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SMALL AIRPORT GOVERNANCE AND EFFICIENCY IMPLICATIONS FOR REGIONAL SOCIOECONOMIC INDICATORS IN AIR TRANSPORT

GOVERNANÇA E EFICIÊNCIA DE PEQUENOS AEROPORTOS E SUAS IMPLICAÇÕES EM INDICADORES SOCIOECONÔMICOS REGIONAIS NO TRANSPORTE AÉREO

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ABSTRACT

Purpose: This study centers on assessing the governance structures and efficiency of small airports, which are key determinants of their competitiveness and potential impact on regional socioeconomic indicators, given the strategic relevance of small airports for regional development and national integration.

Method/approach: The study has evaluated twenty-five small Brazilian airports as its focal points, employing different analytical methods, including Data Envelopment Analysis, Weight Constraint without Consideration of Satisfactory Levels, Multiple Linear Regression, Linear Correlation, and the Tobit method.

Main findings: The findings furnish data inputs for regression analyses, which delineate the infrastructure and organizational characteristics and ascertain their respective levels of significance. Variables such as GDP per capita, population size, proximity to the nearest airport relative to the serviced municipality, frequency of flight delays, and airport attraction index emerge as substantial attributes poised to enhance the efficiency of small airports and foster regional development.

Theoretical, practical/social contributions: The main contributions of this study revolve around the efficiency analyses conducted on small airports with diverse governance structures, along with their primary implications for regional development.

Originality/relevance: This study holds relevance in its comprehensive examination of both the existing literature and practical dimensions concerning the efficiency and governance of small airports, a topic that is underrepresented in current literature. By spotlighting key variables and elucidating their significant roles in air transportation and regional development, the research fills a gap in the state-of-the-art.

Keywords: Aeronautical infrastructure. Business. Operational management. National integration.

RESUMO

Objetivo: O principal objetivo desse estudo consiste na análise da eficiência de pequenos aeroportos a partir de diferentes variáveis e estruturas de governança, sendo essas organizações consideradas estrategicamente relevantes para o desenvolvimento regional e a integração nacional.

Método/abordagem: O estudo avaliou vinte e cinco pequenos aeroportos brasileiros, empregando diferentes métodos analíticos, incluindo a Análise Envoltória de Dados, Restrição de Peso sem Consideração de Níveis Satisfatórios, Regressão Linear Múltipla, Correlação Linear e o método Tobit.

Principais Resultados: Os resultados fornecem dados para análises de regressão, que delineiam as características de infraestrutura e organizacionais e determinam seus respectivos níveis de significância. O PIB per capita, o tamanho da população, a proximidade do aeroporto mais próximo em relação ao município servido, a frequência dos atrasos nos voos e o índice de atratividade aeroportuária emergem como atributos substanciais na eficiência dos pequenos aeroportos de diferentes estruturas de governança nas suas contribuições para o desenvolvimento regional.

Contribuições teóricas/práticas/sociais: As principais contribuições deste estudo giram em torno das análises eficiência realizadas em pequenos aeroportos com diferentes estruturas de governança, juntamente com suas principais implicações para o desenvolvimento regional.

Originalidade/relevância: O estudo se apresenta relevante por considerar as dimensões conceituais e práticas relativas à eficiência e governança de pequenos aeroportos, temas pouco abordados na literatura. Ao destacar variáveis-chave e apresentar os seus papéis significativos no transporte aéreo e no desenvolvimento regional, esse estudo preenche uma expressiva lacuna no estado da arte.

Palavras-chave: Gestão operacional. Infraestrutura Aeronáutica. Integração Nacional. Negócios.

1 INTRODUCTION

Given the strategic relevance of air transportation infrastructure for a country's regional, national, and international integration (Bonilla-Bolaños, 2021; Patrick, 2008; Tsekeris & Vogiatzoglou, 2014), airports emerge as one of the main drivers of regional development (Borgatti, 2008; Díaz Olariaga & Alonso-Malaver, 2021). In managerial analyses of such organizations and their relationship with the development of specific regions, the literature commonly examines airports' various operational and strategic characteristics. The identification of air transport infrastructure parameters is also necessary to inform endeavors aimed at attracting national and international investments (Khadaroo & Seetanah, 2010), particularly in light of airport infrastructure concessions to the private sector, as recently observed in Brazil (ANAC, 2023; Brito et al., 2021; Freitas et al., 2021; Pereira Neto et al., 2016; Rolim et al., 2016).

Reference is often made to airports with extensive passenger processing under private management, owing to the professional and robust data that these airport structures can offer (Merkert et al., 2012). A pertinent research inquiry arising concerning airport infrastructure is: What are the main implications of small airports for regional development in terms of business efficiency, considering various infrastructure and governance strategies? Although the literature on transportation planning and management considers different governance structures and their socioeconomic impacts, the literature examining small organizations, particularly small airports, has several gaps in both characterizing these structures´s efficiency and identifying their relationships with regional development indicators.

