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RAFAEL PAIVA TEIXEIRA

A TWO-STAGE NETWORK DEA APPROACH FOR ASSESSING EFFICIENCY SCORES OF THE BIGGEST AIRPORTS IN BRAZIL

Rio de Janeiro

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Master's dissertation presented to the Instituto Coppead de Administração, Universidade Federal do Rio de Janeiro, as part of the mandatory requirements in order to obtain the degree of Master in Business Adminstration (M.Sc.).

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ABSTRACT

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This dissertation aims to measure and analyze the efficiency of the most relevant Brazilian airports using a two-stage network DEA analysis. The first stage will focus on examining the Infrastructure efficiency of the selected airports. Then, the second stage will target the evaluation of their Business efficiency. The results of this NDEA indicate that the airports analyzed do not have high levels of both Infrastructure and Business efficiency at the same time. After that, these efficiency scores were coupled up with some contextual variables and used in a regression analysis that showed that the airports managed by the private sector have not had a better result in the Customer Satisfaction Index compared to those still managed by the public sector.

LIST OF FIGURES

LIST OF TABLES

SUMMARY

1. INTRODUCTION

1.1. Research motivation

In beginning of the decade there was a general perception that the infrastructure of Brazilian airports had many bottlenecks that needed to be overcome in order to sustain its economic development. This perception was a consequence of different factors. At that moment, there was an increased demand for airport services due to a combination of economic growth, better income distribution, increased availability of consumer credit and decrease of airfare prices.

Furthermore, Brazil was set to host mega events such as the 2014 World Cup and the 2016 Olympic Games in Rio de Janeiro, which created an expectation for the arrival of a large number of tourists in the country that would result in a sharp and huge increase in the demand for airport services.

Within this scenario, the Brazilian government had, at first, two options for expanding the investments in the airport’s infrastructure. First, the *Empresa Brasileira de Infraestrutura Aeroportuária* (INFRAERO), a state-owned company responsible for operation of the main commercial airports in Brazil, could invest in the airport segment with government resources. Second, the government could grant some airports for the private sector, with the condition that the sector would be responsible for doing the expansion needed.

Ultimately, the government opted for a mixed strategy, which combined direct investments with public funds and concessions for the private sector. INFRAERO invested in airports such as Santos Dumont (Rio de Janeiro) and Congonhas (São Paulo). Meanwhile, the government executed a big concession plan, transferring some of the most important airports in Brazil, such as Guarulhos (São Paulo), Galeão (Rio de Janeiro), Viracopos (São Paulo), Brasília (Federal District) and Confins (Minas Gerais), to the private sector, keeping INFRAERO as minority shareholder. The Brazilian government also granted other airports to the private sector, in different regions of the country.

Considering the development of this process and the importance of airport infrastructure in Brazil, this dissertation aims to analyze the evolution of the efficiency in the 15 biggest airports in Brazil between 2013 and 2017. Among the selected airports, six of them were already operated by private companies in the same period, and the remaining were operated by INFRAERO.

The purpose of this research is to evaluate if the efficiency of the main Brazilian airports has increased in this period, and to compare if the private-managed airports achieved better efficiency than those still managed by the public sector. Moreover, it will be assessed how the efficiency of the evaluated airports affects the satisfaction of its customers.

In order to do so, this dissertation will apply a two-stage data envelopment analysis (DEA) model, also known as Network DEA (NDEA) to calculate two sets of efficiencies. The first will measure the infrastructure of the airports, and the second will measure its business performance.

For the first stage of the NDEA, initial inputs of Terminal Size (m^2), Number of Fingers, Number of Parking Slots, Tracks Length ($m^{2)}$, Tracks Width (m2), Number of Tracks, Terminal Capacity and Aircraft's Movement (landings and takeoffs) will be used to evaluate the infrastructure efficiency. Then, in the second stage of the NDEA, the former two variables will be used to determine the final outputs of Number of Passengers and Tons of Cargo transported, in order to evaluate its business performance. Finally, it will be measured how these efficiencies can affect the Customer Satisfaction index.

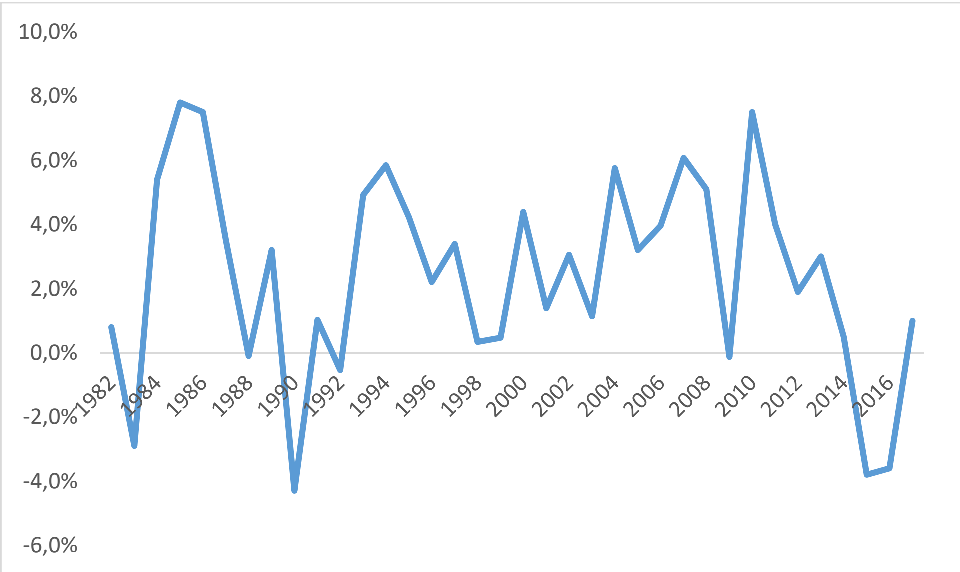
With this method, it will be possible to evaluate if the airports that were granted to the private sector perform better than those still manage by the public sector. Moreover, this dissertation intends to observe how the level of efficiency can affect the degree of satisfaction of the airport's customers, using Ordinary Least Squares (OLS), during the period of 2013 to 2017.

1.2. Contextual settings

According to Yoshimoto et al. (2016), the airport segment in Brazil was highly regulated both in price and entry rules. However, between 1992 and 2002, there were successive rounds of liberalization of the civil aviation market, which helped extinguish the airlines monopoly, increase price competition and open the market for the entry of new companies. This liberalization of the sector brought more dynamism in the offer of air travel services, fostering the outbreak of demand in recent years.

Brazil's GDP grew at an annual rate of 2.6% between 1982 and 2001 and 3.6% between 2002 and 2014, while airplane ticket prices declined over the years. As a result, the demand for air tickets increased, impacting directly the airport services' supply and quality. Because of that, the infrastructure bottlenecks of the Brazilian air network became evident.

Figure 1 – Brazilian GDP growth



In 2010, BNDES (the National Bank for Economic and Social Development in Brazil) hired Mckinsey, an international consulting company, to evaluate the situation of the Brazilian airports' infrastructure. The research showed the existence of bottlenecks in 13 of the 20 largest airports terminals. This situation, besides generating a significant deterioration in the quality of the services, would tend to pressure ticket prices, putting the social benefits achieved with the liberalization of the sector at risk. In addition, a saturated airport infrastructure would also have negative consequences for the economy of the country, like limiting the mobility of executives and tourism travelers.

