Article

Jet Fuel Efficiency in Brazilian Regular Air Transport

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Abstract: Since World War I, the commercial aviation industry has seen many improvements that now allow people and goods to reach the other side of the world in few hours, consuming much less fuel than in recent decades. Improvements in cargo capacity and energy efficiency were significant and, in this scenario, commercial airlines were able to thrive and bring great benefits to world economy. However, this sector is facing environmental challenges due to the intensive use of aviation fuel. Brazil is one of the largest domestic air passenger markets in the world and still has great growth potential, considering its economic potential and territorial dimensions: roughly the same size as the US and twice the size of the European Union. This paper discusses partial productivity of jet fuel in Brazilian domestic aviation and proposes an econometric method to support public regulators and airlines decisions. The proposed model uses variables such as aircraft size, route characteristics and idle flight capacity in a panel data analysis. The results show that reducing idle capacity is one of the best ways to achieve better short-term fuel efficiency and therefore will reduce environmental impacts and have positive economic effects on commercial air transport activities.

Keywords: Jet fuel productivity; Environment; Idle capacity; Panel Data

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1. Introduction

Research to improve aviation fuel efficiency and productivity has been an ongoing effort for aviation companies and mainly Airlines and Turbines Manufactures. Discussions on fuel consumption efficiency can help sustainable air transport activities around the world and particularly in emerging countries such as Brazil.

The aviation industry is at the forefront of industry in reducing the adverse impacts of its activities, which to some extent contribute to the economic efficiency and sustainability of air transport services. Market pressures, including regulatory measures and competition, require business productivity improvements, whether they are material suppliers (such as turbine and aircraft manufacturers), service providers (such as air navigation service providers), ground operators (such as airports) or major entities in the production chain, the airlines themselves [[1]]. To some extent, the environmental and financial objectives of airlines are convergent at the airline's main operating cost [[2]] and the idle capacity is a concern in any industry because could resulting in increased capital needs and operating costs.

However, Schnell [[3]] suggests that airlines intentionally maintain idle resources in response to uncertain demand, anticipated growth opportunities and competition. This happens despite affecting the cost position of airlines, increasing the main operating cost component, which is fuel. In addition, environmental issues are on the agenda of all sectors. An important measure of efficiency in air transport is the weight carried by burnt fuel. This article discusses how to manage factors that affect partial aviation fuel productivity and how to achieve a situation that will allow the air transport industry to sustainably improve.

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Another significant step towards preservation and sustainability is to use renewable and non-polluting energy sources. There is a lot of research on alternative aviation fuels to reduce greenhouse gas emissions, however, there are still major barriers to their operation, given the high production costs and the scarcity of raw materials and processing plants. Therefore, this work will be limited to the analysis of operational alternatives that could contribute to fuel productivity, also proposing short term solutions to reduce the environmental impacts caused by the burning of aviation fuel.

Fuel burn productivity can be influenced by the airline's idle capacity expressed by the unused portion of aircraft capacity (load factor) and aircraft size and weekly frequency and among other factors. When an airline decides to take a specific route, it must make decisions about which aircraft to use and how often to fly a specific route. It also shall make decisions about which aircraft model to use and flight frequency. In this study, all variables will be indicated by their annual averages on each route. Givoni and Rietveld [4] found that airlines' choice of aircraft size depends on route characteristics rather than airport characteristics. Accordingly, aircraft size and flight frequency can be seemed as representing the supply side of route characteristics.

Although air transport is not on the list of the activities that most pollute the planet, its main environmental effect occurs at high altitudes, a very specific location and one that is of major concern to environmentalists [5]. As a result, because of their possible adverse impacts, air transport activities have been monitored with considerable attention. In Brazil, fuel burn in domestic air transport constitutes the leading source of pollution by this sector. In that light, this paper examines how air transport performance has progressed in terms of its consumption of jet fuel and discusses the prospects for the future. May we be reaching a limit or is there room to improve performance with existing technologies? Observation of real data on a market like Brazil's, estimated to become the fourth largest national market by the late 2020s [6], can yield important information as regards the world scenario. The paper's scientific contribution is concentrated in using an objective method to ascertain performance trend patterns in an industry that is important to the issue of sustainability and thus opening up a discussion of possible sector measures that can lead to new productivity gains, which are an essential factor for an industry with prospects of high growth rates in coming years.

This paper is organized into seven sections. The Introduction sets out the context and the problem issue to be addressed. The next section offers a directed Literature Review, which identifies the most relevant papers to be considered. The Methodology section then states the quantitative approach that will support the Brazilian fuel burn productivity and idle capacity in Brazilian domestic air transport presented in the following section. The Results and Discussion sections offer, respectively, an analysis of the results obtained by applying the methodology and the paper's contributions and suggestions for policies better suited to developing domestic air transport. Lastly, the Conclusion summarize the main findings and offer suggestions for concerns to be addressed in policy making related to jet fuel usage in Brazilian domestic air transport and opportunities for future research on the subject.