To gain a deeper comprehension of the role of small airports in regional development, this study adopts the concept of spatial economic theory for airport-centric development, as proposed by Mokhele (2018). This framework considers parameters including the nature and scope of economic space, the driving economic characteristics, the utilization of distance and proximity by airport-centric firms, and the patterns of linkages, agglomeration, and clustering among these firms. Given the regional significance of small airports, their geographical location often affects both their operations and managerial objectives. Consequently, such factors may not be adequately assessed using conventional benchmarking and efficiency analysis methods, necessitating the adoption of more sophisticated approaches such as alternative analytical methods to yield more dependable results.

Hence, this study aims to conduct a mathematical analysis of the significance of small airports for regional development, focusing on managerial factors such as the adopted governance structure, operational variables, including runway length, aircraft apron size, and passenger terminal capacity, as well as socio-economic indicators of the surrounding region, as the gross domestic product (GDP) per capita of the local population, the city's attractiveness index, and the distance from the airport to the influential city center, the airport attractiveness index, etc.

For this purpose, a sample of 25 small Brazilian airports, classified based on their passenger processing in 2019, according to data from the National Civil Aviation Agency (ANAC, 2020), underwent analysis. The study employed different methodologies, including Data Envelopment Analysis (DEA), the Enhanced Additive Two-Stage Weight-Constrained Optimization (EATWOS) technique (Peters et al., 2012), multiple linear regression, linear correlation, and the Tobit method. The choice of 2019 data was deliberate, as it precedes the onset of the pandemic caused by the severe acute respiratory syndrome coronavirus 2 (SARS-

CoV-2), ensuring that the analyses are not influenced by pandemic-related biases in passenger processing.

In addition to this theoretical and practical contextualization in the introduction, this article is organized as follows: Section 2 presents the literature review with the theoretical basis used in the study related to the efficiency analysis of small airports, Section 3 the methods adopted, variables and objects of study considered, Section 4 the discussions of results from the quantitative data analysis, and Section 5 with the final considerations to the theory and practice, as well the conclusions of the study.

2 LITERATURE REVIEW

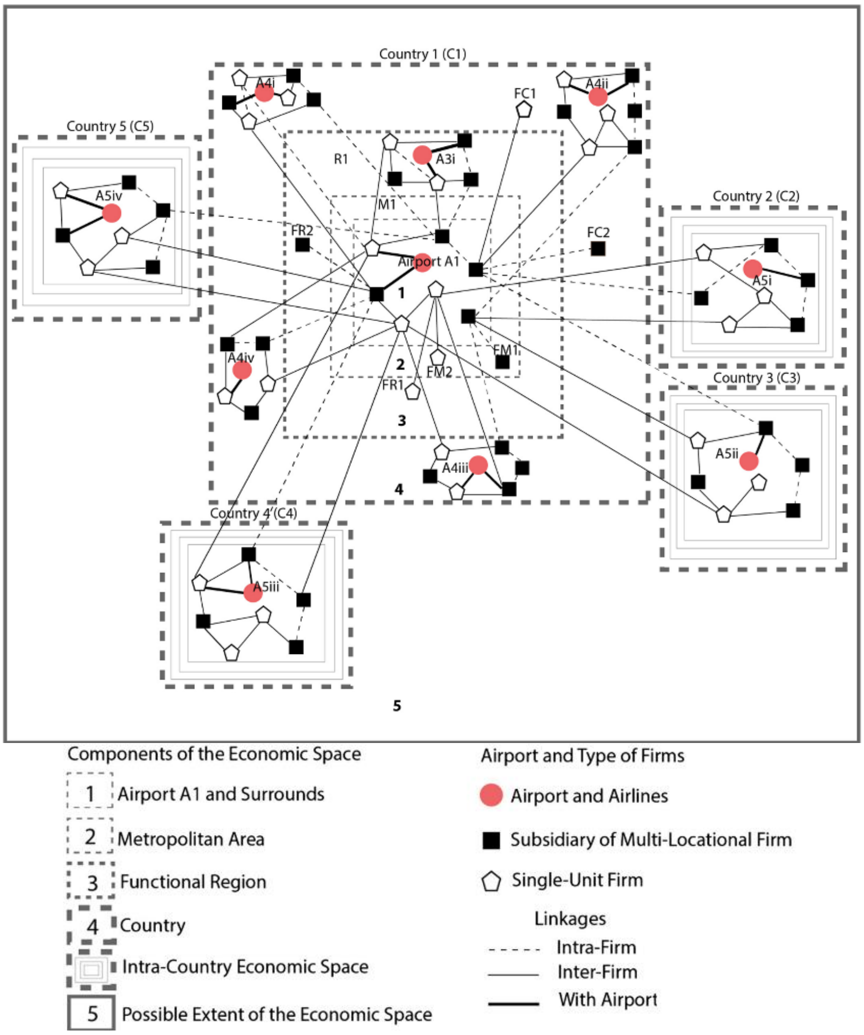
Many methods have been employed in analyzing the efficiency of small airports, with many studies considering the influence of regional factors. Merkert and Mangia (2014), for instance, assessed the efficiency of Italian and Norwegian airports utilizing DEA, which encompassed two stages to evaluate technical and financial efficiency. Additionally, the authors conducted a truncated regression analysis to explore efficiency and competitiveness, examining the relationship between the distance of airports from transportation hubs within population catchment areas and the time required to reach another airport. Furthermore, employing multiple linear regression, Dziedzic et al. (2020) scrutinized the demands of 146 airports across 21 European countries, of which approximately 60% would be classified as small airports according to the criteria utilized in this study. The analysis revealed a direct correlation between the volume of passengers processing at a given airport and factors such as population size, airport charges, and capacity coordination. However, the authors did not stratify small airports based on their contribution to regional development indicators, nor did they delineate the governance strategies employed by these airports.