In order to overcome existing and future bottlenecks, one of the proposed solutions was to attract entrepreneurs willing to invest in the sector by conceding public managed airports to the private sector. By doing so, instead of expending public resources in order to improve the current infrastructure, the government would receive a huge amount of concession requests for grants and the private sector would be in charge of investing in the airports.

The first airport granted to the private sector was in Natal International Airport in 2011. Afterwards, two major concession rounds were made in 2012 and 2013, for Guarulhos International Airport (São Paulo), Brasília International Airport (Federal District), Viracopos International Airport (São Paulo), Rio de Janeiro International Airport/Galeão (Rio de Janeiro) and Confins International Airport (Minas Gerais). In 2017, another round was carried out contemplating Fortaleza International Airport (Ceará), Porto Alegre International Airport (Rio Grande do Sul), Salvador International Airport (Bahia), and Florianópolis International Airport (Santa Catarina).

The table below summarizes the airports that were studied in this research. They were selected based on their relevance in the airport sector and because they were the ones that had available customer satisfaction data for the period.

Table 1 – Airports analyzed in this study

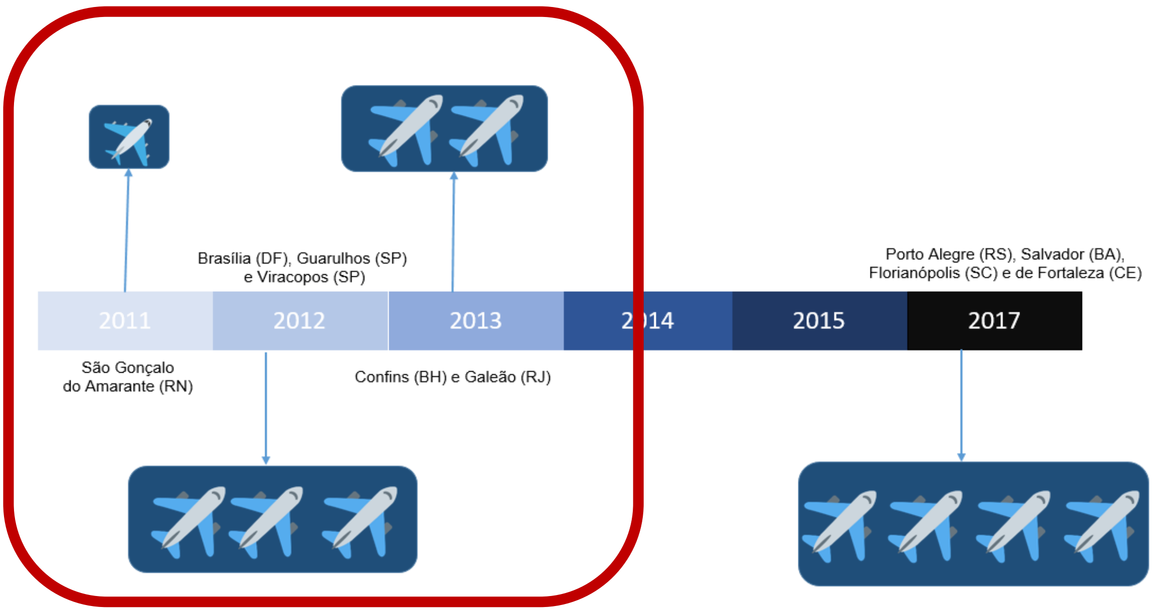
Airports researched	ICAO Code	Operation (1)
Brasília International Airport (Brasília-DF)	SBBR	Granted
Guarulhos International Airport /Governador André Franco Montoro (Guarulhos-SP)	SBGR	Granted
Viracopos International Airport (Campinas-SP)	SBKP	Granted
Rio de Janeiro International Airport/Antônio Carlos Jobim/Galeão (Rio de Janeiro-RJ)	SBGL	Granted
Confins International Aiport /Tancredo Neves (Belo Horizonte-MG)	SBCF	Granted
São Paulo Airport/Congonhas (São Paulo-SP)	SBSP	INFRAERO
Rio de Janeiro Airport/Santos Dumont (Rio de Janeiro-RJ)	SBRJ	INFRAERO
Salvador International Airport/Dep. Luís Eduardo Magalhães (Salvador-BA)	SBSV	INFRAERO
Porto Alegre International Airport/Salgado Filho (Porto Alegre-RS)	SBPA	INFRAERO
Recife International Airport/Guararapes - Gilberto Freyre (Recife-PE)	SBRF	INFRAERO
Afonso Pena International Airport (Curitiba-PR)	SBCT	INFRAERO
Governador Aluízio Alves International Airport (Natal-RN)	SBSG	Granted
Manaus International Airport/Eduardo Gomes (Manaus-AM)	SBEG	INFRAERO
Cuiabá International Airport/Marechal Rondon (Cuiabá-MT)	SBCY	INFRAERO
Fortaleza International Airport/Pinto Martins (Fortaleza-CE)	SBFZ	INFRAERO

(1) Status in 2017

As shown in Table 1, Governador Aluízio Alves International Airport (Natal-RN), Brasília International Airport (Brasília-DF), Guarulhos International Airport/Governador André Franco Montoro (Guarulhos-SP), Viracopos International Airport (Campinas-SP), Confins International Airport/Tancredo Neves (Belo Horizonte-MG) and Rio de Janeiro International Airport/Antônio Carlos Jobim/Galeão (Rio de Janeiro-RJ) have been operated and managed by private companies since their bidding rounds between 2011 and 2013.

Even though Porto Alegre International Airport/Salgado Filho (Porto Alegre-RS), Salvador International Airport/Dep. Luís Eduardo Magalhães (Salvador-BA) and Fortaleza International Airport/Pinto Martins (Fortaleza-CE) were granted in 2017, this dissertation will consider them as operated by INFRAERO since it takes a while for the operation to be transferred to the private concessionaire. In fact, INFRAERO operates the airport for the first months after it has been granted, then, there is a period of joint operation and, finally, the private company becomes fully responsible for operating and undertaking the airport.

Figure 2 – Brazilian biddings



2. LITERATURE REVIEW

There are many studies that focus on the efficiency analysis of airports in several countries. For the most part, these studies have used two main methods for assessing airport efficiency (Wanke et al., 2016): Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). The first method is directly associated to the econometric theory. The latter is a non-parametric method, related to mathematical programing.

As mentioned before, this dissertation will be based on the DEA related methods. The Appendix of this study shows many DEA related studies that consider different sets of Decision Making Units (DMUs), inputs and outputs in order to measure airport efficiencies.

Nwaogbe et al. (2018) and Wanke et al. (2016) have respectively examined 30 and 36 airports in Nigeria. Périco et al. (2017) estimated the efficiency of 16 airports in Brazil. Wanke and Barros (2016) investigated a sample of 19 airports in Latin America. Tsui et al. (2014) focused their study in 11 airports in New Zealand. Tavassoli et al. (2014) analyzed 11 Iranian airports. Wanke (2013) wrote two articles exploring a sample of 63 airports in Brazil. Gitto and Mancuso (2012) estimated the efficiency of 28 airports in Italy. These are just some examples of recent studies that used DEA-methods to calculate airport efficiency, as shown in the Appendix.

