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Are passengers less willing to pay for flying turboprops? An empirical test of the "Turbo Aversion Hypothesis"

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Are passengers less willing to pay for flying turboprops?
An empirical test of the “turbo aversion hypothesis”

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Abstract

Turboprop airplanes are known for their fuel efficiency on short-haul routes and thus naturally have a competitive advantage over jets in regional air transport. In Brazil, however, the market share of turboprops has considerably decreased in regional routes since the early 2010s. One possible explanation for this trend is the “turbo aversion hypothesis” (TAH), in which passengers dislike flying in turboprops, making carriers in regional markets more prone to operate either regional or smaller narrow-body jets based on demand-side economics. We empirically test this hypothesis by employing an econometric model of air travel demand in Brazilian regional markets. We find strong evidence rejecting the TAH, suggesting that the cost-side economics of the falling fuel prices apparently fully explains the observed erosion of the turboprop participation in the market.

Keywords: air transport; demand; regional aviation; turboprop; jet.

JEL Classification: D22; L11; L93.

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1. Introduction

Regional air transport is usually associated with low-to-medium density and short-haul routes and, as a subset of the airline industry, is widely recognized as relevant to the promotion of economic growth and the connection of remote regions of a country (Baker, Merkert & Kamruzzaman, 2015). Participating carriers in this market typically operate either regional jets or twin-engine turboprops (Ryerson & Ge, 2014)[1], and with the intensifying competition in the 70 to 130 seat segment, the choice set for airlines operating denser routes has been considerably amplified.

Turboprops are typically regarded as more fuel efficient than jets (Babikian, Lukachko & Waitz, 2002; Hanlon, 2007), especially on short-haul routes and in hub feeding, which represents a notable competitive advantage in most markets of the regional airline segment. In Brazil, however, the market penetration of turboprops has recently decreased to its lowest historical levels after reaching an almost sixty percent market share when oil prices increased in the late 2000s. This "crowding out" effect of regional and smaller narrow-body jets replacing turboprop airliners is consistent with the experience of other regions in the world and has been noted in the literature (Ryerson & Hansen, 2010). Offering similar capacity, the aircraft types have key differences regarding operating performance. For example, jets are faster and usually have a greater maximum total range than turboprops. Turboprops, on the other hand, are more fuel efficient than regional jets on short-haul routes (Bonaccorsi & Giuri, 2000; Babikian, Lukachko & Waitz, 2002), but their economic advantage over jets vanishes with distance (Brueckner & Pai, 2009; Ryerson & Hansen, 2010). Additionally, jets are known for having higher productivity as measured by seat-miles per hour flown (Hanlon, 2007). In sum, it is possible that lower fuel prices, along with operational shortcomings associated with shorter ranges and lower cruising speeds, may constitute the sources of the observed shift away from turboprops that allowed the notable growth of jet flights in Brazil.

One possible explanation for the decline of turboprops in regional markets is the "turbo aversion hypothesis" (TAH), in which passengers dislike flying in turboprops, making carriers more prone to operate jets than turboprops based on demand-side economics (Hanlon, 2007; Brueckner & Pai, 2009; Ryerson & Hansen, 2010). Hanlon (2007) discusses the passengers' perceptions of propeller aircraft "as being 'old' and relatively less safe."[2] The author also observes that turboprops are usually perceived as being less comfortable than jets, with the in-flight experience of passengers being "affected by noise, vibration and pressurization to a far greater extent in propeller aircraft" (Hanlon,

[1] Jets technology has evolved, and there are at least three different types of them currently available: pure jets, turbojets and turbofans.

[2] Hanlon (2007), p. 179.

2007, p. 179). All these factors motivate the possible existence of a turboprop aversion component in the preference formation of passengers. In contrast, anecdotal evidence suggests that such a phenomenon may be geographically determined, with some regions, such as the Middle Eastern airline market, being marked by a high turbo aversion of passengers compared to other regions, such as South America.[3]

We examine the issue of passenger aversion related to turboprops by empirically investigating the behavior of demand in the regional air travel markets of Brazil via an econometric model. In particular, we estimate the price elasticity of demand in regional markets and its possible variations associated with the presence of turboprop aircraft operations. By inspecting the possible shifts in the price elasticity of air travel demand caused by changes in the proportion of turboprop flights in the markets, we aim to examine whether the attribute "aircraft engine type" would be related to actual changes in the passengers' willingness-to-pay. As far as we know, we are the first to formally test the validity of the TAH. Our analysis allows investigation of the relative importance of demand and cost economics in explaining the preferences for airlines regarding the existing aircraft technologies available in the market.

The remainder of this paper is organized as follows: Section 2 presents a literature review and a conceptual discussion of the TAH; Section 3 presents the research design, with a description of the evolution and characteristics of the regional air transportation industry in Brazil, the available data set, the empirical model development and the estimation strategy. Section 4 presents the estimation results and their discussion. Section 5 presents some robustness checks. Section 6 describes some additional challenges to the empirical approach by estimating extended versions of the main econometric model. Finally, in Section 7, we present concluding remarks.

2. Air travel demand in regional markets and the "turbo aversion hypothesis"

As in the United States and Europe, liberalization has brought about major changes in Brazilian air transport. The process began in the early 1990s and has increased competition, which has led to lower fares and higher flight frequencies. Some routes became unprofitable, and airlines ceased to serve them. Due to this new higher competition scenario, airlines had to be more stringent about costs and aircraft selection, usually based on aircraft attributes and market characteristics, since it

[3] Source: "*Turbo aversion, turbo reversion*" - The Economist, Feb 16th, 2012.

could cause significant financial loss if not backed by the expectations of consumers (Han & Choi, 2014).

Aircraft models have their economics characteristics that consider acquisition and operational costs. Acquisition costs, assumed as fixed, are a direct cost expended by the consumer to purchase the aircraft and the inventory of repairable parts offered by the aircraft manufacturer. Operational costs are variable and include the pilot, cabin crew, maintenance and fuel, and when calculated per trip, they increase across aircraft size for short-haul flights (Swan & Adler, 2006). [4]

In relation to engine type, interest in turboprops has been renewed due to high fuel costs (until 2014) and airlines' need to reduce operational costs. Lower costs diminish the break-even point at which trips are cost-effective, allowing airlines to serve routes with lower load factors. According to Arnoult (2001), however, "passengers have a clear preference for jets over turboprops, viewing the former as quieter, faster, safer and more comfortable." Brueckner and Pai (2009) also add that turboprops provide significantly less comfort, especially because of higher noise levels and aircraft dimensions. Thus, manufacturers have worked to reduce in-flight noise and cabin comfort in order to increase passenger´s comfort while flying (Ryerson & Ge, 2014).

