note: Green circle with a check mark inside: non-negative values; red circle = negative values.

Figure 5 shows the accumulated quarterly variations for the selected periods of the different network metrics. The objective of this empirical exercise is to compare the period immediately following the pandemic crisis with the most recent recovery phase of the air sector (after the most pronounced recovery phase of air traffic). For this purpose, the following longer periods (highlighted in bold) were selected: (i) before the pandemic crisis: from the second quarter of 2017 to the first quarter of 2020; and (ii) the recent recovery phase: from the first quarter of 2022 to the fourth quarter of 2023.

Figure 5 – Results of the variation in international flight network metrics for selected periods - Anac data

Start Date	Final Date	Δd	ΔA	ΔP	ΔPA	x
2017-Q2	**2020-Q1**	**-12,3%**	**34**	**207.398**	**-192.699**	*
2018-Q3	2019-Q1	6,5%	14	536.680	68.335	13%
2019-Q3	2020-Q1	-12,7%	28	67.407	28.699	43%
2022-Q1	**2024-Q4**	**34,3%**	**57**	**2.045.592**	**168.790**	**8,3%**
2023-Q1	2023-Q4	3,3%	20	588.559	69.608	11,8%

Source: Own Elaboration (2025).

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Regarding period (i), an initially counterintuitive result is observed, as there is a simultaneous increase in the number of net edges (ΔA = 34) and a reduction in the contribution (in terms of seat offer) of these same edges. The explanation for this is that, even though two new edges with weight 1 are added, the fact that one edge with weight 4 is simultaneously removed is enough to make PA negative (-2), even though ΔA is positive (+1).

Due to the negative result in period (i), and in order to compare the previous growth profile of air traffic with the more recent period, the same metrics were calculated for periods (i.1) Q3 2018 to Q1 2019 and (i.2) Q3 2019 to Q1 2020, which present a more consistent growth scenario (before the pandemic) for analytical purposes. The results show different intensities of contribution from the new net edges to network expansion, with period (i.1) showing an extensive network expansion indicator (x) of 13%, while in period (i.2) the weighted contribution of new net edges was 43%. However, it should be noted that in absolute terms (PA), the contribution of the new net edges was significantly higher in period (i.1) compared to period (i.2), which may indicate a percentage closer to typical scenarios of air sector expansion or a specific growth pattern during the analyzed period.

In the 2022-23 biennium, it was found that the indicator x reached 8.3%, a percentage lower than that of periods (i.1) and (i.2) before the pandemic. However, when calculating the same metrics only for 2023, it was found that the indicator x for that period was 11.8%, which is very close to the value observed for the periods before the pandemic. Thus, it is understood that, based on the data available up to 2023, it can be concluded that no significant shift in the growth pattern of the network in the international air sector, concerning flights departing from or arriving in Brazilian territory, can be identified considering the current scenario.

To deepen the understanding of the dynamics of the international flight network, dispersion measures were calculated for the network metrics ΔP and ΔPA to identify possible breaks in the pattern in the post-pandemic period, as shown in Figure 6.

Figure 6 – Results of the dispersion measures for the network metrics ΔP and x for the selected periods - Anac data

		(1)		(2)		(1)/(2)	
Start Date	Final Date	Standard deviation		Mean		CV*	
		ΔP	PA	ΔP	PA	ΔP	PA
2017-Q2	2020-Q1	303.741	82.380	17.283	-16.058	17,6	-5,1
2022-Q1	2023-Q4	235.896	33.254	255.699	21.099	0,9	1,6
2023-Q1	2023-Q4	226.143	34.643	147.140	17.402	1,5	2,0

Source: Own Elaboration (2025).

As observed, there is a notable change in the dispersion measures during the post-pandemic period. The coefficient of variation (CV) of ΔP decreased to 0.9 in the 2022-23 biennium, compared to 17.6 in the 2017-Q2 to 2020-Q1 period. Furthermore, with the reduction of the CV, this indicator, which was previously much higher than that of PA (5.1 in absolute terms) in the initial period, is now lower than the CV of 1.6 for PA in the post-pandemic period. To explain these results, several hypotheses can be outlined, such as asymmetric shock effects (oil prices, geopolitical factors, etc.) affecting the dynamics of the sector's operations. However, one plausible explanation is a lower risk appetite among airline companies - many of which are financially more fragile - for taking on the risk of increasing seat capacity during the recovery phase of the sector. Another factor is that the unavailability of aircraft might be discouraging airlines from entering new routes (even though the subsequent result could be an exit later), which explains the reduction of the CV of PA as well as ΔP. From an antitrust analysis perspective, the main contribution of this article is to highlight that there may have been structural changes in the post-pandemic scenario that could negatively affect the competitive dynamics of the sector, which would require more detailed and in-depth analyses within the scope of concentration analysis in the sector.