Even though the airport segment is key for improving the Brazilian economy, there is a lack of DEA-based publications in international journals analyzing the efficiency of the sector in the country. Moreover, the existing ones are not up to date, and do not reflect the changes in the sector due to the recent government program of airports concessions. Table 2 summarizes DEA studies about airports in Brazil.

Périco et al. (2017) measures the efficiency of 16 international airports in Brazil between 2010 and 2012. By that time, 9 of the 16 samples airports were operating overcapacity. The results showed that the airport in Curitiba had the best efficiency scores and Galeão and Manaus had the worst scores. In addition, airports were classified as medium, huge and very huge[1]. The paper shows that the very huge ones were more efficient than the huge ones.

Wanke (2013) focused in the capacity issues in Brazilian airports by evaluating a sample collected in 2009 regarding 63 airports. This study concluded that most of them did not have the adequate infrastructure to meet future demand for growth. Some airports could only support it by decreasing the quality of their services. In other words, just few of them could handle a significant increase in passengers and cargo volume while keeping the quality of their services.

[1] Airports were classified as very huge (Guarulhos, Congonhas, Brasília e Confins), as huge (Salvador, Porto Alegre, Recife, Curitiba e Fortaleza) and as medium (Belém, Florianópolis, Maceió, Manaus, Natal, São Luís).

Table 2 – DEA-based studies on the efficiency of Brazilian airports

Authors	Sample Size	Sample Year	Methodology	Inputs	Outputs
Périco et al. (2017)	16	2010-2012	Bootstrapped DEA	Number of runways, number of check-in counters, number of parking places, passenger terminal area	Passengers
Wanke (2013)	63	2009	Two-stage Network DEA	Terminal area, aircraft parking spaces, runways, landing and take-offs per year, regular flights	Landing and take-offs, passengers, cargo
Wanke (2012)	63	2009	DEA VRS with bootstrapped efficiency estimates	Airport area, apron area, number of runways, total runway length, number of aircraft parking spaces, terminal area, and number of parking places.	Number of passengers, express cargo throughput, and number of landings and take-offs
Alana et al. (2011)	Monthly series	1999-2000	Fractional integration	Number of incidents	Victims, plane crashes, helicopter crashes
Pacheco et al. (2006)	58	1998-2001	DEA VRS envelopment, input-oriented model due	Payroll, operating expenses, employees	Passengers, cargo, operating revenues, commercial revenues
Pacheco and Fernandes (2003)	35	1998	DEA VRS envelopment, input (financial) and output-oriented (operational) models due to different airport sizes.	Employees, payroll, operating expenses	Passengers, cargo, mail, operating revenue, commercial revenue
Pacheco and Fernandes (2002)	35	1998	DEA CRS/VRS envelopment, output-oriented models	Airport area, check-in counters, departure lounge, curb frontage, vehicle parking spaces, baggage claim area	Passengers

Wanke (2012) used a sample of 63 Brazilian airports in 2009 to model a two-stage DEA analysis, where the first stage regarded physical infrastructure efficiency, and the second stage focused on flight efficiency. The results showed that the physical structure of most of the largest and newest airports in Brazil were not efficient. Moreover, only one sample, that was Viracopos (São Paulo), had a 100% score in flight efficiency.

Alana et al. (2011) analyzed the capacity bottlenecks of the airports in Brazil in a different manner. The author inspected the number of monthly incidents in airports between 1999 and 2000.

Pacheco et al. (2006) used a sample of 58 airports in Brazil between 1998 and 2001 in order to explore how internal management changes could affect the airport results. His study showed that the performance of most airports operated by INFRAERO improved just before shifts in the internal management.

Pacheco and Fernandes (2003) studied the management efficiency of 35 airports based on their 1998's financial performance. The results of the research showed that the most efficient airports in terms of management were also the ones with their physical capacity on the limit, meaning that they were already in need for investment in their expansion.

Finally, Fernandes and Pacheco (2002) analyzed the capacity of 35 Brazilian airports in 1998. By using demand forecasts, they measured when the selected airports should start to expand their capacity. The results of the paper showed that most airports in Brazil should have already started their infrastructure expansion by that time in order to attend future demand, considering the current level of their services.

In addition to the lack of DEA-based publications in international journals analyzing the efficiency of the airport sector in Brazil, there is no study regarding the relation between customer satisfaction and airport efficiency. Additionally, there are not enough studies that analyze these correlations taking as sample airports in other countries which shows a research a gap that should to be filled.

This dynamic has recently become more important, as Merkert and Assaf (2015) argued that airports are becoming more than just gateways for travelers and cargo. Instead, nowadays they are also becoming large shopping malls, logistics hubs and even mini cities. The consequence of this trend is that the quality of airport services becomes increasingly important for maximizing revenues and profits. Vokác et al (2017) defends that customer satisfaction is reflected both in revenue and costs. Satisfied customers are more willing to cooperate and are more likely to spend money, which reflects in the airport financial results.

In Brazil, analyzing customers satisfaction has become more important for granted airports since the concession agreements relates the ticket prices to the airports' Satisfaction Index. However, there is no study that examines this correlation in Brazilian airports, even though it is key for evaluating airport's performance, and that shows an important gap in this subject literature that this dissertation aims to address.

3. METHODOLOGY

3.1. The data

The data of the characteristics and performance, from 2013 to 2017, of the 15 selected airports, was collected from INFRAERO's website, the Air Transport yearly book from Agência Nacional de Aviação Civil (ANAC), which is responsible for regulating the aviation activities in Brazil, and from the respective airport's websites and annual reports. All these variables mentioned in this dissertation are very common in worldwide DEA-based studies, as explained in the Appendix.

The results of the Passenger Satisfaction Survey were collected from the website of the Brazilian Ministry of Transport, Ports and Civil Aviation website. The survey has been carried out since 2013 and it shows the degree of passengers' satisfaction with the processes and services offered by the airports.

The Passenger Satisfaction Survey is conducted through individual face-to-face interviews, where a standard questionnaire is applied to passengers in the boarding and landing areas of the surveyed airports. The survey aims to produce several indicators related to aspects of infrastructure, services and processes to which the passenger was submitted. The index goes from 1 (worst score) to 5 (best score).

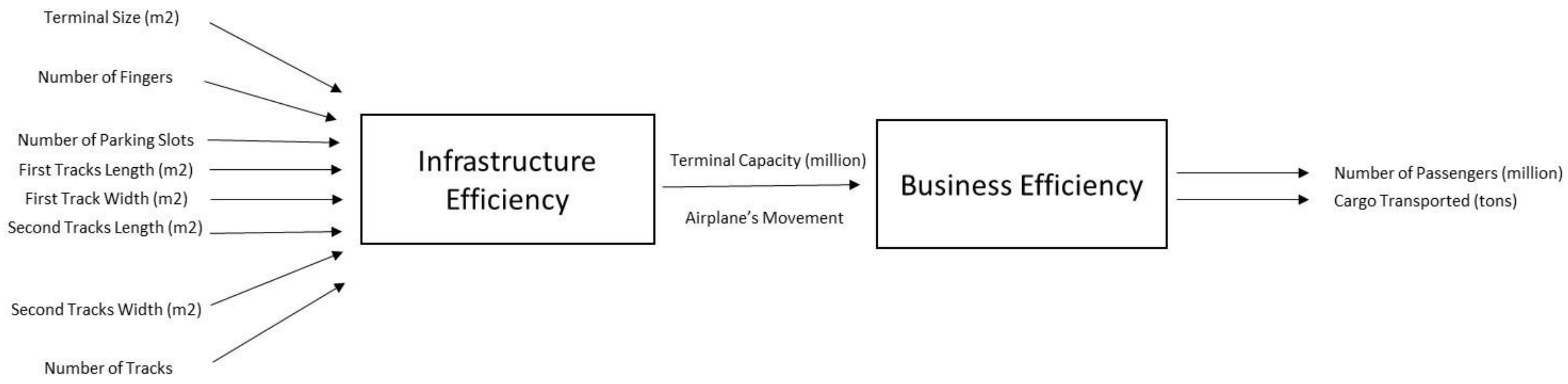
This survey is especially important for the airports that were granted to the private sector since their Satisfaction Index is one of the variables for updates in airfares prices. As a result, this index affects the airports revenues directly.