Jets fly at approximately 485 knots, while turboprops travel at approximately 300 knots. Since turboprops are slower, the total travel time by turboprop for the same distance is greater than that by jet. Longer flight duration could increase passengers' disutility, and for short-haul routes, the travel time would be comparable to other means of transport if one includes the time expended in airports before and after the flight. Additionally, as jets are faster, it is possible to increase frequency – Brueckner & Pai (2009) and Fageda & Flores-Fillol (2012) – which improve aircraft productivity and diminishes specific operational costs. According to Wong, Pitfield and Humphreys (2005), the most likely result of increasing flight frequency is the rise of demand, as it is easier to accommodate passengers' timetables. Dresner, Windle and Zhou (2002) affirm that regional jets are mainly used on new hub-and-spoke routes and appear to increase demand on dense routes when they replace turboprops.

Hess (2010) finds that respondents to his online stated-choice survey have a strong dislike for turboprops compared to widebody jets, narrow-body ("standard") jets, and regional jets. The results of the author indicate a clear materialization of what is known as a "turbo aversion" by passengers,

[4] It is important to highlight that Swan and Adler (2006) have studied aircraft manufactured by Boeing and Airbus, which are not normally considered as regional aircraft. In their presented results, they have classified flights shorter than 1000 km as short-haul flights. This distance is close to the upper limit capability of some turboprops assayed in the current work.

i.e., a disutility of flying with turboprops because they are associated with old aircraft that are slower, noisier, less comfortable and less safe than jets (Hanlon, 2007; Brueckner & Pai, 2009; Ryerson & Hansen, 2010), which induces carriers to prefer operating jets over turboprops based on demand-side considerations.

Therefore, on the one hand, jets could attract more passengers based on their supposed better service, and on the other hand, airlines could increase the utilization of turboprops due to recognized costs savings in regional markets, particularly in a scenario of high fuel prices. The question that we pose is would passengers' clearly stated preference for jets over turboprops result in a lower willingness-to-pay for flights operated with turboprops? In other words, does the stated preference regarding "turbo aversion" by passengers ultimately translate into higher price elasticity of demand when airlines operate turboprops? We believe that a better understanding of this dimension of passenger preference formation could add greater confidence to airlines when assigning the proper aircraft, mainly in a segment that has a good range of aircraft options. We therefore raise the following hypothesis:

- **Turbo aversion hypothesis (TAH):** Passengers have lower willingness-to-pay for flights operated with turboprop airliners than by jets because, to them, traveling with turboprops constitutes a lower-quality service experience based on their perceptions regarding in-flight comfort, cabin noise, sensations related to pressurization, safety, flight speed or aircraft "age."

Using aggregate data, we suggest approaching the issue of the possible passenger aversion related to turboprops by empirically examining the demand in regional air travel markets via an econometric model. In particular, we propose estimating the price elasticity of demand and to empirically test its possible variations associated with turboprop operations. We believe that such a methodology is not only easy to implement but also very straightforward for testing the raised TAH.

3. Research Design

3.1. Application

We develop an econometric model to empirically examine and test the "turbo aversion hypothesis" of passengers in Brazilian regional airline markets. Our empirical model aims to test the possible effects of turboprop aircraft operations on the market price elasticity of demand. We therefore estimate the possible shifts in the price elasticity of demand by resorting to the use of interacted terms of price and proxies for turboprop operations. With such a procedure, it is possible to test whether the type of aircraft engine is associated with changes in the aggregate willingness-to-pay of passengers. The model adds to the literature by testing for the existence of a higher disutility related to flights operated with turboprop airplanes when contrasted with jets. The higher disutility would be due to the untested TAH that passengers have an overall - and unobserved to us - perception of turboprop airplanes being less comfortable than jets due to speed, noise, safety, innovativeness, etc. To achieve this goal, we consider the case of the Brazilian regional air transport industry.

We can see in Table 1 the evolution of regional air transportation in Brazil since the early 2000s and the relative importance of turboprop and jets in this market. The table shows the evolution of the number of carried passengers, prices and flight frequency on regional routes - respectively, “pax,” “avg fare” and “flights.” We define regional routes as all domestic city-pair markets that do not involve two state capitals (or the federal capital) as endpoints.

Table 1 - Evolution of regional air transportation in Brazil

Period	All regional routes							≤ 500 nm				≤ 7 weekly flights			
	pax (million)	avg fare (2018 R$)	flights (000)	turboprops		jets		turboprops		jets		turboprops		jets	
				flights (000)	*share*	flights (000)	*share*	flights (000)	*share*	flights (000)	*share*	flights (000)	*share*	flights (000)	*share*
(1) 2002-05	4.4	683	132	59	*45%*	73	*55%*	57	*47%*	65	*53%*	26	*65%*	14	*35%*
(2) 2006-09	6.7	529	163	94	*58%*	69	*42%*	92	*60%*	61	*40%*	37	*83%*	8	*17%*
(3) 2010-13	13.3	433	247	115	*47%*	132	*53%*	113	*51%*	111	*49%*	39	*74%*	14	*26%*
(4) 2014-17	16.2	409	219	91	*41%*	128	*59%*	88	*46%*	102	*54%*	20	*57%*	16	*43%*
% Variation															
(2)/(1)	*52%*	*-23%*	*23%*	*59%*		*-6%*		*61%*		*-6%*		*42%*		*-43%*	
(3)/(2)	*98%*	*-18%*	*52%*	*22%*		*92%*		*23%*		*82%*		*5%*		*75%*	
(4)/(3)	*21%*	*-6%*	*-11%*	*-21%*		*-3%*		*-22%*		*-8%*		*-49%*		*14%*	
(4)/(1)	*266%*	*-40%*	*66%*	*53%*		*76%*		*54%*		*57%*		*-23%*		*14%*	

Sources: National Civil Aviation Agency, Air Transportation Market Statistical Database – Monthly Traffic Report, Active Scheduled Flight Report – VRA, and Microdata of Commercial Air Fares Database, with own calculations.

We can see in Table 1 that regional air transportation in Brazil increased by 266% in the whole period - i.e., contrasting year-brackets (4) 2014-2017 and (1) 2002-2005. In fact, the number of carried passengers rose from 4.4 million passengers to 16.2, with an average year-over-year growth that was 28% higher than the growth of the mainline markets of the country in the same period. Part of this notable evolution is due to the 40% drop in the average air fare, as we can see in Table 1. Another source of growth is related to the evolution of the number of regional flights in the country, which grew 66% from an average of 132 thousand yearly flights in 2002-2005 to 219 thousand in 2014-2017.