2. Literature review

Fuel burn correlates strongly with emissions, thus contributing directly to undesirable externalities in air transport [7] and it is the airlines' main cost item [2]. Papers examining issues relating to jet fuel burn generally address airlines' efficiency and their pollution potential namely: the depletion of oil, the possibility of replacing the fuel currently used with another that is less polluting. pollution-free or renewable, the option of other means of transport or even the introduction of an additional tax on jet fuel burn. Although no extensive literature review was presented, studies considered relevant to defining the approach of this paper were selected.

Simões and Schaeffer [8] examined Brazilian air transport's contribution to greenhouse gas emissions. They offer a series of mitigation options, which include improving air traffic flow management, introducing a tax on each flight based on jet fuel burn for the route, introducing intermodal options for the dense air connections between Rio de Janeiro and São Paulo by implementing a high-speed train and so on. They also estimate that, if the recommendations they propose were applied, they would reduce long-term CO2 emissions from air transport by 28.5%.

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Chèze et al. [9] made projections for aviation fuel demand in eight regions of the world for the period 2008-2025. Their forecasts were based on an econometric model using dynamic panel data. The main scenario they explored returned a 100% increase in world air traffic in the period, at an annual growth rate of 4.7%. In that same period, fuel burn would grow by 38%, at an annual 1.9%. They claim that this growth in consumption already takes account of all efficiency improvements to turbines and aircraft aerodynamics. Accordingly, their opinion is that technological progress will continue to be essential to mitigating the impacts of increasing air traffic on fuel burn. Given that the improvements introduced have not been reflected in lower fuel burn rates, they alert that it will take industry-wide disruptive innovation for that scenario to change.

O'Kelly [10] examined the efficiency of hubs from the environmental standpoint using fuel burn as an indicator of environmental cost. He considered the fuel cost associated with larger aircrafts in order to determine the implications of high load factors on dense routes and thus to specify the implications for hub and gateway location. He showed that by adding a fixed charge when modelling fuel burn, a multiple-allocation hub-and-spoke model can be adjusted to direct flow to the inter-facility connector. Chang et al. [11] studied the economic and environmental efficiency of 27 global airlines in 2010, using a data envelopment analysis model with the weak disposability assumption. They concluded that Asian airlines are generally more efficient, while the operational and environmental performance of European and North America airlines are inefficient. Airlines' inefficiency can be attributed to two main factors: inefficient fuel burn and less diversified revenue structure.

Park and O'Kelly [12] estimated fuel burn considering the distance between markets, with a given aircraft fleet composition and seat configuration. They concluded that distance is a crucial factor in estimating fuel burn: on long-haul routes, the lowest fuel burn rates are found in operations of from 1000 to 2500 nautical miles. They speculated that fuel burn per seat-distance can be considered a criterion for levying environmental taxes on airlines. Zou et al. [13] investigated fuel efficiency among 15 main airlines and their subsidiaries in the United States. They found that fuel burn is amply explained by, and strongly correlated with, revenue passenger miles (RPM) and number of take-offs and that, although regional airlines have improved accessibility provision, they display higher fuel burn per RPM.

González and Hosoda [14] examined the growing impact of commercial aviation on CO2 emissions in Japan, as well as the potential impact on climate change. The investigation comprised the effects of the aviation fuel tax introduced by the Japanese government on all domestic flights. They used a time series model with monthly observations of aviation fuel burn from 2004 to 2013. They estimated the amounts of CO2 emissions that would be produced in the event the fuel tax was not applied. Cui et al. [15], using data envelopment analysis, studied the impacts on airline performance resulting from emissions limits established by the European Union. They used total revenue as desirable output and greenhouse gas emissions as undesirable output. As input variables, they used number of employees and aviation fuel burn. The sample comprised 18 large global airlines, from 2008 to 2014, and the finding was which airlines showed most potential for increasing the outputs. Cui and Li [16] used data envelopment analysis to measure the dynamic efficiency of 19 airlines, from 2009 to 2014. The input variables selected were number of employees and aviation fuel burn; outputs were revenue tonne kilometers, revenue passenger kilometers and total revenue. The dynamic factor selected was capital stock. They concluded that Scandinavian, Emirates and Cathay Pacific were the sample's benchmark airlines.

Zou and Chau [17] estimate fuel price effects on freight volumes on various modes of transport in Shanghai. They found a causality running from rail to road transport. That allocating more time and routes for rail freight traffic and reducing rail freight taxes can increase the volume of rail freight and thus decrease overall energy use. Their findings contribute to the economics of freight transport, which correlates with the intent of our paper, which aims to show that idle capacity utilization can bring fuel efficiency without increasing gas emissions.

It can be seen from the literature review that research into jet fuel burn is directed to the environmental issue and leaves aside the discussion of financial benefits to airlines. There is a trend for such studies to address the issue of fuel burn in association with the definition of benchmark

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company and its relationship with the environment. Mostly, there is certain pessimism as to the possibility of significantly reducing fuel burn through short- to medium-term technological advances. However, there is the argument of the need for disruptive innovation in order to attain new levels of efficiency. The literature reviewed offered no discussion of operational proceedings that airlines in general can introduce on routes to reduce jet fuel burn. This study also examined mean partial productivity of fuel burn by air route, regardless of the airline, in terms of idle capacity and other market characteristics in Brazilian regular domestic air transport. This knowledge will both assist airlines in their planning and operating procedures and inform government formulation of regulations and policies to stimulate air transport, all with due regard for environmental concerns.