The first step of the analysis outlined in this dissertation will present a two-stage DEA analysis calculated using R as the statistical program. The first stage has the following initial set of inputs: Terminal Size (m^2), Number of Fingers, Number of Parking Slots, Number of Tracks and their Length (m^2) and Width (m^2). Then, the first stage outputs are Airplane's Movement (per year) and Terminal Capacity (millions per year). As Wanke (2013) explained in his dissertation, these variables assess the infrastructure efficiency of the selected airports and, because of this, this stage will be referred as Infrastructure Efficiency is this study.

For the second stage, the former mentioned outputs were considered as inputs. The final outputs were Number of Passengers (million per year) and Cargo Transported (Ton per year), which are very common variables for measuring the productivity efficiency of airports, according to Barros et al. (2010). Since this data is pertinent to the core business of the airports, this stage will be referred as Business Efficiency.

The overview of these tests can be seen in Figure 3.

Figure 3 – Two-stage Network DEA Analysis



The second step of the analysis will be carried out through the Ordinary Least Squares (OLS) method, in order to measure how the Customer Satisfaction Index is affected by the Infrastructure Efficiency and Business Efficiency, together with some contextual variables. The contextual variables are if the airport: i) is Granted or Not Granted to the private sector; ii) Offers Nonstop Services (5+ hours without any airplane movement); iii) Number of Companies that offers commercial flights; iv) Offers International Flights; and v) is in a State Capital. In addition, linear and squared trend evaluation were added to the analysis with the intention to show if it can be inferred that the selected airports have a learning curve in the period (Wanke et al., 2016).

As Yu (2010) explained, contextual variables should not be neglected in the airports' efficiency analysis since contextual variables have a positive impact on airport efficiency, which means that the location of the airport can boost many of the airports' results.

All of the contextual variables mentioned above, like i) Granted or Not Granted to the private sector; ii) Offers Nonstop Services, iv) Offers International Flights; and v) is in a State Capital, are dummy variables, which means that they are scored 0 or 1 in the regression analysis, depending on the presence or absence of the referred categories that they refer to.

An overview of the variables mentioned above is presented in table 3.

Table 3 – Sample Variables considered for this dissertation

SAMPLE VARIABLES							
			MIN	**MAX**	**MEAN**	**SD**	**CV**
First Step Analysis	**First Stage**	**INPUTS**					
		Terminal Size (m2)	7.200,0	387.870,0	93.077,7	100.832,4	1,1
		Number of Fingers	-	58,0	14,6	12,8	0,9
		Number of Parking Slots	306,0	10.200,0	2.774,6	2.267,1	0,8
		First Tracks Length (m2)	1.323,0	4.000,0	2.760,5	671,9	0,2
		First Tracks Width (m2)	42,0	60,0	45,6	3,5	0,1
		Second Tracks Length (m2)	-	3.300,0	1.045,1	1.253,9	1,2
		Second Tracks Width (m2)	-	47,0	20,4	22,0	1,1
		Number of Tracks	1,0	2,0	1,5	0,5	0,3
		OUTPUTS					
		Terminal Capacity (million)	5,7	42,0	14,8	9,2	0,6
		Airplane's Movement	14.311,0	283.757,0	96.093,6	62.476,4	0,7
	Second Stage	**INPUTS**					
		Terminal Capacity	5,7	42,0	14,8	9,2	0,6
		Airplane's Movement	14.311,0	283.757,0	96.093,6	62.476,4	0,7
		OUTPUTS					
		Number of Passengers (million)	1,6	39,2	11,2	8,8	0,8
		Transported Cargo (Ton)	6,2	510,3	86,8	121,8	1,4
Second Step Analysis	**Contextual Variables**	Number of companies doing commercial flights	3,0	23,0	7,9	4,6	0,6
		Operates 24 hours	Yes	9		No	4
		Located in the State Capital	Yes	9		No	6
		International Flights	Yes	13		No	2
		Granted for a private company	Yes	6		No	9

3.2. Network Data Envelopment Analysis – NDEA

Data Envelopment Analysis - DEA is a nonparametric model that was first introduced by Charnes et al. (1978) in order to evaluate the efficiency of different types of Decision Making Units (DMUs), which are subject to many diverse inputs and outputs.

DEA measure the efficiency of a set of different DMUs with a ratio of weighted outputs in relation to weighted inputs. These estimator is computed with linear programming techniques which provides a best practice frontier and evaluates the relative efficiency of the DMUs in comparison to these referred frontier.

The DEA model with constant returns to scale can be described as:

$$\mathrm{E}_0 = \max \frac{\sum_{\mathrm{r}=1}^{\mathrm{s}} \mathrm{u}_\mathrm{r}.\mathrm{y}_{\mathrm{r}0}}{\sum_{\mathrm{i}=1}^{\mathrm{m}} \mathrm{v}_\mathrm{i}.\mathrm{x}_{\mathrm{i}0}}$$

$$s.t. \frac{\sum_{\mathrm{r}=1}^{\mathrm{s}} \mathrm{u}_\mathrm{r}.\mathrm{y}_{\mathrm{rj}}}{\sum_{\mathrm{i}=1}^{\mathrm{m}} \mathrm{v}_\mathrm{i}.\mathrm{x}_{\mathrm{ij}}} \leq 1, j = 1,2,\dots,n \qquad (1)$$

$$\mathrm{u}_\mathrm{r}, v_i \geq \boldsymbol{\varepsilon}, i = 1,2,\dots,m; r = 1,2,\dots,S$$

$$\mathrm{u}_\mathrm{r}, v_i \; being\ the\ weights$$

However, since the present analysis will separate the Infrastructure Efficiency and Business Efficiency, a two-stage DEA approach will be used for this study (Wanke 2013). The Network DEA tries to access the fact that, in many cases, there is a connection between the information analyzed in a single-stage DEA model. Because of that, the efficiencies E_0^1 and E_0^2 are respectively linked to the first and second stage of the NDEA.