Table 1 also presents a breakdown of the evolution of the number of flights by type of aircraft. It is possible to perceive that the growth of jets from period (1) to period (4) was 76%, versus the 53% for turboprops. This evolution was not monotonic, however, since in period (2) - the years 2006-2009 - the turboprops acquired a majority stake of a 58% market share against 42% for the jets. In fact, it can be noted that the market share loss of turboprops occurs in periods (3) and (4), with a reversal of the situation in the early 2000s, i.e., jets dominating almost 60% of the regional routes.

To further inspect the historical evolution and recent trends in the market, Table 1 shows the evolution of subsets of routes more highly associated with regional airline markets, namely, short-haul flights and low-density routes. We consider two subsets: routes shorter than 500 nautical miles and routes with less than 7 weekly flights. It can be seen that there was a considerable advance of jets on the regional routes even in the markets considered more typical for turbo propellers' operation: in the more recent period (4), jets enjoyed a majority stake of a 54% market share on short-haul routes and reached a peak market participation on low-density routes of 43%, from only 17% in period (2). Concurrently, the difference between all turboprop flights and the ones on routes shorter than 500 nm indicates that at most 4% of total turboprop flights occur on routes longer than 500 nm. Quite stable from periods (1) to (3), this share solely increased in period (4): 1 thousand extra flights.

The above analyses clearly reveal airlines limiting turboprop utilization on routes longer than 500 nm and their recent preference for operating jets rather than turboprops in the regional segment of the airline industry in Brazil, especially since 2010. We can see in Figure 1 that one of the possible explanations for the decrease of turboprop flights' participation in the regional market is the substantial drop in the oil barrel price in the international market. Indeed, after reaching peak prices above US$ 100 (Brent) and US$ 90 (WTI) in the early part of 2010, oil prices have dropped significantly since then, which pushed down aviation kerosene prices in the domestic market of the country. Figure 1 also shows the evolution of the number of turboprop flights in regional aviation from 2002 to 2017. It can be seen that after reaching a peak of more than 120,000 annual flights in Brazilian regional markets in 2012, the absolute amount of regional flights has fallen considerably since then, returning to levels similar to those of the mid-2000s, that is, below 80,000 annual flights. A strong correlation between the number of turboprop flights and the oil barrel price series can be noted in the figure - Pearson's correlation coefficient between the series is 0.85 (Brent) and 0.80 (WTI).

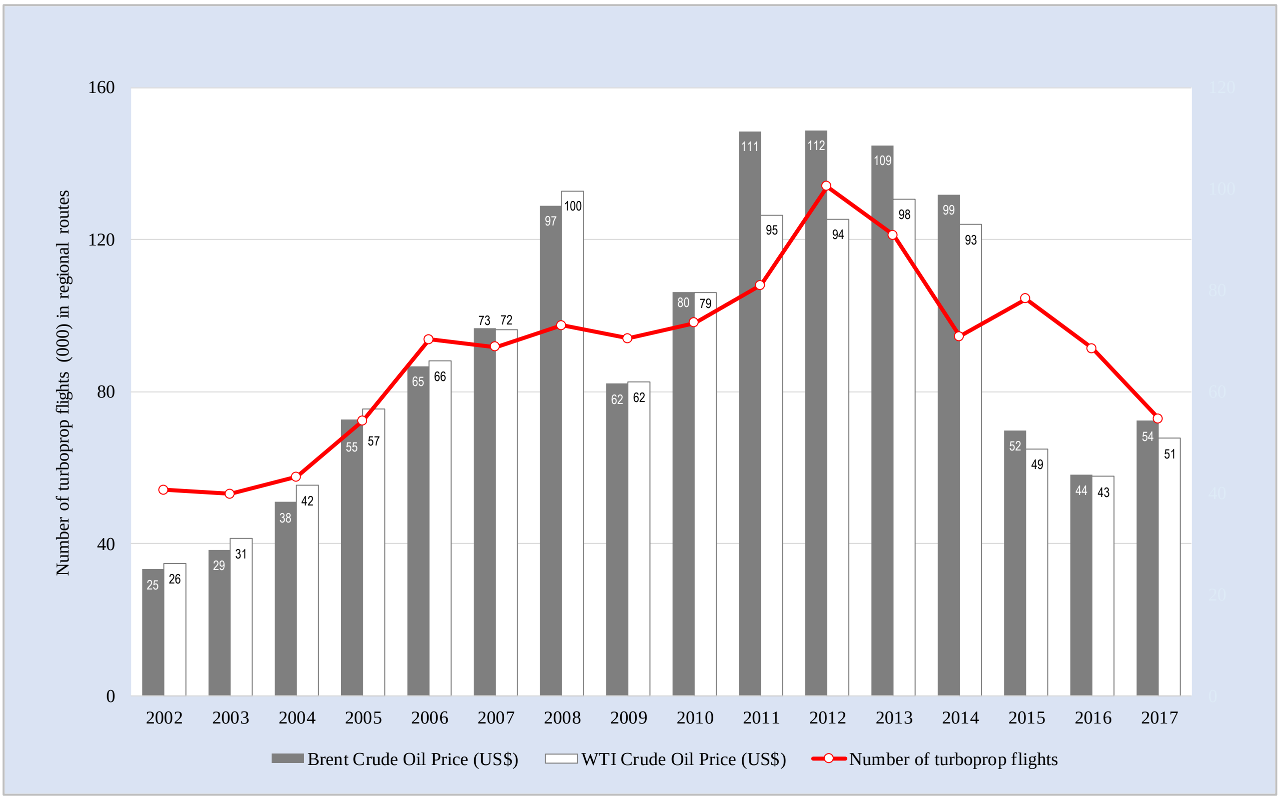

Figure 1 - Evolution of turboprop flights on Brazilian regional air transport routes against crude oil price

Sources: National Civil Aviation Agency, Active Scheduled Flights Report (VRA), and Institute for Applied Economic Research – Ipea (WTI and Brent prices). Number of turboprop flights in thousands. See the description of the data set for details on the definition of regional airline routes.