6 CONCLUSION

In relation to demand-side substitutability, the analysis focused on identifying key routes and assessing alternatives in Brazil's international aviation network. Two main evaluations were conducted: one on the redundancy index, which highlighted important routes based on their contribution to multiple paths, and another on the impact of removing international flights from Brazil on alternative routes and travel times.

The redundancy index revealed that routes to Santiago and Buenos Aires, even from less trafficked cities, were crucial, while European routes, particularly to Lisbon, were dominant. Most origin-destination pairs (91.4%) had alternatives, suggesting good connectivity, though limited pricing data prevented a deeper understanding of route substitutes.

As a result of the edge removal analysis, it is evident that the elimination of specific international routes originating in Brazil can have significant ripple effects across the entire network. Routes that may appear to be of lesser importance in terms of passenger volume can still play a crucial role in the overall connectivity, with some removals leading to substantial increases in travel time. This highlights how interconnected the aviation network is with certain flights, despite low traffic, acting as critical links that affect the redundancy of other routes. Conversely, the removal of high-traffic routes often results in only marginal increases in travel time, especially when alternative routes from central hubs like São Paulo and Rio de Janeiro are available. These insights underscore the importance of considering network dynamics when assessing the impact of route discontinuations. Additionally, the findings have relevance for the antitrust context, where the European Commission's approach of defining relevant markets by point-of-origin and point-of-destination pairs aligns with the analysis presented here, emphasizing the strategic significance of specific routes within the broader network. Further research could expand this framework to include a wider range of affected routes and explore their implications on network structure and competition. Another important finding is that, when accounting for network effects, the impacts of a merger might be better estimated, as it considers not only the impact in competition for a route, but for a larger scope. The same goes for analyzing network synergies. A traditional approach might miss some of the positive impacts of the airlines' network optimization.

In relation to supply-side substitutability, the initial hypothesis of this study posited that airlines would not substantially alter their fleets in response to short-term changes; therefore, new destinations would primarily be added through the introduction of new aircraft. However, our findings suggest that the evolution of the air traffic network in the post-COVID-19 period has not yielded conclusive results. A comparison of pre- and post-pandemic growth periods reveals that the extensive expansion indicator (x) reached 8.3%, which is lower than the values observed in various pre-pandemic periods. However, when the same metrics were calculated for 2023 alone, the indicator x for that period was 11.8%, closely aligning with values seen in the pre-pandemic periods. Thus, it is not possible to discern any significant change in the growth pattern of the network within the international air sector for flights departing from or arriving in Brazilian territory under the current conditions.

Conversely, the dispersion measures applied to certain network metrics reveal a clear shift in behavior patterns in the post-pandemic period. While numerous hypotheses can be considered, one plausible explanation is a reduced risk appetite among airlines, many of which are financially more fragile, making them less inclined to increase seat availability during the sector's recent recovery phase. Another contributing factor could be the unavailability of aircraft, which may be discouraging airlines from entering new routes, even if this leads to eventual exits, as pointed out in the qualitative analysis section.

From an antitrust analysis perspective, the data suggests the potential for structural changes that could negatively impact the competitive dynamics of the air sector. Therefore, ongoing studies and detailed analyses are necessary to assess from the demand side the potential influences of the hub-and-spoke model on consumers' route selection, given that flight frequency is a significant factor in choosing an airline. On the supply side, there is a need to deepen the analysis of metrics behavior, aiming to link them with other relevant variables, such as aircraft occupancy rates and profitability changes of airlines, which can be influenced by fluctuations in oil prices.

From a regulatory perspective, understanding competitive dynamics through network theory applied to the airline sector enables regulators to act in ways that prevent strategic behavior related to slot usage. For instance, an incumbent airline could transfer flights from one airport to another with the sole purpose of maintaining its dominant position at the latter, where slots are more contested. This could lead to the creation of artificial hubs and harm the competitive process.

From an academic standpoint, the application of network theory to the analysis of competition in the airline sector opens new avenues for understanding market dynamics beyond traditional frameworks. By capturing the structural interdependencies between routes - and their recent transformations in the post-pandemic period - this study sheds light on the multiple dimensions that can influence competitive outcomes. Future research is needed to integrate both demand- and supply-side aspects into a unified framework, including operational constraints (such as airport capacity and slot availability) as well as dynamic games of entry deterrence (Aguirregabiria; Ho, 2010), to simulate the potential impacts of mergers and acquisitions in the commercial aviation sector. To this end, it is essential to improve the public database of international flights maintained by Anac, in order to incorporate all passenger connections and enable integration with the airfare pricing database published by the regulatory agency.

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