An examination of airport efficiency and its governance is imperative due to the role airports play as drivers of regional development. Governance stands out as a crucial parameter, particularly in the context of enterprise internationalization (Brandão et al., 2014). According to the theoretical framework proposed by Mokhele (2018) for airport-centric developments, airports serve as focal points for intra and inter-firm relations within their local and international contexts, as depicted in Figure 1.

According to Figure 1, planning transcending international borders hinges upon the interplay between various organizations, with airports and airlines serving as central nodes in facilitating economic interactions among different nations. These relationships are orchestrated to streamline the movement of aircraft and passengers, thereby bolstering the contributions of air transport to economic growth, a particularly observed phenomenon between high-income and middle-income countries (Kaya & Aydın, 2024). Consequently, on the other hand, there may be a tendency to prioritize investments in specific airports that exhibit the highest contribution rates to regional development in terms of passenger processing (Berawi et al., 2018).

Considering the relevance of passenger processing and aircraft movement in determining airport competitiveness, Moura et al. (2020) elucidate that variables such as the GDP of the city where the airport is situated, the number of non-aeronautical establishments, the total area of the passenger terminal, and the number of airlines significantly influence the airport competitiveness index. While this study encompasses both public and private airports, the authors do not delve into the influence of governance structure on this index.

Figure 1
A descriptive model of airport-centric developments.



Source: Mokhele (2018).

Despite the pronounced influence of passenger volume on airport competitiveness, there exists a reciprocal relationship when contemplating the necessity of privatizing less trafficked airports. In the case examined by Rolim et al. (2016) regarding the impact of Brazilian airport privatization on airline demand, the authors assert that airports exhibiting subpar performance in terms of growth in passenger processing and lower per capita income are deemed prime candidates for privatization. It is posited that such findings are attributed to the enhanced capacity of private organizations to generate employment and income within airport facilities, thereby underscoring the relevance of scrutinizing the governance and performance of small airports.

In the selection of small airports over larger counterparts, the aggregate cost of travel plays a relevant role. Thus, Gao (2019) conducted a sensitivity analysis on the catchment area of small airports in Indiana, United States, vis-à-vis competition with major airports in neighboring Chicago. The author estimated uptake by associating car trip costs with parking fees and air transport expenses, examining the relationship between passenger distribution across districts and each airport. The analysis revealed that catchment areas are influenced by factors such as location, service quality, and airport traffic. Furthermore, Borgatti (2008) underscored the need to develop air transport infrastructure to enhance trade and integrate remote regions, as evidenced by his study on 30 small island developing states.

Complementing the association of aeronautics infrastructure with regional development, Ngo and Tsui (2020) conducted a performance assessment of New Zealand airports. They employed DEA and a slacks-based measure (SBM) to estimate cost efficiency, and to identify pertinent factors in their analysis, the authors utilized efficiency in a Tobit regression model, which considered various factors including the influence of private management and local mobility on airport efficiency. Additionally, Nascimento & Caetano (2020) present the financial performance of 18 small public airports managed by a federal agency, analyzing both aeronautical and non-aeronautical revenues and their impacts on airport finances. All small airports assessed in the study exhibited negative financial performance indices, potentially indicating the socio-economic significance of these facilities for regional development and national integration via air transportation, as one strongly justificative for their working.

The analysis of airport efficiency and its different methods identified in the literature is presented in Table 1.

Table 1
Airport efficiency analysis methods identified in the literature.