The following figures present the spatial evolution of the Brazilian regional routes served by turboprops (Figure 2) and jets (Figure 3) in a sequence of maps in which the years 2002, 2010 and 2017 are used as geographical evolutionary analysis references. We can see in the figures that both flight equipment showed a significant evolution since the beginning of the 2000s due to the considerable expansion of mainline and regional airlines with the economic deregulation of the market during this period. It is noticeable in Figure 2 that turboprop progress is considerable when comparing the years 2010 and 2002. This advance, however, has been relatively frozen since the beginning of the year 2010, resulting in a reasonably similar or slightly shrunk network in 2017. On the other hand, the operations of jets have remarkably intensified in the present decade, with the resulting network in 2017 visibly denser compared to that in 2002. This result, as discussed above, is probably the result of falling fuel costs since the end of the previous decade.

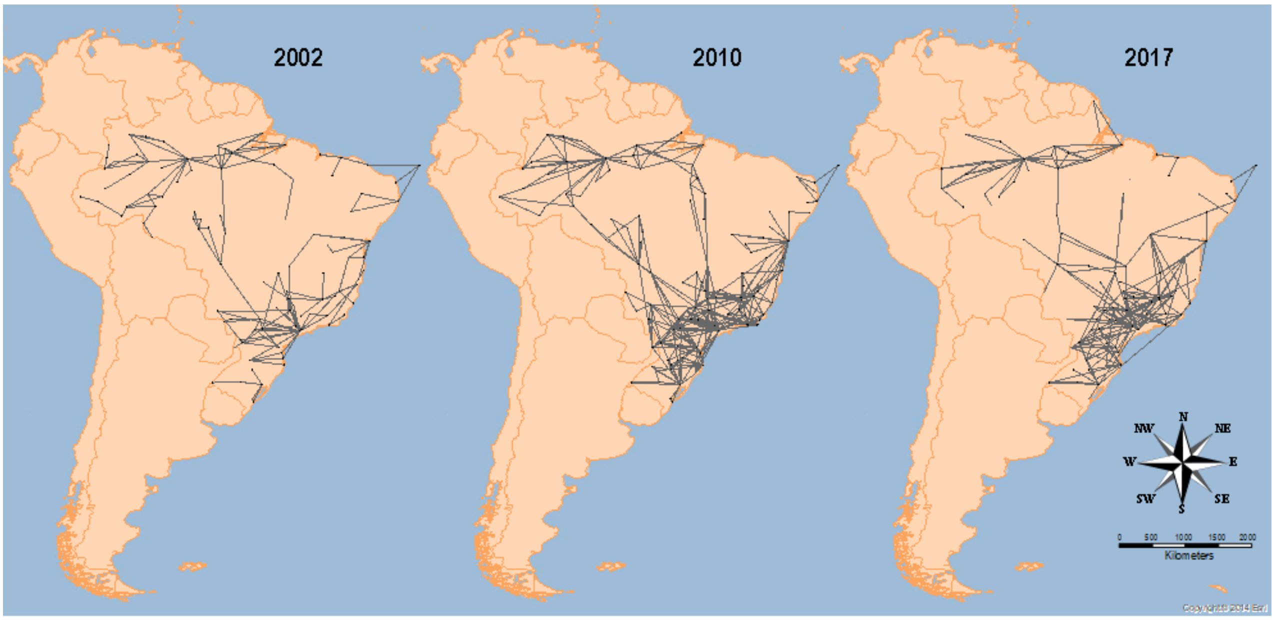

Figure 2 - Evolution of turboprop flights in Brazilian regional air transport

Source: National Civil Aviation Agency, Active Scheduled Flights Report, Air Transportation Market Statistical Database – Monthly Traffic Report, with own calculations, 2002-2017. See the description of variables in the empirical model for details.

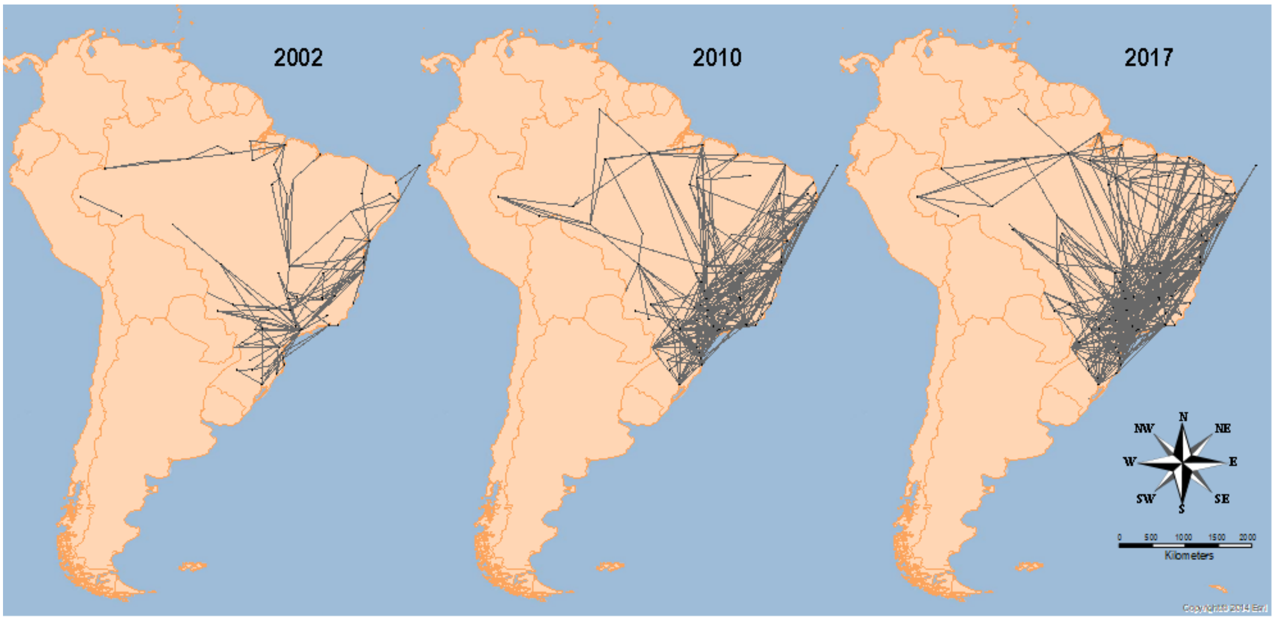

Figure 3 - Evolution of jet flights in Brazilian regional air transport

Source: National Civil Aviation Agency, Active Scheduled Flights Report, Air Transportation Market Statistical Database – Monthly Traffic Report, with own calculations, 2002-2017. See the description of variables in the empirical model for details.