$$E_0^1 = \max \frac{\sum_{\mathrm{d}=1}^{\mathrm{D}} w_\mathrm{d}.z_{\mathrm{d}0}}{\sum_{\mathrm{i}=1}^{\mathrm{m}} \mathrm{v}_\mathrm{i}.\mathrm{x}_{\mathrm{i}0}}$$

$$s.t.\ \frac{\sum_{d=1}^{D} w_d . z_{dj}}{\sum_{i=1}^{m} v_i . x_{ij}} \leq 1, j = 1,2,\dots,n \qquad (2)$$

$$w_d, v_i \geq \boldsymbol{\varepsilon}, i = 1,2,\dots,m; r = 1,2,\dots,D$$

$$E_0^2 = \max \frac{\sum_{r=1}^{S} u_r . y_{r0}}{\sum_{d=1}^{D} w_d . z_{d0}}$$

$$s.t.\ \frac{\sum_{r=1}^{S} u_r . y_{rj}}{\sum_{i=1}^{D} w_d . z_{dj}} \leq 1, j = 1,2,\dots,n \qquad (3)$$

$$u_r, w_d \geq \boldsymbol{\varepsilon}, d = 1,2,\dots,D; r = 1,2,\dots,S$$

Until now, the models presented in this work showed a fractional system. In order to enable methods of linear programming, these formulas need to be converted into linear forms, as follows:

$$E_0 = \max \sum_{r=1}^{s} u_r . y_{r0}$$

$$s.t. \sum_{i=1}^{m} v_i . x_{i0} = 1$$

$$\sum_{r=1}^{s} u_r . y_{rj} - \sum_{i=1}^{m} v_i . x_{ij} \leq 0, j = 1,2,\dots,n \qquad (4)$$

$$\sum_{d=1}^{q} w_d . z_{dj} - \sum_{i=1}^{m} v_i . x_{ij} \leq 0, j = 1,2,\dots,n$$

$$\sum_{r=1}^{s} u_r . y_{rj} - \sum_{d=1}^{q} w_d . z_{dj} \leq 0, j = 1,2,\dots,n$$

$$u_r, v_i, w_d \geq \boldsymbol{\varepsilon}, i = 1,2,\dots,m; r = 1,2,\dots,S;\ d = 1,2,\dots,D$$

The Overall Efficiency (E_0^g) will be calculated by the product of the two stages efficiencies, the Infrastructure Efficiency (E_0^1), and the Business Efficiency (E_0^2).

The DEA analysis generates an efficient frontier where all DMUs will have their efficiency scores measured based on how close they are to the frontier. These scores should be restricted to a number below 1. However, since the DEA analysis is based on linear programming, some results can be unfeasible because the referred restrictions do not apply to them.

In these cases, the outliers are the ones responsible for the unfeasibility of the analysis and, because of that, the supper-efficient DEA analysis should be used instead, as Banker and Gifford (1988) and Andersen and Petersen (1993) suggest. The super-efficient DMUs could be interpreted by input savings or output surplus from an efficient DMU.

In order to deal with the super-efficient scores and to manage comparing all the efficiencies presented in this study, the current DEA methodology will exclude each super-efficient DMU under-evaluation from the reference set. This method will keep the efficient scores bellow 1 and will enable comparison between the efficient scores.

Later, the Ordinary Least Square (OLS) will be used in order to calculate the effect of the Infrastructure Efficiency (E_0^1), Business Efficiency (E_0^2), Overall Efficiency (E_0^g), and the contextual variables in the Customer Satisfaction Index. This analysis will demonstrate if these selected parameters actually affect the customer satisfaction scores in each airport.

In order to avoid correlation between the Infrastructure Efficiency (E_0^1), Business Efficiency (E_0^2), Overall Efficiency (E_0^g), three regressions will be calculated as follows:

$$
\begin{aligned}
y &= \beta_i \,.\, E_0^1 + \beta_i \,.\, E_0^{1\ 2} + \beta_i \,.\, Contex\ Var._i \\
y &= \beta_i \,.\, E_0^2 + \beta_i \,.\, E_0^{2\ 2} + \beta_i \,.\, Contex\ Var._i \qquad (5) \\
y &= \beta_i \,.\, E_0^g + \beta_i \,.\, E_0^{g\ 2} + \beta_i \,.\, Contex\ Var._i
\end{aligned}
$$

3.3. Bootstrapping

In order to enable statistical inference, the bootstrap method was applied in the regressions above (5). This method defends that an empirical distribution of a sample (i.e. $X_i, \ldots X_n$) eventually converges into its true distribution in *n* (Robert. & Casella, G. Introducing Monte Carlo Methods with R. 2009). The idea of the bootstrap is to repeatedly create random set of data and to re-estimate Satisfaction results. By repeatedly doing it, it will be possible to draw approximate conclusions of the sampling distribution.

In this analysis, 100 bootstrap replications were performed in the regressions using the Customer Satisfaction as a dependent variable and the Efficiencies and Contextual Variables as independent variables (5).

4. RESULTS AND DISCUSSION

The Infrastructure and Business efficiency levels that were calculated in the NDEA model based on the 15 biggest Brazilian airports from 2013 to 2017 can be seen in the figure 4.

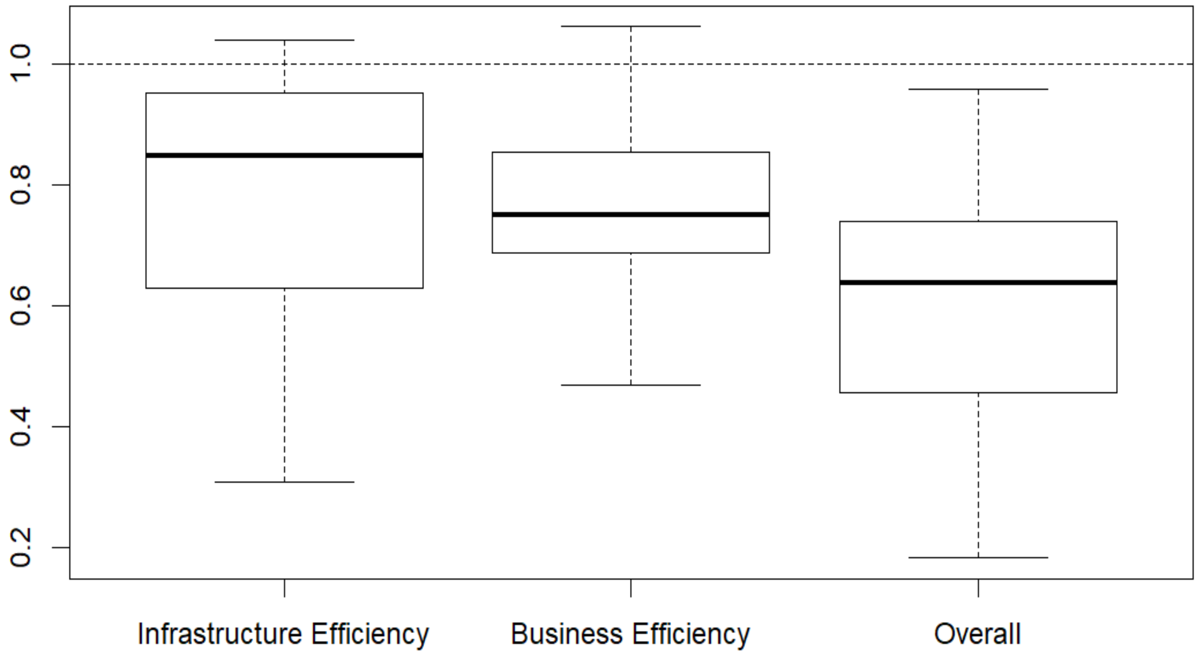
The median value of the Infrastructure Efficiency is the highest one when compared to the Business and Overall values. This result suggest that these selected airports tend to have a better performance in converting Terminal Size (m^2), Number of Fingers, Number of Parking Slots, Number of Tracks and their Length (m^2) and Width (m^2) in higher Airplane's Movement (per year) and Terminal Capacity (millions per year), compared to converting Airplane's Movement (per year) and Terminal Capacity (millions per year) in a higher Number of Passengers and Cargo Transported per year.