3. Idle Capacity Analytical Methodology

Panel data is a structure recommended when the explanatory variables are time dependent, also known as longitudinal data, representing repeated observations of a set of units in cross section. That is, the predictive and explanatory variables of interest are measured on different occasions, generally over time, for each single individual or element (in the case of this study, air routes). In longitudinal studies, the observations on an individual over time are correlated and thus demand statistical techniques that take account of that dependence [18]. Longitudinal data offer several advantages over data distributed in cross section or time series only. The benefits include being able to study dynamic relations over time and model differences among individuals [19]. Approaches using econometric analysis of panel data have evolved over the years and experts have developed several methodologies to contemplate specific characteristics of the observed data [20]. The literature recommends experimenting with various approaches in order to select the most appropriate modelling. Statistical tests have been developed to assist the process of selecting among approaches.

The analytical model proposed in this paper endeavours to explain the relation between partial productivity of fuel and idle capacity. As the paper focuses on average air transport efficiency per route per year, no distinction is made between airlines and aspects of competition among airlines on the routes are not addressed. It is important to point out that in the model addressed in this study we aim to explain a variable related to the operational cost of the route which is strongly linked to the fuel consumption. Thus, the productivity of the fuel in a specific route in a given year can be determined by operational characteristics of the airline company operating that route in that specific year. There is an expectation that with the passing of years we can observe an improvement in the performance of airline companies related to the fuel usage either by the refinement of operational procedures or by a continuous technological improvement in the industrial sector such as more efficient airplanes and improvements in land operational and management procedures, more direct routes etc. In this sense, the hypothesis of a fixed or random annual effect will be tested in the choice of the model. Another important aspect is the characteristic of each route that cannot be explained solely by the distance between two airports. It is necessary to consider an effect for each route that must be fixed or random, accordingly with the statistical tests carried out. Therefore, in order to confirm the suitable type of model, we will perform the following tests: Redundant Fixed Effects or Chow test (Likelihood Ratio), Omitted Random Effects (Lagrange Multiplier), and Correlated Random Effects (Hausman test).

Once defined the Panel Data approach, it is necessary to consider the possibility of endogeneity in the model, which can define a Two Stage Least Square Panel approach using an instrumental variable. Therefore, the model will include: a variable that represents the usage level of the airplanes (capacity); an operational variable defining the airline companies in the route and an instrumental variable which can mitigate endogenous problems in the model. The dependent variable will be ton.km transported per liter of fuel. The variable linked to the level of usage will be the idle capacity which is determined by the airplane total capacity minus the annual average load factor. The airline companies' operational decision on the operation of the route will be represented by the annual average payload offered in that particular route. The models' instrumental variable will be the average weekly frequency of flights in a specific route per year. The proper effects of each route and of each period will be defined in accordance with the results suggested by the statistical tests carried

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out (fixed or random effects). In the period considered it is observed a uniform pattern of the fleet usage in the routes considered. Once the analysis is performed for each route per year, the specification and technical characteristics of the airplanes were not included in the formulation of the models.

All variables reflect the annual mean on each route (from city i to city j) for each year t. The corresponding model used to estimate the regression parameters is shown in Equation 1.

$$\ln FPROD_{i,j,t} = \omega_{i,j} + \eta_t + \alpha \ln \overline{IC}_{i,j,t} + \beta \ln ASIZE_{i,j,t} + \varepsilon_{i,j,t} \quad (1)$$

where,

$\ln$: the natural logarithm of the variables;

$\omega_{i,j}$: Cross-section fixed effect coefficients estimated;

$\eta_{i,j}$: Period fixed effect estimated;

α and β: regression model coefficients estimated;

$FPROD_{i,j,t}$: mean fuel productivity on route i to j in year t;

$ASIZE_{i,j,t}$: mean aircraft size on route i to j in year t;

$\overline{IC}_{i,j,t}$: mean idle capacity on route i to j in year t; and

$\varepsilon_{i,j,t}$: regression error.

$\overline{IC}_{i,j,t}$ instrumental variable in Equation 2.

$$\ln \overline{IC}_{i,j,t} = c + a \ln ASIZE_{i,j,t} + b \ln WF_{i,j,t} + u_{i,j,t} \quad (2)$$

where,

$WF_{i,j,t}$: mean weekly frequency on route i to j in year t;

$u_{i,j,t}$: regression error.

c,a and b regression model coefficients estimated;

4. Data

The data set was formatted as unbalanced panel data for domestic air routes in Brazil from 2007 to 2016. Although the data base comprises information since the year 2000 the period chosen for the analysis was defined considering the years when the four airline companies operating the air domestic Brazilian routes reached the figure of 90% of market share (see Table 1). From 2000 up to 2006 Brazil experienced a process of consolidation and bankruptcy of Brazilian airline companies which caused the market to be unstable considering its operational conditions. From 2007 on, two airline companies, TAM and GOL, dominated the Brazilian domestic air market. After this year, AVIANCA which entered the market in 2003 began to have a significant share; in 2008 AZUL entered the market increasing very quickly its share. In 2016 these four companies represented 99% of the market share for commercial domestic routes. The evolution of participation in revenue passenger-kilometer (RPK) in the total of Brazil is shown in Table 1.