Authors	Studies	Methods
Adler et al. (2013)	Small regional airport sustainability.	DEA
Ennen and Batool (2018)	Airport efficiency in Pakistan.	DEA
Dziedzic et al. (2020)	Air traffic from small European airports.	Multiple linear regression and linear correlation
Fragoudaki and Giokas (2020)	Airport efficiency with privatization in Greece.	DEA and Malmquist Index (MPI)
Gao (2019)	Capturing small airports in competition with large airports.	Analytical approach to total travel cost
Kutlu and Mccarthy (2016)	Management and efficiency of American airports.	Sthocastics Frontier Analysis (SFA)
Lim and Karanki (2020)	Agreements for the use of American airports.	DEA by SBM
Merkert and Hensher (2011)	Effects of strategic management and fleet planning on airline efficiency.	DEA and Tobit
Merkert and Mangia (2014)	Efficiency of Italian and Norwegian airports.	DEA and Tobit. Equation created for competitiveness
Moura et al. (2020)	Competitiveness of the seven busiest Brazilian airports.	Multivariate data analysis and multiple regression
Nascimento and Caetano (2020)	Small airport business competitiveness.	Econometric models
Ngo and Tsui (2020)	New Zealand airport efficiency.	DEA and SBM to costs. IV-Tobit to airports
Rolim et al. (2016)	Impact of airport privatization on airline demands.	DW95 regression. Ordinary least squares (OLS) costs. 2SGMM estimate, bootstrap, and Heckit
Uludağ (2020)	Turkish airport productivity.	EATWOS and DEA-CCR

From Table 1, it is evident that studies commonly employ multiple calculation methods for airport efficiency analysis. DEA methods are frequently utilized to gauge efficiency and productivity. Additionally, to identify determinants such as traffic, catchment area, and business indicators, researchers have explored other methods including regression analysis and analytical approaches. The analysis presented in this study aims to identify the primary determinants of efficiency in small Brazilian airports by examining their managerial, operational, and regional characteristics. This investigation draws on insights from prior studies, such as Ngo and Tsui (2020), and Merkert and Mangia (2014), which analyze airport efficiency primarily from an operational standpoint. These characteristics are then juxtaposed with other factors pertinent to airports, including the impact of local GDP, governance structure, and regional development. Furthermore, this study effectively supplements the findings of small airports identified by Adler et al. (2013), offering a benchmark of efficiency grounded in economic savings in airport operations, thus incorporating socioeconomic variables into the analysis.

3 METHODS

Small Brazilian airports spanning all five regions of the country were selected as case studies for analysis, driven by the necessity to examine these smaller-scale organizations, their governance frameworks, and their interplay with the socioeconomic indicators of their respective regions. This endeavor aims to fill the gaps in the literature about these entities, which have been relatively understudied thus far.

Five analyses were conducted based on input and output data from small airports. Firstly, Data Envelopment Analysis (DEA) was employed to investigate the relationship between aircraft movement and operational characteristics of airports, following the approach outlined by Fragoudaki and Giokas (2020).

Secondly, the Weight Restriction Method without Consideration of Satisfactory Levels (EATWOS), proposed by Peters et al. (2012), was utilized to examine the weights of airport operational characteristics. Uludağ (2020) employed this method to assess airport competitiveness and delineated the weight of each variable in the output/input relationship. This method offers a distinct perspective and utilizes a common regression approach, thereby providing robust data for comparison and validation of results.

In the third analysis, a multiple linear regression was conducted to explore the relationship between competitiveness factors and the extent of airport service coverage within regions. This study incorporated regional information and georeferenced data analytics to align with international insights into this potential market, thereby enriching the dataset.

Fourthly, a linear correlation analysis, as outlined by Dziedzic et al. (2020), was performed to elucidate the relationship between governance structure and efficiency.

Finally, in the fifth analysis, the data were subjected to regression using the Tobit method to validate the findings obtained from the previous regressions.

To initiate this study, the airports under analysis were first sized and classified using Equation 1, as stipulated by the Federal Aviation Administration (FAA) in its airport classification system. Small airports are those processing between 0.05% and 0.25% of the annual passengers carried on regular flights within the country.

$$0{,}0005 \sum PP_{2019} \leq Small\ aiport \leq 0{,}0025 \sum PP_{2019} \quad (1)$$

According to Equation 1, $\sum PP_{2019}$ represents the total number of passengers processing scheduled flights at Brazilian airports in 2019 (ANAC, 2020). The annual passenger processing at small airports falls from 57,846 to 289,228 passengers. Based on this classification, Table 2 presents the 25 small airports categorized by the number of passengers processing, along with their respective locations within Brazilian territory and governance structure.

According to Table 2, the identified small airports are administered by different entities, including Infraero - until then a federal public aeronautical management and infrastructure company, state governments, municipal authorities, and others that have been privatized. These governance structures were determined at the time of the research, with some airports previously under public management recently transitioning to private ownership. Private airports considered in this study encompass those operating under concession contracts effective until the conclusion of 2019. The majority of these concessions were awarded to the consortium formed by Socicam and Universal Armazéns Gerais e Alfandegados, managing airports such as Glauber Rocha Airport - Vitória da Conquista/BA (SBVC), Sinop/MT (SBSI), and Alta Floresta/MT (SBAT).

Table 2
Small Brazilian airports analyzed (Source: research data).