However, it can also be seen that the variability of the Infrastructure Efficiency is higher than the Business Efficiency since the size of the boxplot is considerably bigger. It shows that the selected airports had more similar Business Efficiency levels than Infrastructure Efficiency.

The median of the Overall Efficiency is lower than the Infrastructure and Business efficiencies, which demonstrates that airports that have higher levels of Infrastructure Efficiency do not have higher levels of Business Efficiency, and the ones with higher levels of Business Efficiency do not have better levels of Infrastructure Efficiency, since the Overall Efficiency is the product of these both efficiency levels.

In addition, it is important to state that these results do not consider the outliers efficiency levels since they were eliminated in the super-efficiency analysis.

Figure 4 – Efficiency breakdown

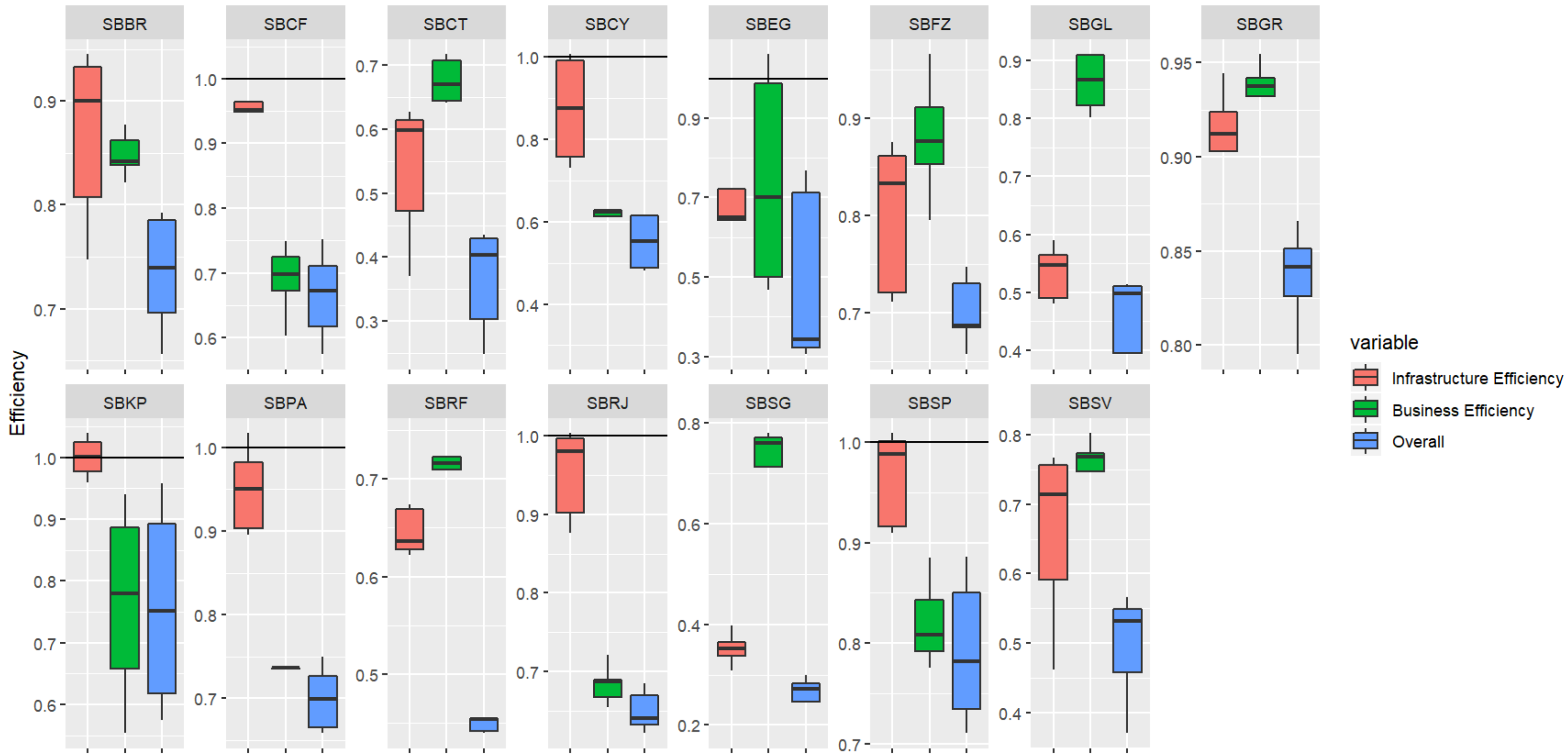


A better understanding of these efficiencies can be seen by analyzing the results for each airport as in Figure 5. The Aeroporto Internacional de Viracopos (SBKP), Aeroporto do Rio de Janeiro/Santos Dumont (SBRJ) and Aeroporto de São Paulo - Congonhas (SBSP) had the highest levels of Infrastructure Efficiency.

On the other hand, Aeroporto Internacional de Fortaleza/Pinto Martins (SBFZ), Aeroporto Internacional do Rio de Janeiro – Galeão - Antônio Carlos Jobim (SBGL) and Aeroporto Internacional de São Paulo - Guarulhos - Governador André Franco Montoro (SBGR) were the ones with the highest levels of Bussiness Efficiency.