The annual information was organized from the available Brazilian National Civil Aviation Agency (ANAC) data base. The main reason the data set is unbalanced is the variation in Brazil's air transport network during the study period, mainly regional routes. Additionally, to avoid the presence of outlier data, two conditions were stablished for the sample. The first considers that the route should have at least the average of one round trip per week. The second stablished that load factor should be higher than 10%. These two conditions limit the sample to regular operations along the year, avoiding seasonal or sporadic operations.

Table 1. The 4 main Airlines percentage of the Brazil's total domestic RPK

ANO	TAM	GOL	AZUL	AVIANCA	TOTAL
2000	14%	0%			14%
2001	30%	5%			35%
2002	34%	11%			45%
2003	32%	19%		0%	51%
2004	35%	21%		0%	56%
2005	42%	26%		0%	68%
2006	48%	34%		1%	84%
2007	48%	40%		2%	90%
2008	50%	37%	0%	3%	90%
2009	45%	41%	4%	3%	92%
2010	43%	40%	6%	3%	91%
2011	40%	37%	9%	3%	89%
2012	40%	34%	10%	5%	90%
2013	40%	35%	13%	7%	95%
2014	38%	36%	17%	8%	99%
2015	37%	36%	17%	9%	99%
2016	35%	36%	17%	11%	99%

Once there is a relation linking the amount of fuel an airplane needs at the moment of take-off, the total weight of the airplane, the embarked weight and the airport at the destiny, an approach to measure the partial productivity of fuels is the transported weight per fuel unity because this ratio reveals the specific average performance of usage of fuels, an important input for airline companies. Thus, in this paper we adopt the Work Load Unit (WLU) as an indicator of the weight being transported. Fuel is the most relevant item in the raising of airline companies' operational costs in Brazil. Estimates indicate that 40% of those total operational costs are due to the fuel consumption.

Fuel efficiency was chosen as the dependent variable because it displays characteristics that are important both to airline performance and to monitoring the use of this resource and related

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environmental impacts. Airlines reduce their operating costs by increasing the productivity of this important item on their cost spreadsheets. Meanwhile, society benefits from an activity that is essential to economic and social development by its efficient use for which there is, as yet, no alternative, but which results in adverse environmental impacts. Another no less important aspect is that productivity is fundamental to economic and social development, and no measure should neglect this variable as an important item in the decision-making process, as regards both air transport policy and airline operations planning. At present, one prominent policy aspect is restrictions on pollutant gas emission levels. The fuel productivity variable is expressed by Equation 3.

$$FPROD_{i,j,t} = \frac{RTK_{i,j,t}}{FUEL_{i,j,t}} \tag{3}$$

where,

$RTK_{i,j,t}$: total revenue tonne-kilometer on route i to j in year t;

$FUEL_{i,j,t}$: total fuel burn on route i to j in year t.

A revenue tonne-kilometer (RTK) is generated when a metric tonne of revenue load is carried one kilometer. Where that load includes passenger load, the number of passengers is converted into weight load, usually by multiplying this number by 90 kilograms (to include baggage).

The independent variable of the model, the idle capacity ($1-LF_{i,j,t}$), represents what percentage of capacity offered is not used by the market. The $LF_{i,j,t}$ variable is estimated as the ratio of RTK to ATK. Available tonne-kilometers (ATK) is the volume of tonne-kilometers offered, that is, the sum of the product of payload (the total available load weight per aircraft available for transporting passengers, freight and post) and the route distance. A high load factor means that the flight is being more fully utilized and accordingly it is expected that fuel burn productivity will be higher. This is one of the main indicators of air transport performance and will be significantly related to the partial productivity of fuel. The variable $LF_{i,j,t}$ is expressed by Equation 5.

$$LF_{i,j,t} = \frac{RTK_{i,j,t}}{ATK_{i,j,t}} \tag{5}$$

where,

$RTK_{i,j,t}$: total revenue tonne-kilometer on route i to j in year t;

$ATK_{i,j,t}$: total tonne-kilometers available (supplied) on route i to j in year t.

The aircraft size variable $(ASIZE_{i,j,t})$ is represented by the mean payload supplied on the route in a certain year. The variable $ASIZE_{i,j,t}$ will be expressed by Equation 4.

$$ASIZE_{i,j,t} = \frac{PAYLOAD_{i,j,t}}{TAKEOFFS_{i,j,t}} \tag{4}$$

where,

$PAYLOAD_{i,j,t}$: total payload supplied on route i to j in year t;

$TAKEOFFS_{i,j,t}$: total take-offs on route i to j in year t.