ICAO Code	Passager processing in 2019	Governance structure	City/Federal Unit	Population arrangement	Influential cities
SBAE	125,182	State	Bauru/SP	Bauru	São Paulo
SBAT	60,554	Private	Alta Floresta/MT	Sinop	Cuiabá
SBAU	107,078	State	Araçatuba/SP	Araçatuba	São José do Rio Preto
SBCA	219,017	Municipal	Cascavel/PR	Cascavel	Curitiba
SBCJ	131,383	Infraero	Parauapebas/PA	Marabá	Marabá
SBCN	80,754	Private	Caldas Novas/GO	Itumbiara	Goiânia
SBCX	201,433	State	Caxias do Sul/RS	Caxias do Sul	Porto Alegre
SBDO	79,843	Municipal	Dourados/MS	Dourados	Campo Grande
SBHT	92,936	Infraero	Altamira/PA	Altamira	Belém
SBIP	109,584	State	Santana do Paraíso/MG	Ipatinga	Belo Horizonte
SBJA/ SBCM-SSIM *	128,318	Private	Jaguaruna/SC	Criciúma	Tubarão
SBJE	89,28	Municipal	Cruz/CE	Sobral	Fortaleza
SBJI	69,172	State	Ji-Paraná/RO	Ji-Paraná	Porto Velho
SBKG	127,044	Infraero	Campina Grande/PB	Campina Grande	João Pessoa
SBMA	269.483	Infraero	Marabá/PA	Marabá	Belém
SBMK	216,882	Infraero	Montes Claros/MG	Montes Claros	Belo Horizonte
SBML	64,696	State	Marília/SP	Marília	São Paulo
SBPF	155,568	State	Passo Fundo/RS	Passo Fundo	Porto Alegre
SBQV/SBVC**	191,511	Private	Vitória da Conquista/BA	Vitória da Conquista	Salvador
SBSI	157,528	Private	Sinop/MT	Sinop	Cuiabá
SBTT	60,916	Infraero	Tabatinga/AM	Tefé	Manaus
SBUR	73,565	Infraero	Uberaba/MG	Uberaba	Belo Horizonte
SBZM	147,921	Private	Goianá/MG	Juiz De Fora	Juiz de Fora
SNBR	74,923	Private	Barreiras/BA	Barreiras	Salvador
SSKW	59,842	State	Cacoal/RO	Ji-Paraná	Porto Velho

* Humberto Ghizzo Bortoluzzi Regional South airport - Jaguaruna/SC (SBJA), considered for 2014, and Diomício Freitas/Forquilhinha airport - Criciúma/SC (SBCM-SSIM), considered for 2019.
** Pedro Otacílio Figueiredo Airport (SBQV), considered for 2014, and Glauber Rocha Airport (SBVC), opened in 2017 and is considered for 2019.

The Zona da Mata airport (SBZM), in Goianá/MG, and Caldas Novas airport/GO (SBCN) were also included in this consortium in 2014. Furthermore, the Jaguaruna/SC airport (SBJA) was granted to RDL Aeroportos in 2014, while the airport in Barreiras/BA (SNBR) was awarded to São Francisco Administração Aeroportuária e Rodoviário Ltda. A notable aspect of airport management in Brazil is that, from the first round of airport concessions in 2011 to the seventh round in 2021, 49 airports were transferred to private ownership, representing approximately 75% of air traffic and 92% of passenger movement in the country (ANAC, 2022). With the most recent concessions carried out at the end of 2023, the country concentrates 93% of passenger processing and 99% of cargo handling in 59 airports of different sizes, managed by the private sector, represented by 11 different airport operators from South America, Europe, Africa, and Asia (ANAC, 2023).

With the identification of small airports, accompanying information about the cities in which they are situated was also gathered, including details regarding the population centers they serve and influential cities in their vicinity. Figure 2 illustrates the geographic locations of these 25 small airports analyzed across Brazil.

As shown in Figure 2, the 25 small airports considered as study cases are distributed across the five different regions of Brazil (South, Southeast, Central-West, Northeast, and North), demonstrating their possible relevance and areas of influence throughout the national territory considering the spatial economic theory for airport-centric development Mokhele, 2018).

Figure 2
Location of Brazilian airports considered.

Source: research data.

3.1 ANALYTICAL METHODS OF EFFICIENCY

One method employed for measuring airport efficiency is DEA, which enables the correlation of operational characteristics—such as runway and terminal sizes—with data on passenger processing and air cargo handling. The approach utilized in this study has been adapted from Fragoudaki and Giokas (2020), Ngo and Tsui (2020), and Uludağ (2020). Specifically, the DEA CCR input-oriented method was employed as the envelopment method to assess the relationship between inputs and outputs, following the framework proposed by Charnes, Cooper & Rhodes (1978). This analysis was conducted based on Equation 2 and subject to the constraints outlined by Equations 3 to 5.

$$Max\ h_0 = \sum_{r=1}^{s} u_r y_{r0} \tag{2}$$

s.t.:

$$\sum_{v=1}^{m} v_i x_{i0} = 1 \tag{3}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{v=1}^{m} v_i x_{ij} \leq 0 \quad \forall j \tag{4}$$

$$u_r\ and\ v_i \geq 0 \tag{5}$$

where $Max\ h_0$ refers to the objective function, u_r and y_{r0} indicate the inputs and outputs, respectively.