3.2. Data

The data set consists of an unbalanced panel comprising information on approximately 870 Brazilian regional routes and 139 airports from July 2010 to December 2017, amounting to 29,388 observations. A "regional route" was defined as any city-pair market that does not have both endpoints airports located in a state capital or its catchment area. The data are publicly available from the airline regulator - the National Civil Aviation Agency (ANAC) - namely, the Air Transportation Market Statistical Database – Monthly Traffic Report and the Active Scheduled Flight Report (VRA). The sources of the data set were the National Civil Aviation Agency (ANAC), the Brazilian Institute of Geography and Statistics (IBGE), the Institute for Applied Economic Research (Ipea), the Brazilian Central Bank and the state-owned enterprise Infraero, who, within the sample period, was in charge of managing most of the Brazilian regional airports.

3.3. Econometric model

To study the willingness-to-pay of passengers in regional markets with availability of both jet and turboprop aircraft, an empirical study of demand for Brazilian regional air transport will be carried out. The model will test the "turbo aversion hypothesis" by estimating the price elasticity of demand for regional flights and their shifters, especially the shifters related to the presence of this type of aircraft on the route. In the econometric model of demand for air travel, we will use several possible combinations of price elasticity shifters, using the interaction terms as regressors, as a way of understanding whether the passenger's airfare purchase behavior would be affected in any way by the probable flight equipment that will be used for travel. Equation (1) presents our empirical model of air travel demand in the Brazilian regional airline industry:

$$\begin{aligned}\ln \text{weekly pax}_{kt} = {} & \beta_1 \ln \text{grav gdp per capita}_{kt} + \beta_2 \ln \text{flight frequencies}_{kt} + \\ & \beta_3 \ln \text{mean served cities}_{kt} + \beta_4 \text{presence major carriers}_{kt} + \\ & \beta_5 \ln \text{yield}_{kt} + \beta_6 \ln \text{yield}_{kt} \times \text{business}_k + \\ & \beta_7 \ln \text{yield}_{kt} \times \text{intermodal}_k + \beta_8 \ln \text{yield}_{kt} \times \text{monopoly}_{kt} + \\ & \beta_9 \ln \text{yield}_{kt} \times \text{turboprop}_{kt} + \gamma_k + \gamma_t + u_{kt},\end{aligned} \tag{1}$$

where *k* denotes the route, i.e., the non-directional city-pair (1051 routes related to 139 cities), and *t* denotes the time period (87 months).[5] The components of Equation (1) are as follows:

[5] Two months were missing from the dataset: June and July 2014. These were World Cup periods in which the regulator had problems with data collection.

- weekly pax_{kt} is the average number of weekly revenue passengers on route (city-pair) *k* at time (year-month) *t*. Source: National Civil Aviation Agency, Air Transportation Market Statistical Database – Monthly Traffic Report.
- grav gdp per $capita_{kt}$ is the product of the gross domestic product per capita of the origin and destination cities of route *k* at time *t*. This metric was adjusted for inflation, has yearly periodicity and therefore had to be interpolated to produce monthly series. Source: Brazilian Institute of Geography and Statistics (IBGE), with own calculations.
- flight $frequencies_{kt}$ is the total number of scheduled non-stop flights of the carriers for city-pair *k* at time *t*. Source: National Civil Aviation Agency, Active Scheduled Flight Report – VRA, with own calculations.
- mean served $cities_{kt}$ is the mean number of destinations served, computed between both endpoint cities of city-pair *k* at time *t*. It includes only destinations served with non-stop flights from these cities. This variable is designed to capture the hubbing activity of major carriers (hub size with respect to the number of served cities) and the role of regional carriers as feeder airlines. Source: National Civil Aviation Agency, Active Scheduled Flight Report – VRA, with own calculations.
- presence major $carriers_{kt}$ is a dummy variable to account for the presence of major carriers LATAM (formerly TAM) and Gol in regional market *k* and time *t*. Source: National Civil Aviation Agency, Active Scheduled Flight Report – VRA, with own calculations.
- ln $yield_{kt}$ is the average price per kilometer of carriers for city-pair *k* at time *t*. This variable was adjusted for inflation and includes all air tickets sold for all itineraries within the city-pair travel market in time *t*. Source: National Civil Aviation Agency, Microdata of Commercial Air Fares Database, with own calculations.
- $business_k$ is the proportion of business-related air passengers on route *k*. This variable is interacted with the yield variable in order to inspect its effect on the price elasticity of demand – the higher the business traffic proportion is, the lower the price elasticity of demand. Source: Air Transportation Passengers Origin and Destination Survey – Brazilian Enterprise for Planning and Logistics – EPL, 2014, with own calculations.
- $intermodal_{kt}$ is the proportion of air passengers that used alternative means of transportation on the same route in the previous year for route *k*. It is a proxy for the degree of exposure to intermodal competition of air carriers on route *k*. As with $business_k$, this variable is interacted with the yield variable to capture its effect on the price elasticity of demand – the higher the

intermodal competition is, the higher the price elasticity of demand. Source: Air Transportation Passengers Origin and Destination Survey – Brazilian Enterprise for Planning and Logistics – EPL, 2014, with own calculations.

- monopoly$_{kt}$ is a dummy variable assigned the value of 1 if the route is served by a single airline for route *k* at time *t*. It is interacted with the yield variable to allow inspection of how the lack of competition alternatives lowers the price elasticity of demand. Source: National Civil Aviation Agency, Microdata of Commercial Air Fares Database, with own calculations.

- turboprop$_{kt}$ is the proportion of turboprop flights on route *k* at time *t*. This is the most important variable utilized in the econometric framework in order to inspect the "turbo aversion hypothesis" (TAH). We insert this variable interacted with the yield variable to inspect its possible effect on the price elasticity of demand. Under the validity of the TAH, the coefficient of the interaction variable would be negative, meaning that the higher the proportion of turboprop flights is, the more sensitive the air travel demand to price - i.e., the less willing to pay the passengers on the route are. Source: National Civil Aviation Agency, Active Scheduled Flight Report – VRA, with own calculations.

- γ_k and γ_t are, respectively, the city-pair and time fixed effects.

- $\beta_1, \ldots, \beta_9$ are unknown parameters.

- u_{kt} is the disturbances term.

In an extended version of the model presented in Equation (1), we try inserting the following additional variables to check the robustness of the results related to the turboprop$_{kt}$ variable. Most of these variables were included in the specification of Equation (1) as interaction terms to assess their potential intensification or attenuation effect of the turboprop aversion phenomenon on the price elasticity of demand.