This is a decisive variable by which the airline determines how much transport capacity to offer on the market. Although cases of over-supply may exist for reasons of competition, such cases are distributed across all operations on the route in the year, thus reducing the bias that such cases can cause in assessing the variable. As the study worked with a very large data set it is to be expected that such distortions will be minimized.

As the presented model suggests the possibility of endogeneity, it was necessary to include a decision variable related to the airline companies in order to mitigate this problem. This was done

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using Least Squares Two Stage Panel model estimation. The chosen variable was the average weekly frequency of take-offs, observed in a specific year for that route. This variable is defined according to Equation 6.

$$WF_{i,j,t} = \frac{TAKEOFFS_{i,j,t}}{52} \tag{6}$$

where,

$WF_{i,j,t}$: average weekly frequency on route i to j in year t.

5. Case study

Brazil covers a geographical area of 8.5 million km², making it the world's fifth largest country, after Russia, Canada, China and the United States. After Brazil, the countries with the largest territories are Australia and India. It also has the fifth-largest population: 205 million in 2015. Its economy ranks seventh, with a gross domestic product (GDP) of about 3.192 trillion Int$ (PPP $ - International dollar) in 2015. Also, in 2015, however, with per capita GDP of about 15,600 Intl$, Brazil ranked only 76th, far from the group classified as developed countries – as is also the case with other countries with large territories and significant GDPs, such as Russia, China and India. Brazil is a federative republic of 26 states and a federal district (the capital city). Each Brazilian state has a municipality where the state capital city is located. Brazil has 5570 municipalities, of which 309 had populations of more than 100,000 residents in 2016, a condition that may be considered attractive for air transport operations when the town is at a certain distance from any airport with regular air transport. Rail passenger transport is practically non-existent, and the road transport network is weak in much of Brazil, particularly in the Mid-west and North regions and a large part of the Northeast. Figure 1 shows number of domestic passengers and amount of cargo embarked at Brazilian airports and the number of towns served by regular domestic air transport. Domestic air transport accounts for some 90% of passengers embarked at Brazil's airports – just over 85 million passengers in 2016. Meanwhile, it is important to note that, from 2015 to 2016, the number declined as a result of the severe political and financial crisis affecting Brazil. Domestic cargo grew between 2007 and 2011 but has subsequently steadily declined. The number of airports offering regular domestic air transport services has decreased over the years, indicating that traffic is being directed towards higher-density routes, where it is easier to optimize operations.

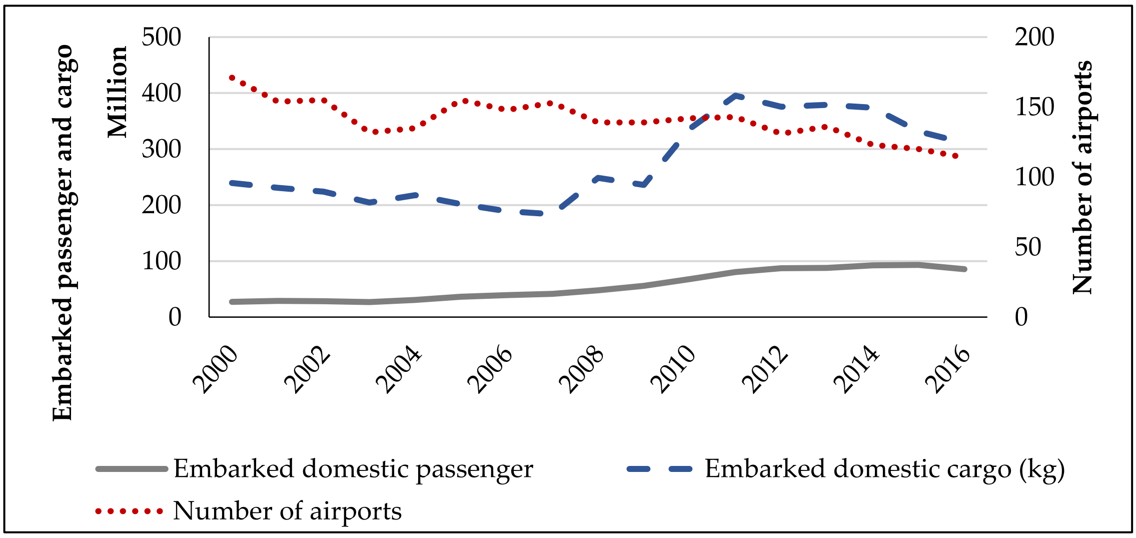

Figure 1. Domestic passenger and cargo movement and number of airports. Source: ANAC

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Table 2 shows the passenger aircraft fleet of Brazilian air transport airlines for a set of years. The figures in the Table show a decreasing number of smaller aircraft, while the number of those with more seats are growing, a trend that is significant when thinking about Brazilian regular air transport. The two first levels of Table 2 show significant changes throughout the years and are linked to an important reduction of the regional routes in the period. We can see that in the case of regional routes there is a trend towards standardization of airplanes in the range 51-150 seats. In the three intermediary levels we see a diminishing of the number of airplanes due to a search for offer optimization in domestic traffic related to regular and non-regular main routes. The least two levels of airplanes are related to international long routes which are not addressed in this paper.