To ensure consistency and comparability, all results were evaluated on a standardized decimal scale, thereby ensuring that they align with the DEA frontier. Efficiency can also be assessed using the EATWOS method, which independently analyzes samples in terms of both inputs and outputs. This approach provides partial efficiency assessments for each set of samples, as depicted in Equation 6.

$$P_l = \frac{\sum_{t=1}^{x} m_{lt}.w_t}{\sum_{t=1}^{x} r_{lk}.v_k};\ \forall \in l \tag{6}$$

where P_l refers to the productivity of each trait, m_{lt} and r_{lk} indicate the distances between the inputs and outputs, respectively.

The ratio between these sets furnishes an efficient outcome for productivity. Following this reasoning, Uludağ (2020) compares the results obtained via DEA with those acquired through EATWOS. Additionally, the EATWOS method facilitates the determination of weights *w* and *v*, assigned to each characteristic, as presented in Equations 7 and 8, providing a measure to comprehend the significance of this information within the collected sample.

$$W_t = \frac{P_t}{\sum_{t=1}^{y} P_t};\ \forall \in t \tag{7}$$

$$V_k = \frac{U_k}{\sum_{k=1}^{n} U_k};\ \forall \in k \tag{8}$$

where W_t represents the weight of the inputs, while V_k indicates the weights of the outputs, P_t and U_k denote the degrees of diversification, and t and k represent the input and output, respectively.

Table 3 presents the factors employed as inputs and outputs in the DEA and EATWOS approaches.

Table 3
Factors used in DEA and EATWOS methods.

Groups	Factors
Inputs	Runway length (m).
	Aircraft apron size (m²).
	Passenger terminal size (m²).
	Parking positions (n).
Outputs	Air cargo handling (ton).
	Total aircraft movement (n).
	Total of passengers processing (n).

Such methodologies identify characteristics presented in Table 3, such as runway length, aircraft apron size, and passenger terminal size, used as inputs, air cargo handling, total aircraft movement, and total of passengers processing, used as outputs.

3.2 REGRESSION METHODS

To ascertain factors pertinent to airport competitiveness, investigations conducted by Dziedzic et al. (2020), Ngo and Tsui (2020), Merkert and Mangia (2014), and Rolim et al. (2016) have scrutinized the correlation between the analyzed region and airports utilizing regression methodologies. In this study, data from the latest research by the Brazilian Institute of Geography and Statistics (IBGE) were harnessed to delineate these factors, encompassing GDP per capita, population density, city attraction index, and airport-specific attraction index. The attraction indexes were gauged via surveys wherein residents of a given city were queried about their shopping preferences, airport utilization, healthcare facilities, and other activities undertaken outside their municipality. Furthermore, a separate attraction index for airports was computed to signify the patronage of specific airports.

Utilizing georeferenced data, the study measured the distances from the airports to their respective influential cities, along with identifying the shortest distance between the studied airport and any other airport within its catchment area. The research aims to correlate information gathered from 2014 and 2019 to ascertain the evolution of regional assessments over time. One of the methodologies utilized to evaluate the coverage region of airport services is introduced by Gao (2019), who gauges airport selection predicated on passenger trip costs, delineated in Equation 9.

$$U = D + P + A \tag{9}$$

where *U* is the total travel expenses, *D* is the passenger's car travel cost to the airport, *P* is the airport parking daily rate, and *A* is the passenger’s flight cost with the ticket.

Appropriate modifications have been implemented in the variables of Equation 9, where the devised model centers on the actual travel cost. In Equation 10, the cost of traveling by car, denoted as *D*, incorporates the sum of toll expenses (*Ped*) and the ratio between the average price of a liter of regular gasoline (*Gas*) in 2019, and the distance (*dist*) between the principal cities within the airport's catchment area (in kilometers).

$$D = \left[(Gas_j^{-10}.dist) + Ped\right] \tag{10}$$

To estimate the passenger’s flight cost with the ticket, a model was devised that takes into account the ratio between airfare rates and the number of seats sold per flight at an airport, as depicted in Equation 11. This model was constructed using takeoff and landing data sourced from selected airports in 2019 (ANAC, 2020).

$$A = \sum_{j=1}^{n} Tar_{ij} \Big/ \sum_{j=1}^{n} ass_{ij} \tag{11}$$

where i is the selected airport, j is the year in which the rate was applied, Tar is the fee applied per flight operation, and ass is the number of seats sold per flight operation.

The variables presented in Table 4 were used in the multiple linear regression analysis.

Table 4
Variables used in the multiple linear regression.

Group(s)	Variables
Dependent Variable	Airport efficiency (n).
Independent Variables	GDP per capita of the population arrangement (BRL)
	People at the population arrangement (n).
	City attraction index of population arrangement (n).
	Attraction index for airport (n).
	The closest distance to the airport of the same population arrangement (km).
	Distance from the airport to the city of influence (km).
	Canceled flights (n).
	Flights delayed by more than 30 minutes (n).
	Flights delayed by more than 60 minutes (n).
	Total cost of the trip (BRL).