- nr of carriers$_{kt}$ is the average number of carriers operating on route *k* at time *t*. The higher the number of carriers is, the higher the competition and possibly the turbo aversion of passengers. Source: National Civil Aviation Agency, Active Scheduled Flight Report – VRA, with own calculations.

- flight distance$_{kt}$ is the geodesic flight distance between the origin and destination (Vincenty's formula) cities. In the case of multiple airports in the same endpoint city, the average distance was computed. The higher the flight distance is, the higher the turbo aversion of passengers may be.

- coexisting jet tp_{kt} is a dummy variable to control routes on which both jets and turboprops operate simultaneously at time *t*. If turboprops suffer from turbo aversion from passengers, then on these routes in which both alternatives are available, this effect would be more prominent. Source: National Civil Aviation Agency, Active Scheduled Flight Report – VRA, with own calculations.

- non AZU_{kt} is the number of turboprop flights operated by carriers other than Azul Airlines on route *k* at time *t*. Azul is widely recognized as a high-quality low cost carrier[6] and has a fleet composed of both jets and turboprops. By accounting for the non-Azul turboprop flights, we aim at avoiding a confounding effect of turboprop utilization (turboprop aversion) and perceived higher quality associated with the carrier that could induce a false negative result. Source: National Civil Aviation Agency, Active Scheduled Flight Report – VRA, with own calculations.

- ffp_{kt} is the proportion of air passengers on route *k* that traveled by air for more than four round trips within the previous twelve months. It is a proxy for how well-informed and aware the average passenger on route *k* is of the overall service attributes of air carriers and, in particular, of the difference between turboprops and jets. The higher the consumer loyalty is, the higher the price elasticity of demand. Source: Air Transportation Passengers Origin and Destination Survey – Brazilian Enterprise for Planning and Logistics – EPL, 2014, with own calculations.

- crowd out_k is a dummy variable to control for the routes that experienced a sharp substitution of turboprops by jets in the sample period - a "crowding out" effect. By quickly filling the place of turboprops, jets may provoke a change in the passengers' perception of the service quality that may result in the emergence of a turbo aversion attitude. We then expect a higher price elasticity of demand on routes in which turboprop-jet crowding out was observed. To construct this variable, we considered the routes that had more than 75% of flights operated by turboprops in the first sample year. A value of 1 was assigned to the dummy when the percentage of flights on any of these routes changed to more than 75% of flights operated by jets in the final sample year. Source: National Civil Aviation Agency, Active Scheduled Flight Report – VRA, with own calculations.

[6] The carrier was ranked 8th in the World's Best Low-Cost Airlines 2017 by Skytrax (www.worldairlineawards.com)

- aircraft size$_{kt}$ is the average number of seats on the airplanes operated by carriers on route k at time t. Source: National Civil Aviation Agency, Active Scheduled Flight Report – VRA, with own calculations.

Henceforth, we omit indexes k and t. Table 2 presents descriptive statistics of the main variables of our empirical model.

Table 2 - Descriptive statistics - variables of the empirical model

Variable	Unity	Nr. Observ.	Mean	Std. dev.	Min	Max
weekly pax	average	29,388	431.69	618.84	0.23	5,440.81
gdp per capita (origin)	BRL per person	29,388	2,945.01	1,555.76	528.37	12,547.24
gdp per capita (destination)	BRL per person	29,388	2,932.09	1,551.42	528.37	12,547.24
flight frequencies	count	29,388	56.20	69.02	1.00	592.00
served cities (origin)	count	29,388	9.86	9.19	1.00	40.00
served cities (destination)	count	29,388	9.82	9.17	1.00	41.00
presence major carriers	dummy	29,388	0.64	0.48	0.00	1.00
yield	BRL per km	29,388	0.85	0.58	0.04	16.00
business	proportion	29,388	0.49	0.21	0.00	1.00
intermodal	proportion	29,388	0.23	0.17	0.00	1.00
monopoly	proportion	29,388	0.34	0.47	0.00	1.00
turboprop	proportion	29,388	0.56	0.47	0.00	1.00
nr of carriers	count	29,388	2.22	1.10	1.00	6.00
flight distance	km	29,388	601.95	401.82	43.54	2,855.65
coexisting jet tp	dummy	29,388	0.14	0.35	0.00	1.00
non AZU	count	29,388	13.97	24.18	0.00	216.00
ffp	proportion	29,388	0.26	0.18	0.00	1.00
crowd out	dummy	29,388	96.78	43.23	17.00	232.00
aircraft size	count	29,388	0.04	0.18	0.00	1.00

3.5. Estimation strategy

We assume that the yield variable and its interactions are correlated with the unobserved demand shifters. Due to the endogeneity of these regressors, utilizing the Ordinary Least Squares (OLS) estimation in this case would provide biased results. As a countermeasure, we employ an instrumental variables estimator. We therefore generate a set of proxies for the unit cost of airline inputs as instrumental variables similar to Rolim, Bettini & Oliveira (2016). We utilize the following cost shifters as instruments: the minimum fuel price between the origin and destination cities - with up to three lags and inflation adjusted - the proportion of flights operated by leased aircraft, and the average speed of airplanes on the route. These unit cost drivers have monthly periodicity and were collected from the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) and the National Civil Aviation Agency (ANAC).

To further instrument the yield variables, we utilized variables associated with the number of holidays in the period. As the number of holidays (and the number of working days) of a given month is exogenous, we developed a set of instruments based on this variable. We employed the current, lagged and forward realizations of the number of holidays in each month, aiming at accounting for the pricing dynamics mainly associated with the seasonality of leisure-related trips and the search behavior of travelers that is engendered by the seasonality.

We conducted several statistical tests to check the statistical validity and relevance of the proposed instrumental variables set. The results of all of these tests are available at the bottom of the result table in the next sections. We basically employed the Hansen J tests to verify the validity of the over-identifying conditions – labelled "J test statistic" – and the Kleibergen-Paap rk LM underidentification tests – labelled "KP underidentif statistic" – to inspect the relevance of the instruments set. We also report the Cragg-Donald Wald F statistic and the Kleibergen-Paap rk Wald F statistic – labelled "CD weak identif statistic" and "KP weak identif statistic" – to check for the presence of weak instruments. As we will see in the robustness check section, we further challenged our instrumentation approach by utilizing a reduced set of overidentifying restrictions set. We obtained evidence suggesting the orthogonality and relevance of the proposed set of instrumental variables from the analysis of all hypothesis tests and checks

4. Estimation Results

Table 3 presents the results of our empirical model. It can be seen that Table 3 contains seven columns of results. The columns are distinguished by the employed estimator, the instrument set and the empirical specification utilized. In Column (1), we have the results of the baseline model. In this specification we consider the variable ln yield alone, without any type of interaction term. In addition, consistent with the model formulated by Equation (1), we account for the demand shifters ln *gdp per capita*, ln *flight frequencies* and ln *mean served cities* and the dummy variable *presence major carriers*. The results of Column (1) indicate a statistically significant price elasticity of -1.2353. This figure increases across the alternative specifications of the subsequent columns. In Column (2), we estimate an extended model, adding to the baseline model the interaction terms ln *yield* × *business*, ln *yield* × *intermodal* and ln *yield* × *turboprop*. The estimated coefficients of these interaction variables are statistically significant and consistent with ex-ante expectations, indicating a decline in the price elasticity of demand for regional air travel in monopoly and more business-related markets and an increase in price elasticity of demand when intermodal competition exists. Moreover, these variables are statistically significant in all other specifications displayed in Table 3.