The movement is consistent with efforts by airlines, which are undergoing financial difficulties and have not returned positive financial statement balances in recent years, to optimize their operations. This trend reduces the flexibility available to airlines for matching supply and demand, particularly on regional aviation routes where demand is fluctuating.

Table 2. Aircraft fleet of Brazilian airlines 2000, 2007 and 2016

Seats	2000	2007	2016
Up to 50	141	122	6
51-100	-	36	52
101-150	212	182	139
151-200	13	226	211
201-250	13	50	48
251-300	13	14	5
Over 300	-	-	16
Total	405	630	498

Source: ANAC

Tables 3 and 4 show, respectively, the descriptive statistics and correlation matrix of the variables used in the analysis, in terms of natural logarithm and their specific units. By and large, all the variables can be seen to vary substantially about the mean, while upper and lower values are quite distant. The minimum flight distance considered for analysis was 200 km, which is regarded as reasonable by Brazilian air transport experts for establishing regular flights between two localities.

Table 3. Descriptive statistics for variables of the model

	$\ln(FPROD_{i,j,t})$	$\ln(IC_{i,j,t})$	$\ln(ASIZE_{i,j,t})$	$\ln(WF_{i,j,t})$
Upper	2.82	-0.22	10.47	6.57
Lower	-4.13	-4.30	7.59	0.00
Mean	0.50	-0.90	9.30	2.47
Standard deviation	0.43	0.31	0.51	1.22
Obs.	5839			
Correlation matrix				
$\ln(FPROD_{i,j,t})$	1			
$\ln(IC_{i,j,t})$	-0.70	1		
$\ln(ASIZE_{i,j,t})$	0.52	-0.31	1	

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$\ln(WF_{i,j,t})$	0.22	-0.23	0.53	1

Table 4. Descriptive statistics for variables of the model without the logarithm

	$FPROD_{i,j,t}$	$IC_{i,j,t}$	$ASIZE_{i,j,t}$	$WF_{i,j,t}$
Upper	16.80	0.80	35100	714
Lower	0.02	0.01	1980	1
Mean	1.79	0.43	12246	26
Standard deviation	0.73	0.12	5165	50
Obs.		5839		
Correlation matrix				
$FPROD_{i,j,t}$.	1			
$IC_{i,j,t}$	-0.69	1		
$ASIZE_{i,j,t}$	0.49	-0.31	1	
$WF_{i,j,t}$	0.027	-0.08	0.31	1

In the period 2007/2016, the means of all variables had a favorable variation for the improvement of performance (Table 5). Fuel productivity is improving in regular domestic aviation in Brazil. From 2007 to 2016, the annual mean of RTK per liter of fuel observed in the sample increased from 1.95 to 2.40. Annual mean of IC reduced from 0.42% to 0.34%, the annual mean of $ASIZE$ reduced from 17310 kg to 16483 kg and the annual mean of WF increased from 8841 to 15087.

Table 5. Annual evolution of the annual mean of $FPROD$, IC, $ASIZE$ and WF from 2007 to 2016

Year	$FPROD$	IC	$ASIZE$	WF
2007	1.95	0.42	17310	8841
2008	1.95	0.41	17215	9231
2009	1.96	0.34	14892	10697
2010	2.11	0.36	16458	12208
2011	2.19	0.35	16484	13676
2012	2.19	0.34	16359	14352
2013	2.19	0.33	16344	15169
2014	2.30	0.31	15491	17172
2015	2.29	0.34	16080	16942
2016	2.40	0.34	16483	15087

6. Results and discussion

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As described in the Methodology, the Chow, Breusch-Pagan and Hausman tests were applied for the definition of the estimation pool, with fixed or random effects for the cross-sections and the periods. The Chow test (Table 6) rejected (p-value <0.05) the null hypothesis of pool estimation for the cross sections as well as the periods, suggesting that the fixed effects are more suitable.

Table 6. Redundant fixed effects tests (Chow test)

Test cross-section and period fixed effects			
Effects Test	**Statistic**	**d.f.**	**p-value**
Cross-section F	9.91	(987,4840)	0.00
Period F	21.18	(9,4840)	0.00
Cross-Section/Period F	10.22	(996,4840)	0.00

The tests to verify the random effects versus no effect (pool), rejected also the null hypothesis of the pool modelling (p-value < 0.05), suggesting in this case that the random effect is the most suitable. Table 7 shows the results of the tests performed.

Table 7. Lagrange Multiplier Tests for Random Effects (Breusch-Pagan LM)

	Test Hypothesis		
	Cross-section	**Time**	**Both**
Breusch-Pagan	4624.83	811.51	5436.34
p-value	(0.00)	(0.00)	(0.00)

For the definition between the fixed and random effects for the cross sections and the periods the Hausman Test was applied (Table 8). Either for the cross sections and the periods, the Hausman Test rejected the null hypothesis for random effects (p-value<0.05). In this case, the modelling developed considered the fixed effects for cross-sections and for periods.