To ascertain the relationship between the dependent and independent variables outlined in Table 4, it was necessary to ensure that the measurements were standardized to similar decimal places. The independent variables (*x*) were normalized as per Equation 12, wherein they were divided by the mean value obtained from each respective set of variables.

$$x_{ij_{normal}} = x_{ij}/\bar{x} \tag{12}$$

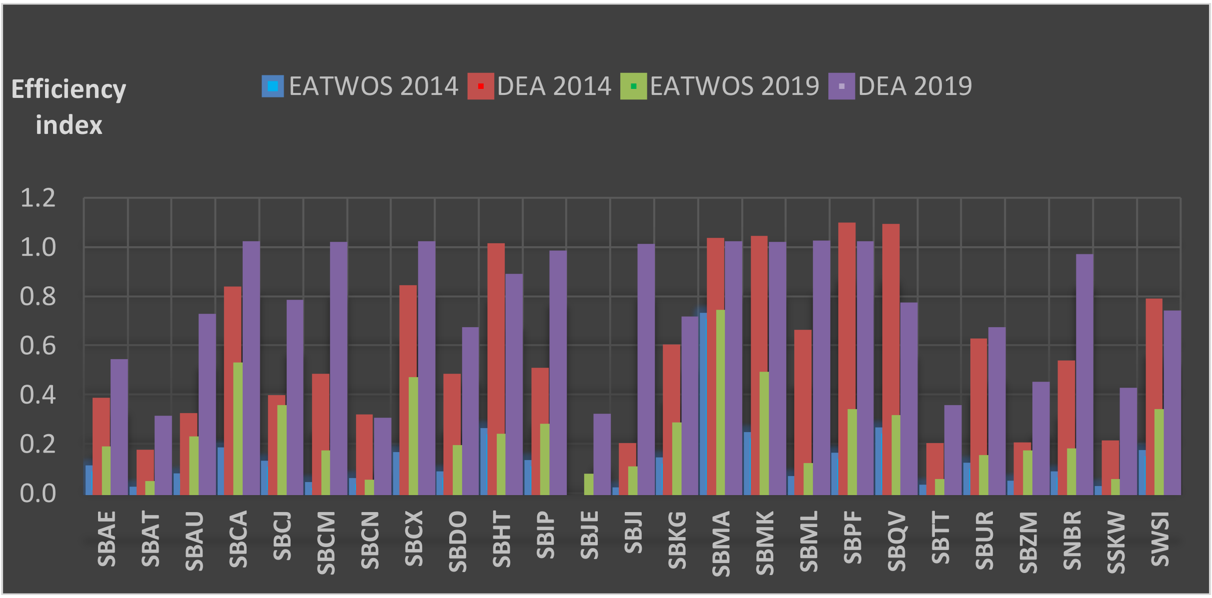
A dummy variable was established based on the governance structure and efficiency values acquired, assigning a value of 0 and 1 to represent the presence or absence of a particular governance structure at the airport. A value of 1 was assigned for airports where the specified governance structure was present, while a value of 0 was assigned for those where it was absent. These values were treated as independent variables for assessing the efficiency of each airport. This methodology, akin to that employed by Dziedzic et al. (2020), facilitates the correlation of governance structures and the variables of interest. The authors associated the highest obtained values and the significance of the relationship to identify the most pertinent correlations. Tobit regression serves as a fitting tool for this purpose, as it can accommodate values that, though correlated, lie beyond the collection boundary. An instance is binary data featuring values of 1 and 0, which may deviate significantly from the linear correlation boundary even after normalization, as also evidenced in studies conducted by Ngo and Tsui (2020), and Merkert and Mangia (2014).

4 DISCUSSIONS OF RESULTS

To assess the efficiency of small airports, the data from 2019 were juxtaposed with those from 2014. However, it is worth noting that the Jaguaruna/SC (SBJA), Cruz/CE (SBJE), and Vitória da Conquista/BA (SBVC) airports were not operational in 2014. In such instances, the airports with commercial flights closest to the respective cities were considered. Specifically, for the Jaguaruna/SC airport, the Diomício Freitas/Forquilhinha airport - Criciúma/SC (SBCM-SSIM), managed by Infraero at the time, was examined. The case of Pedro Otacílio Figueiredo Airport - Vitória da Conquista/BA (SBQV), managed by Socicam, was operational in 2014. However, there was no equivalent airport for the Cruz/CE (SBJE) airport in 2014. Therefore, no substitute was utilized for this airport in the present study.

The efficiency scores derived for each small airport through the EATWOS and DEA methods, as depicted in Figure 3, elucidate the correlation between inputs (such as runway length, terminal size, parking positions, and apron capacity), and outputs (including aircraft movement, air cargo handling, and passenger processing), presented in the form of an index. Values nearing 1 signify a favorable relationship between the calculated input and output groups, indicating higher efficiency levels.

Figure 3
Efficiency in 2014 and 2019 were measured by EATWOS and DEA.
Source: research data.