Column (3) presents our main empirical results. In this specification, consistent with the model of Equation (1), we insert the interaction of the variable ln *yield* with the proportion of turboprop flights on the route - the *turboprop* variable. Note that although the coefficient of this variable is negative, potentially indicating an increase in the market price elasticity, it is associated with a small value compared to the average price elasticity, estimated as -1.5120 in Column (3). Additionally, this coefficient is not statically significant, and therefore, we must conclude that there is no effect on the price elasticity caused by this interaction. It can be seen from the results of Column (3) that there is no evidence that the turboprop operation induces a real disutility to passengers that is sufficient to increase their overall sensitivity to airfares - i.e., the "turboprop aversion hypothesis" (TAH) is rejected. This result therefore suggests that the operation of turboprop airplanes on a given route apparently does not represent possible losses of competitive advantages for the airline in regional markets, at least when considering the aggregate level of the market.

5. Robustness checks

We implemented a series of robustness checks aiming at challenging the validity and sensitivity of our results regarding the test for the "turbo aversion hypothesis" (TAH). The results of these robustness checks are shown from Columns (4) to Column (7) of Table 3. The robustness checks were as follows:

- Column (4): we discard the ln *yield* x *monopoly* variable to check if our results would be driven by the fact that turboprops typically operate monopoly routes.

- Column (5): we discard the ln *yield* x *business* variable to inspect if the turbo aversion would be a phenomenon more related to the perceptions of business travelers.

- Column (6): we present the results of the specification of Column (3) but this time employ the limited-information maximum likelihood (LIML), as suggested in Angrist and Pischke (2008) for the case of potentially weak instrumental variables.

- Column (7): we employ a second Angrist and Pischke (2008) estimation recommendation - the just-identified estimation, i.e., the reduction of the number of instruments to be equal to the number of endogenous variables. We employ the LIML in this experiment.

In all the robustness checks, the main results of Column (3), related to the absence of effects of the turboprop operation on the aggregate price elasticity of demand, were not changed.

Table 3 - Estimation results

	(1) ln weekly pax	(2) ln weekly pax	(3) ln weekly pax	(4) ln weekly pax	(5) ln weekly pax	(6) ln weekly pax	(7) ln weekly pax
ln grav gdp per capita	0.7208***	0.5433***	0.4508***	0.4317***	0.5240***	0.3526***	0.3291**
ln flight frequencies	0.3788***	0.3334***	0.3313***	0.3635***	0.3146***	0.3131***	0.2904***
ln mean served cities	0.0619***	0.0756**	0.0991***	0.1234***	0.0924***	0.1210***	0.1145***
presence major carriers	0.1957***	0.2668***	0.2882***	0.2674***	0.2690***	0.3202***	0.3420***
ln yield	-1.2353***	-2.0611***	-2.3106***	-1.6650***	-0.8663***	-3.4519***	-4.2010***
ln yield × business		2.4308**	3.3166***	2.2391**		5.7048***	7.0450***
ln yield × intermodal		-3.8973***	-4.8041***	-3.6756***	-4.1309***	-5.4284***	-6.5368***
ln yield × monopoly		0.9789***	0.9152***		0.7213***	0.9650***	1.4153***
ln yield × turboprop			-0.0423	-0.0334	-0.1482	-0.1201	0.0376
city-pair fixed effects	yes	yes	yes	yes	yes	yes	yes
time fixed effects	yes	yes	yes	yes	yes	yes	yes
estimator	2SGMM	2SGMM	2SGMM	2SGMM	2SGMM	LIML	LIML
instruments set	over-identif	over-identif	over-identif	over -identif	over -identif	over-identif	just -identif
estimated median price-elasticity	-1.2353***	-1.4263***	-1.5120***	-1.3989***	-1.5024***	-1.6459***	-1.8151***
Adjusted R-squared	0.9515	0.9518	0.9518	0.9518	0.9515	0.9518	0.9518
RMSE statistic	0.4250	0.4238	0.4239	0.4238	0.4249	0.4239	0.4239
KP underidentif statistic	52.5117	24.0132	50.1926	64.8891	84.1797	50.1926	39.4975
KP underidentif p-value	< 0.0001	0.0023	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
CD weak identif statistic	43.3434	4.4020	6.4877	7.5462	8.4564	6.4877	11.2621
KP weak identif statistic	17.8833	2.2214	3.2011	4.7311	6.2182	3.2011	8.1532
J test statistic	1.1299	5.7020	11.4305	9.9951	12.3703	8.9788	n/a
J test p-value	0.5684	0.5749	0.4079	0.4409	0.2610	0.6239	n/a
Nr observations	29,388	29,388	29,388	29,388	29,388	29,388	29,388

*Notes: Results produced by the two-step feasible efficient generalized method of moments estimator (2SGMM); statistics robust to heteroscedasticity and autocorrelation. "over-identif" and "just-identif" mean estimation of, respectively, an over-identified and a just-identified model. P-value representations: ***p<0.01, ** p<0.05, * p<0.10. Estimated price elasticity in (2)-(7) extracted at the sample mean of the interaction variables.*

6. Extended model

Table 4 comprises the estimation results for the extended version of our empirical model described in Equation (1). As discussed before, in this extended model, we experiment with the insertion of additional interaction terms related to the turboprop variable. With this procedure, we aim at further challenging the results of our baseline model presented in Table 3, Column (1), by attempting to uncover any intensification or attenuation effect of the turboprop aversion phenomenon that may not have been identified by our empirical strategy so far. Therefore, in Columns (1) to (6) of Table 4, we experiment with further interacting the ln *yield* x *turboprop* term with the following variables:[7] *nr of carriers* (the average number of operating airlines), *flight distance*, *coexisting jet tp* (a dummy of simultaneous operation of jets and turboprops on the route); *non AZU* (the number of turboprop flights operated by carriers other than Azul Airlines); *business* × *ffp* (the proportion of business traffic interacted with the proportion of frequent flier passengers); and *crowd out* (a dummy to account for the routes that experienced a sharp substitution of turboprops by jets). Finally, in Column (7), we utilize the *aircraft size* variable in substitution for *turboprop* in the interaction term with *ln yield* to verify if the "turbo aversion hypothesis" would be simply a materialization of the passenger preference for larger planes, "which are generally more comfortable and are thought to be safer" (Borenstein, 1989, p. 350), instead of being related to their perceptions regarding the aircraft engine type.