Table 8. Correlated Random Effects - Hausman Test

Test Summary	**Chi-Sq. Statistic**	**Chi-Sq. d.f.**	**p-value**
Cross-section random	304.02	2	0.00
Period random	8.45	2	0.01

After examining the various possible options for evaluating panel data modelling, panel two-stage least squares regression model was selected as the most suitable estimator for this analysis. The Chow test (for cross-section fixed effects) indicated that the fixed-effect model fitted better than the pool approach. On the same way Breusch-Pagan LM test indicated that random fixed-effect fitted better than the pool approach. Finally, the Hausman test (of cross-section random effects) showed that the fixed-effect was also better suited than the random-effect for both cross-section and period. Table 9 shows the result of the regression model applied in the study.

Table 9. Panel two-stage least squares regression model

Dependent Variable: $\ln(FPROD_{i,j,t})$

Periods included: 10; Cross-sections included: 988

Total panel (unbalanced) observations: 5839

Instrument specification: $\ln(ASIZE_{i,j,t})$ $\ln(WF_{i,j,t})$ **C**

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Variable	Coefficient	Std. Error	t-Statistic	Prob.
$\ln(\overline{IC}_{i,j,t})$	-0.94	0.47	-2.01	0.04
$\ln(ASIZE_{i,j,t})$	0.48	0.15	3.24	0.00
C	-4.81	1.80	-2.67	0.01
Effects Specification				
Cross-section fixed (dummy variables)				
Period fixed (dummy variables)				
R-squared		0.84		
Adjusted R-squared		0.81		

As this is potential modelling, the coefficients of the explanatory variables represent the constant elasticities of each of them in relation to a dependent variable. The constant elasticity hypothesis can be considered a limitation of the model. However, it is reasonable in that the operating technology in question is similar in all the airlines and no technology breakthrough was observed in the study period. This is confirmed to some extent by the high level of significance of the coefficients of the independent variables. The elasticity of $IC_{i,j,t}$ (-0.94) indicates the negative impact that idle capacity has over fuel productivity, on the other way, the elasticity of $ASIZE_{i,j,t}$ (0.48) shows a positive impact. These two variables can be managed by airlines when they define their level of supply and target market. The variation in the annual means of the variables from 2007 to 2016 shows that the Brazilian airlines are working in the right direction. However, the high level of idle capacity (Table 5) indicates that there is significant room for improvements in operations. It is not only a question of attracting more passengers to air transport, but also of attracting more cargo and postal business. That is not exclusively up to the airlines: the logistical conditions of airport access and bureaucratic streamlining of tax procedures are also extremely important to making this modality of cargo transport more attractive. $IC_{i,j,t}$ is much more elastic than $ASIZE_{i,j,t}$ and, accordingly, it should be borne in mind that good productivity can be attained by focusing on $IC_{i,j,t}$, with no need to abandon lower-density regional routes. The idea is to have a balanced fleet and frequency suited to the type of network that is possible for the Brazilian market. Should the fleet development trend observed in Table 2 continue, the only alternative will be largely to abandon the regional routes, which is neither good for Brazil's economic development nor for the future of regular domestic aviation.

Table 10 shows the period fixed effect dummy variables coefficients from 2007 to 2016. They show no trend to influence positively the fuel performance, four out of ten coefficients are negative. Although the balance is positive, it is a very little positive effect. Considering that, it may be said that technological advancements did not contribute much for the fuel performance improvement. Only a technology breakthrough in air transport could change that scenario.

Table 10. Period fixed effect

Year	Effect
2007	0.051331
2008	0.000610
2009	-0.044556
2010	0.068665
2011	0.037720

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2012	0.005737
2013	-0.003723
2014	-0.075073
2015	-0.030518
2016	0.014526

Figure 2 show the cross-section fixed effects coefficients. From the 988 cross-sections of the study 550 have a positive dummy coefficient and 438 a negative one. The dummy coefficients vary from -2.29 to 0.88. Among the 988 cross-sections 23 have their coefficients between -0.50 and -2.29. On the opposite direction from 0.50 and 0.88 there are 15 routes. From this it is possible to say that only few routes offer extreme negative or positive operational conditions.