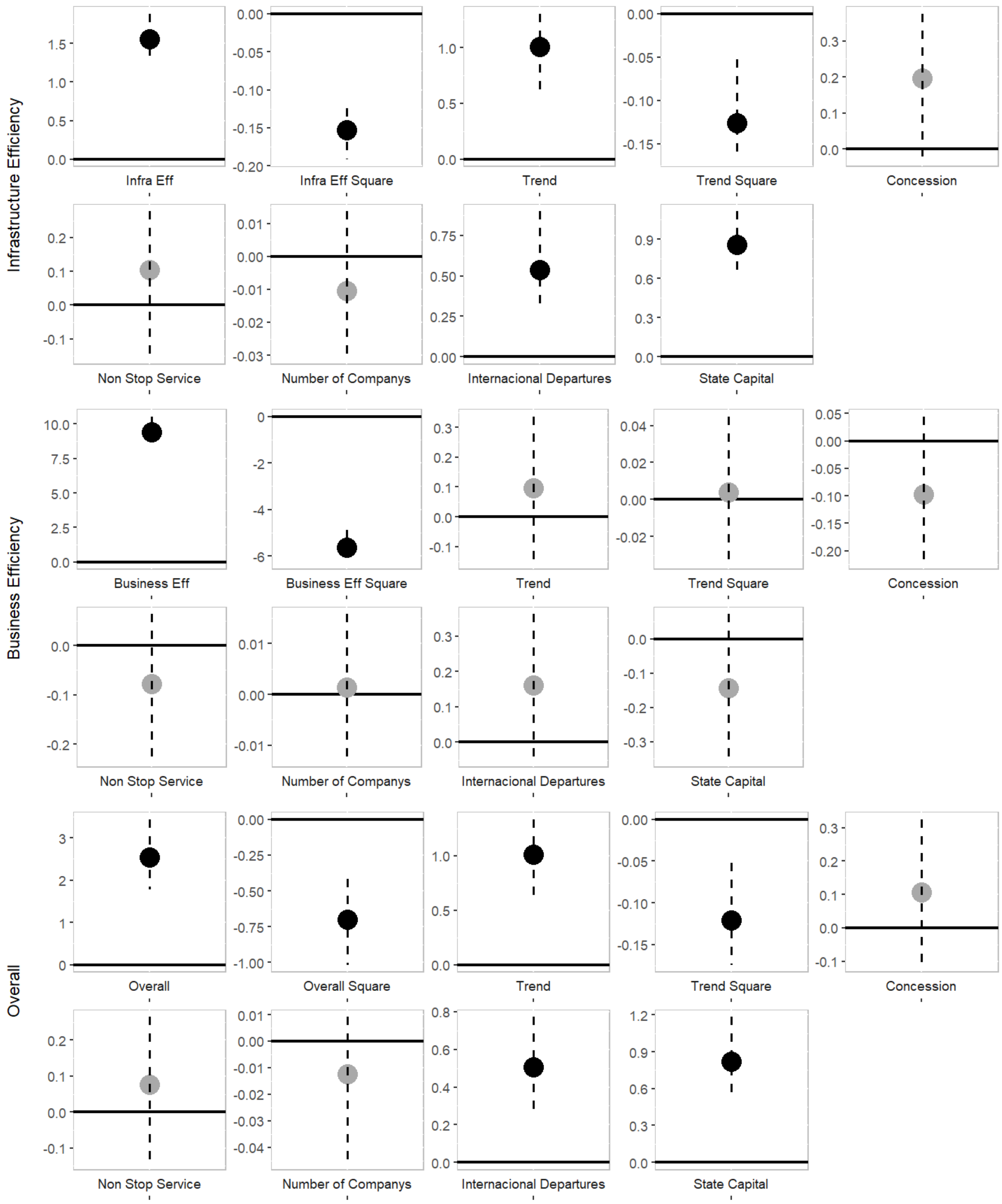
Considering the Overall Efficiency, Aeroporto Internacional de São Paulo - Guarulhos - Governador André Franco Montoro (SBGR) and Aeroporto de São Paulo - Congonhas (SBSP) had the best results.

Figure 5 – Brazilian airports efficiency levels



Finally, a robustness analysis was performed by running the bootstrapped regression (5). The results of these regressions show how the efficiencies scores and the contextual variables affect the results of the Customer Satisfaction Index, as seen in Figure 6.

Figure 6 – Coefficient estimates of the bootstrapped regression



Some results of the three regressions analysis performed for this work are slightly similar. And because of that, this study will first explain the results in common before analyzing the divergence between them.

Initially, both Infrastructure Efficiency and Business Efficiency had positive significance in Customer Satisfaction. This means that a better Infrastructure Efficiency and Business Efficiency will tend to increase customer satisfaction with the airport services.

However, Infrastructure Efficiency Square and Business Efficiency Square, used as measurement for the long-term effect of these variables, are negatively statistically significant. This result could mean that the Customer Satisfaction tend to decrease as a result of a possible saturation of the airports capacity in the long term due to an increase in demand not followed by new investments.

The Overall Efficiency results make sense because it is a product of the Infrastructure Efficiency and Business Efficiency reinforcing the results of the previous paragraphs since it follows the same patterns, both in the short-term and in the long-term.

The number of companies operating commercial flights were not significant in this study. This variable was used as a proxy to understand if a higher number of companies in the airports could result in higher competition between them, causing a positive impact to their customers

Being granted for the private sector also did not affected Customer Satisfaction in the regressions. This result may imply that it does not matter which sector was responsible for making the investments needed. What is important is whether the investments improved the airports capacity and services. Another possible inference is that the concessions are quite recent, so the customers may not have noticed any differences in the airports, in terms of private or public management.

Regarding the different results between the regressions, some statements can be done. In the first regression, Trend which represents the impact over the course of the years on the efficiency levels, shows that the customers of these airports tend to have their satisfaction increased in the short-term. This could show that the Brazilian airports have the capacity to learn how to improve their infrastructure efficiency in the short-term.

On the other hand, Trend Square, which calculates the tendency of customer satisfaction in the long-term, produced an opposite scenario. This could mean that, with the Brazilian economic recovery and a higher demand pressure upon the airport services through the years, the infrastructure will be pressured by an increase in demand. Then, further improvements will be needed in order to maintain a higher level of services. This is one of the reasons the concession contracts have some investments triggers related to demand trajectory.

Analyzing the regression with the Business Efficiency scores, both Trend and Trend Square were not significant in evaluating satisfaction. Since the Business Efficiency derive from the airport management, it seems to have a less positive perception from the customers, especially compared to infrastructure aspects. Moreover, they were significant in the third analysis possibly due to the relevance in the Infrastructure Efficiency regression that is considered in the Overall analysis.

Airports with 24 hours operation had significant scores in the regression analysis that considered the Infrastructure Efficiency. This means that the higher satisfaction results of the airports with non-stop services might be driven because they have a better infrastructure, such as a greater number of fingers, more capacity, etc., in order to attend all flights scheduled for an entire day.

The dummy variables of offering international flights and being located in a state capital were significant in the Infrastructure and Overall analysis but were not significant in the Business one.

For the first regression, offering international flights and being located in a state capital were significant. It could mean that airports with international flights tend to be bigger and to have better infrastructure compared to airports that only offer domestic flights. However, having better structure does not mean that they will surely have better operational efficiency, as seen in figure 5.

Lastly, the airport being located in the state capital showed relevance only in the Infrastructure analysis. Being located in the state capital could mean that the airport has to attend a demand for flights for different destinations, which leads to a higher customer satisfaction since they can travel to many different cities from the same airport hub.

5. CONCLUSION

This dissertation aims to contribute to the efficiency studies of the Brazilian airports, which are still incipient compared to the literature about the efficiency of several airports located in the rest of the world. Moreover, studies on this matter have become more relevant after the recent rounds of concessions in Brazilian airports and the expectation for new biddings for other important airports in the country (the fifth round of airport concessions will happen in 2019).

In order to do so, firstly, this dissertation used a two-stage network DEA approach to evaluate the efficiency evolution of the 15 biggest airports in Brazil between 2013 and 2017. Most of the input and output variables selected in this research are commonly used in other studies worldwide. However, the two-stage network DEA provided in this study was count for separating the airports analysis into Infrastructure and Business Efficiencies.

Based on the super-efficiency results of the first step analysis, Guarulhos International Airport (SBGR), which was granted for the private sector, and Congonhas Airport (SBSP), which is still controlled by INFRAERO, were the best ranked overall among all the other selected airports.

Furthermore, since the median of the Overall Efficiency is lower than the Infrastructure and Business efficiencies, as seen in Figure 4, the conclusion is that airports that have higher Infrastructure Efficiency do not have higher levels of Business Efficiency, and vice versa, since the Overall Efficiency is the product of these both efficiency levels.

Expanding the analysis beyond efficiency scores, comprehending the airport customer's needs is also key for the business. In fact, customer satisfaction is an important variable that needs to be examined closely in many sectors, as well as in the airport segment. In Brazil, as mentioned before, this satisfaction measurement was included in the airfares prices readjustment for the granted airports, further increasing its relevance in the financial results of the granted airports.