Similar to the results of the robustness checks, here, in all specifications considering extended versions of the empirical model of Equation (1), the main results obtained in Table 3, Column (3), were not changed. In fact, all the additional interactions inserted into the model resulted in coefficients that were not statistically significant, and thus, these results further corroborated the conclusion regarding the absence of effects of the turboprop operation on the aggregate price elasticity of demand. We therefore had enough evidence supporting the rejection of the "turboprop aversion hypothesis" in Brazilian regional air travel markets.

[7] See 3.3 for a discussion of these variables and their possible role in shifting the price elasticity of air travel demand.

Table 4 - Robustness checks - estimation results

	(1) ln weekly pax	(2) ln weekly pax	(3) ln weekly pax	(4) ln weekly pax	(5) ln weekly pax	(6) ln weekly pax	(7) ln weekly pax
ln grav gdp per capita	0.4470***	0.4469***	0.4757***	0.4597***	0.4511***	0.4607***	0.4602***
ln flight frequencies	0.3304***	0.3305***	0.3378***	0.3356***	0.3313***	0.3363***	0.3277***
ln mean served cities	0.0979***	0.0985***	0.0908***	0.0956***	0.0984***	0.0972***	0.1025***
presence major carriers	0.2885***	0.2884***	0.2826***	0.2843***	0.2879***	0.2843***	0.2907***
ln yield	-2.3148***	-2.3201***	-2.1397***	-2.2490***	-2.3258***	-2.2517***	-2.8596**
ln yield × business	3.3312***	3.3391***	2.9723**	3.2286***	3.3600***	3.2580***	3.2050***
ln yield × intermodal	-4.8585***	-4.8669***	-4.7700***	-4.8191***	-4.8224***	-4.8261***	-4.5450***
ln yield × monopoly	0.9171***	0.9097***	0.9457***	0.9277***	0.9131***	0.9135***	0.9182***
ln yield × turboprop × nr of carriers	-0.0186						
ln yield × turboprop × flight distance		-0.0001					
ln yield × turboprop × coexisting jet tp			0.1716				
ln yield × turboprop × non AZU				-0.0001			
ln yield × turboprop × business × ffp					-0.1655		
ln yield × turboprop × crowd out						-0.3212	
ln yield × aircraft size							0.1130
city-pair fixed effects	yes	yes	yes	yes	yes	yes	yes
time fixed effects	yes	yes	yes	yes	yes	yes	yes
estimator	2SGMM	2SGMM	2SGMM	2SGMM	2SGMM	2SGMM	2SGMM
instruments set	over-identif	over-identif	over-identif	over -identif	over -identif	over-identif	over-identif
estimated median price-elasticity	-1.5056***	-1.5256***	-1.4470***	-1.5255***	-1.4437***	-1.4492***	-1.5293***
Adjusted R-squared	0.9518	0.9518	0.9518	0.9519	0.9518	0.9518	0.9518
RMSE statistic	0.4238	0.4238	0.4238	0.4234	0.4238	0.4237	0.4236
KP underidentif statistic	50.6477	50.8840	47.4393	42.2134	49.4944	51.1959	47.7685
KP underidentif p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
CD weak identif statistic	6.4002	6.4390	5.6778	5.0348	6.4984	5.3372	6.0277
KP weak identif statistic	3.2292	3.2467	3.0212	2.6821	3.1531	3.2393	3.0335
J test statistic	11.2894	11.2894	11.9210	12.3024	11.3830	11.9701	11.6386
J test p-value	0.4193	0.4193	0.3696	0.3413	0.4118	0.3659	0.3914
Nr observations	29,388	29,388	29,388	29,388	29,388	29,388	29,388

*Notes: Results produced by the two-step feasible efficient generalized method of moments estimator (2SGMM); statistics robust to heteroscedasticity and autocorrelation; "over-identif" means estimation of an over-identified model. P-value representations: ***p<0.01, ** p<0.05, * p<0.10. Estimated price elasticity in (1)-(7) extracted at the sample mean of the interaction variables.*

7. Conclusion

This paper examined the demand-side effects of turboprop aircraft operation in Brazilian regional airline markets. In particular, we tested if passengers facing a higher participation of turboprop airplanes on a route - and consequently a higher probability of flying with turboprops - have lower willingness-to-pay for flights than passengers on routes operated with higher participation of jets. We conclude that passengers' profile, market structure and intermodal competition exposure are key drivers of the price elasticities of demand. We do not find any evidence that turboprop aircraft operation increase the market price elasticity of demand and therefore reject the "turbo aversion hypothesis" (TAH). We therefore conclude that the considerable growth of jets observed in the studied industry has apparently not been related to airlines focusing on passenger preferences (and dislikes) but mainly to cost economics factors, namely, the decline in fuel prices since the late 2000s and the operating advantages associated with jets - higher range, speed and productivity.

The policy implications of our results are related to the fact that airlines typically assign aircraft models with optimal economic performance for each specific route and are thus able to maximize their return on investment and set unit costs in the most efficient way. With no disutility generated to passengers, turboprop airplanes therefore seem to be an important technology to maximize profits and to reduce airline greenhouse gas emissions, at least on short-to-medium haul regional routes. Our results suggest that airlines with both turboprop and jets in their fleets may therefore make fleet assignment decisions regarding regional air travel markets exclusively based on cost economics rather than on passenger preference aspects. Moreover, as turboprops are more economic than jets on shorter routes, these airlines are able to experiment with new routes at lower operational costs without considering passengers' preference. If the new route does not prove itself to be profitable, the result cannot be attributed to turboprop's utilization. On the other hand, however, we stress that our results are confined to the evidence from the Brazilian markets and therefore recommend that further investigation into the issue of the "turbo aversion hypothesis" be attempted to examine the preferences of passengers in other countries and regions.

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