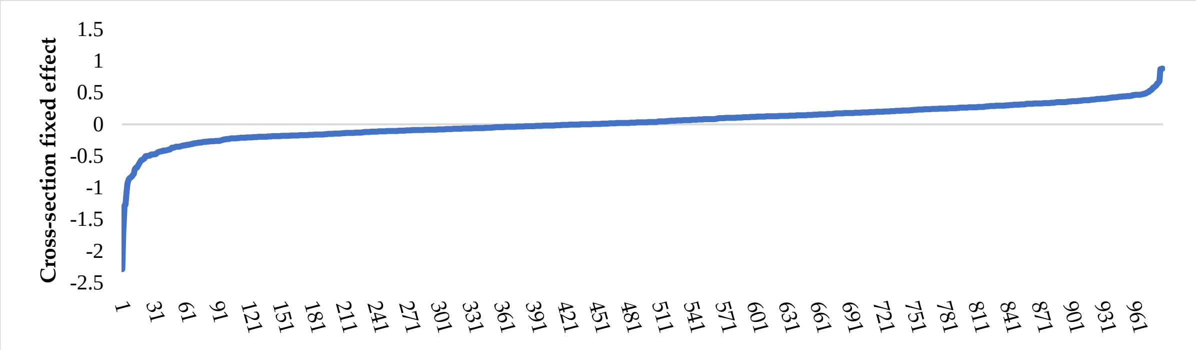

Figure 2. Cross-section fixed effect coefficients

This paper starts with the observation of Schenell, [3], about airlines keeping excess capacity to cope with future demand or competition. Actually, this rationality makes the industry less competitive and inefficient. Once a flight is done, its empty payload does no become revenue and it is lost forever, it become just a cost. This look like a predation strategy and not a good competitive strategy. Naturally, reduced supply may lead to customer discomfort, which is another important point in the analysis. However, when considering an activity that is important to a society's economic development but has adverse collateral effects on the environment (which belongs to the whole society), one has to strive for high levels of performance in the use of resources that produce the effect in question. It is important to raise air transport user awareness of the environmental problems connected with this form of transport, so as to raise tolerance of any possible discomfort that may be necessary in order to increase the productivity of aviation fuel burn. In air transport, idle capacity can be divided into two components: the first is where an airline retains capacity that it does not use, such as an aircraft that is idle for lack of demand; the second is more perverse, involving non-use of a service, which is the case of unused capacity on a flight. The latter, in addition to generating operating costs with no revenue offset, produces environmental harm. Obviously, it is impossible to eliminate all such idle capacity, but airlines and regulators should seek to develop mechanisms to reduce idle capacity in this industry.

Another important concern for countries' air transport policy making is the introduction of a pollution tax on airlines, which will inevitably be transferred to the fare prices the airlines charge their customers. In developing countries such as Brazil, where air transport is under-used and whose transport networks display a number of deficiencies, this subject should be studied with care. If not deployed appropriately, such a tax could be a disincentive to the use of air transport and, by transferring part of the demand to road transport, causing more harm, both economic and environmental, than benefits. Air transport policy should use the tax as an incentive to improve fuel burn productivity by not taxing high-productivity flights, thus encouraging airlines to refine their business portfolios by acting more representatively in cargo transport, for instance. The emphasis on

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productivity would stimulate airlines to strive for greater operational efficiency, rather than being discouraged by a market retraction due to higher operating costs.

5. Conclusions

This paper presents an approach that yields objective measures of the relation between aviation fuel burn, airline operating procedures and future developments regarding fuel efficiency. It also reveals convergent association between improved airline operations and finances and reduced aircraft fuel burn, resulting in lower pollutant gas emissions, in keeping with ICAO recommendation [21]. By a productivity approach, in physical terms, to airlines' main operating cost item, the paper discussed the possibilities of improving the partial productivity of aviation fuel in the Brazilian regular domestic air transport. In that context, it addressed opportunities for improvement in technological, regulatory (government) and operational (airline) terms.

The discussion indicates that the reduction of idle capacity is the most important operational variable in improving the efficiency of the air fleet in Brazil. Another route, regarding the development of a new Jet Fuel with a better rate of emission and energy efficiency can aggregate important gains. The experiences with sugar cane residues and synthetic mixtures began in 2006 aiming at improving the performance of RTK per liter of fuel in air transport. The intention to continue with the research was affirmed in the 2019 release of the Petrobras Strategic Plan and in a continental country like Brazil this means good perspectives for the coming years [22].

Domestic air transport in Brazil offers significant opportunities for improving performance through operational factors. Very high idle capacity can be reduced through operations by making better use of payload supplied; this improvement can be obtained by developing cargo transport and higher seat occupation rates. To that end, airlines must manage their service supply and prices more efficiently. Regulatory agencies can contribute significantly by setting standards favoring airlines that achieve lower idle capacity. For example, approval for new frequencies could be made conditional on achieving idle capacity more compliant with standards, set by the regulator, of ATK not used per liter of fuel, which is the variable considered for analysis here. The study shows important opportunities for improving airlines' financial performance and making more efficient fuel burn in regular domestic air transport in Brazil. Table 5 shows that although idle capacity is reducing in the regular domestic air transport in Brazil, it still very high.

Airlines should be encouraged to increase aircraft size only on routes that can support such growth without decline in load factor. The study confirms that from both environmental and financial standpoints, it is important that airlines operate with the lowest possible idle capacity, as can be seen from the elasticity performance of this factor in the model shown in Table 9. Airlines' fleet composition is fundamental in order to serve their networks with the lowest possible idle capacity. Increasing aircraft size without prior study and proper regulatory procedures can lead to regional aviation being abandoned or neglected, as has been the trend in Brazilian domestic air transport.

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