Because of this, it was analyzed how the efficiency levels affect the Customer Satisfaction of the selected airports. In this step, it was interesting to notice that the concessions did not affect the Customer Satisfaction scores in all the regressions. This could infer that it is not important for customers which sector was responsible for the investments.

In fact, investing in the airports services is a factor that is very important. If the airport is improving in terms of services and process, the customers will be satisfied. However, as mentioned before, another possible inference could be that the government concessions program is recent in the airport sector in Brazil, which means that these results could change in future studies when analyzing a more comprehensive set of data compared to the five-years range set for this article.

5.1. Limitations

Regarding the methodology, DEA related studies has some structure limitations. As mentioned before, since DEA is a nonparametric technique, it is hard to create statistical hypothesis tests. Moreover, this methodology estimates the relative efficiency between the DMUs studied. This means that the DEA efficiency scores are not adequate to measure absolute efficiency of these airports.

Regarding the data analyzed, the first limitation is concerning the number of airports analyzed. Since the Customer Satisfaction Index for the referred period evaluates just these 15 most important Brazilian airports, these research did not evaluated a big range of airports, which would affect the efficient frontier.

The second is regarding the need of a wider set of data, which would probably affect the results seen in this research. Since the concessions of the Brazilian airports begun in 2011, this process is still new. Having new airports granted in the future and being able to compare the performance of the granted airports in comparison to the public ones with a bigger historic data would help to improve the efficiency studies.

5.2. Recommendations

Even though all DEA related studies have some limitations in terms of statistical inferences, this methodology is still well known when assessing airports efficiency and should be more explored in the Brazilian context.

Future studies could include other variables as input and outputs for evaluating other types of efficiencies. Financial data like airfares revenues, commercial revenues, cargo revenues, operating costs and investments made could asses the financial performance of the airports, which is very important to be analyzed.

In addition, after November of 2017, the Customer Satisfaction Index started to cover the airports of Belém (PA), Maceió (AL), Goiânia (GO), Vitória (ES) and Florianópolis (SC), which will increase the data available for future researches interested in evaluating the relationship of airport services and customer's satisfaction.

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7. APPENDIX

Appendix – DEA-based studies related to airports efficiency

Authors	Year	Country	Sample Size	Methodology	Inputs	Outputs
Nwaogbe et al.	2018	Nigeria	30	Bootstrapped DEA, censored quantile regression	Terminal capacity, Runway dimension, Number of employees, Total assets, Total costs	Passenger throughput, Aircraft movements
Périco et al.	2017	Brazil	16	Bootstrapped DEA	Number of runways, number of check-in counters, number of parking places, passenger terminal area	Passengers
Wanke et al.	2016	Nigeria	36	Fuzzy DEA; a-level based approach; bootstrap; truncated regression	Number of movements (000/year), terminal capacity (Pax)	Passengers, headcount
Wanke and Barros	2016	Latin America	19	Virtual frontier dynamic range adjusted model–data envelopment analysis (VDRAM); two-stage DEA; simplex regression	World flights, Latin American and Caribbean flights, domestic flights	Employees, aircraft
Tsui et al.	2014	New Zeland	11	Slacks-based measure (SBM); Malmquist productivity index (MPI); bootstrapping	Operating expenses, number of runways	Operating revenues, passengers, aircraft movements
Tavassoli et al.	2014	Iran	11	Slacks-based measure (SBM); network data envelopment analysis (NDEA); shared inputs	Number of passenger planes, labor, number of cargo planes	Passenger plane kilometers, cargo plane kilometers
Tsui et al.	2014	Asia–Pacific region	21	DEA, regression	Number of employees, number of runaways, total runway length, passenger terminal area	Passenger numbers, air cargo volumes, aircraft movements
Wanke	2013	Brazil	63	Two-stage Network DEA	Terminal area, aircraft parking spaces, runways, landing and take-offs per year, regular flights	Passengers, cargo

Wanke	2012	Brazil	63	Bootstrapped DEA	airport area, apron area, number of runways, total runway length, number of aircraft parking spaces, terminal area, and number of parking places.	number of passengers (per year), express cargo throughput, and number of landings and take-offs
Lai et al.	2012	International	24	Analytic hierarchy process (AHP); assurance region DEA (DEA-AR model)	Number of employees, gates, runways, size of terminal area, length of runways, operational expenditure	Passengers, amount of freight and mail, aircraft movements, total revenues
Gitto and Mancuso	2012	Italy	28	Malmquist; DEA; bootstrap	Aircraft movements, passengers, cargos, aeronautical revenues, non-aeronautical revenues	Labor cost, capital invested, soft cost
Alana et al.	2011	Monthly		Fractional integration	Number of incidents	Victims, plane crashes, helicopter crashes
Curi et al.	2011	Italy	18	DEA VRS envelopment, output-oriented model with bootstrapped efficiency estimates.	Employees, runways, apron area	Landings and take-offs, passengers, cargo
Tsekeris	2011	Greece	39	DEA VRS/CRS envelopment, output-oriented model with bootstrapped efficiency estimates.	Runways, terminal area, airplane parking area, operating hours	Passengers, cargo, landing and take-offs
Marques and Simões	2010	Wordwide	141	DEA	Runways, area of terminal, employees	Landings and take-offs, cargo, passengers

Suzuki et al.	2010	Europe	30	DEA CRS multiplier, outputoriented model altogether with DFM (Distance Friction Minimization).	Runways, terminal area, gates, employees	Passengers, landings and take-offs
Yu	2010	Taiwan	14	Slacks-based measure network data envelopment analysis (SBM-NDEA)	Employees, runways, apron, terminal	Passengers, cargo, landings and take-offs
Lozano and Gutiérrez	2009	Spain	41	VRS; DEA	Total runway area, apron capacity, passenger throughput capacity, number of baggage belts, number of check-in counters, number of boarding gates	Passengers, aircraft, cargo
Barbot et al.	2008	Several	49	DEA; slacks-based model	Fuel consumption, employees, fleet	Revenue tonne-kilometers, available seat-kilometers
Assaf	2007	United Kingdom	27	DEA NIRS/CRS envelopment, outputoriented model with bootstrapped efficiency estimates.	Number of FTE, airport area, runways	Passengers, cargo, landings and take-offs
Barros and Dieke	2007	Italy	31	DEA CRS/VRS envelopment, output-oriented models together with cross-efficiency and super-efficiency models	Operational costs, labor cost, capital invested	Handling receipts, planes, cargo, aeronautical sales, commercial sales, passengers
Yoshida and Fujimoto	2004	Japan	67	Two-stage DEA; CRS/VRS; Tobit regression	Employees, monetary access cost, time access cost, runways, terminal area	Landings and take-offs, passengers, cargo
Bazargan and Vasigh	2003	USA	45	DEA; VRS multiplier	Gates, operating and non-operating expenses, runways	Aeronautic and non-aeronautic revenues, passengers, landing and take-offs
Sarkis	2000	USA	44	DEA VRS/CRS; cross-efficiency	Employees, runways, operating costs	Passengers, revenues, landings and take-offs, cargo

Gillen and Lall	1997	USA	21	Two-stage DEA model; CRS/VRS DEA; Tobit regression	Employees, gates, runways, terminal area, baggage, public parking, airport area	Commuter movements cargo, passengers, landings and take-offs
Schefczyk	1993	International airlines	15	First ever known DEA study for airline efficiency	Number of available ton kilometers	Flight equipment depreciation