From the findings presented in Figure 3, two sets of efficiency samples are discernible for the years 2014 and 2019. Variances in the results are observable, as exemplified by the Marília/SP airport (SBML), which exhibits the most notable disparity between the different measurements based on the DEA method. This approach takes into account operational characteristics concerning passenger processing. Conversely, the EATWOS model analyzes each set of data independently. Consequently, it becomes evident that the SBML airport demonstrates comparatively lower levels of passenger processing and air cargo handling than other small airports. In the context of DEA, the operational structure of the SBML airport aligns proportionally with the measured passenger processing. Hence, despite the significant discrepancies between the values calculated by each method, these results can be construed as mathematically coherent.

Another noteworthy observation from Figure 3 is that the Passo Fundo/RS airport (SBPF) and Vitória da Conquista/BA airport (SBQV) exhibit DEA indices above 1 for the year 2014, with values of 1.08 and 1.07, respectively. This anomaly arises because SBPF lacked parking positions, yet it displayed satisfactory compensation in other input factors during this period. Conversely, SBQV demonstrated a substantial volume of passenger processing in 2014 (191,511), surpassing the passenger processing figures of other small airports, with the group average equating to 10,892 passengers per airport. To further scrutinize the efficiency indices and governance structures based on DEA and EATWOS methods, Figure 4 portrays a box plot chart spanning the considered periods.

Figure 4
Comparison of efficiencies measured by DEA based on the governance structure in small airports in both 2014 and 2019.

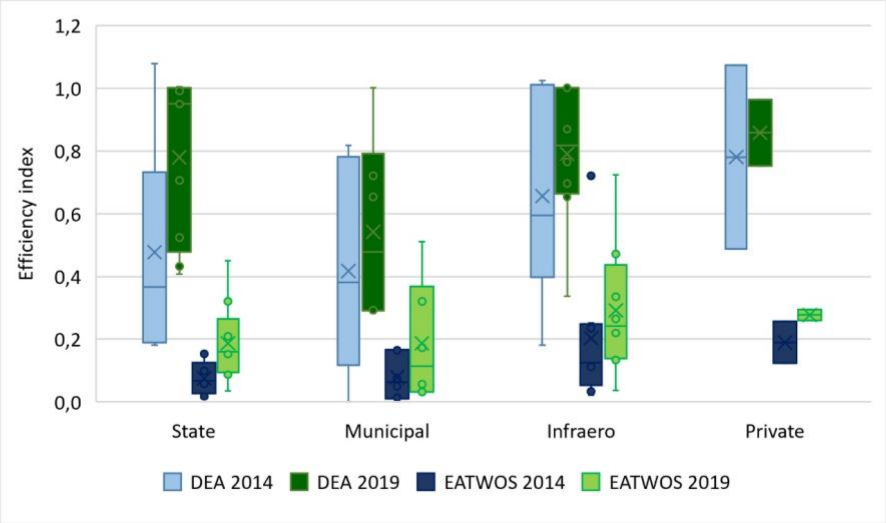


Figure 4 illustrates that the midpoints of the measurements for both 2014 and 2019 are closely aligned, as indicated by the proximity of their respective boxes' extensions, suggesting a similarity in the obtained data. The differences emerge in the airports managed by the state, which exhibit substantially higher midpoints and efficiency outcomes. Conversely, privately managed airports displayed relatively lower efficiency in 2019 compared to 2014, reflecting a closer alignment with the results observed for this governance structure. It is evident from Figure 4 that there exists a discernible evolution in the results obtained in 2019 compared to those from 2014. This can be attributed to the enhanced productivity of these small airports based on the variable weights, as depicted in Table 5.

Table 5
The relationship between the weights assigned to inputs and outputs (Source: survey data).

	Inputs				Outputs		
Year	**Runway**	**Apron**	**TPS**	**Parking**	**Air cargo**	**Aircraft**	**Passengers**
2014	0,222	0,268	0,265	0,246	0,584	0,290	0,125
2019	0,223	0,241	0,267	0,268	0,375	0,313	0,312

Note: Runway refers to the length of the runway; Apron denotes the size of the airfield; TPS represents the size of the passenger terminal; Parking indicates the number of parking positions; Air cargo pertains to the handling of air cargo; Aircraft denotes the total aircraft movement; Passengers signify the total number of passengers processing.

The weights corresponding to the maximum and minimum variables were determined by individually assessing the variables within their input and output groups. Subsequently, each weight was calculated relative to a total value of 1, reflecting the contribution of each variable to the composition of its respective group. The summation of the weights within each group equaled one, thereby validating the weights obtained.

In the analysis of the weights depicted in Table 5, it is evident that the measurement of runway length exhibits a lower correlation with apron size, terminal size, and parking positions. Moreover, there seems to be minimal disparity in the evolution of weights associated with this variable, likely due to the absence of significant differences among the sample measurements. Conversely, air cargo handling emerges as the most influential factor. However, in 2019, there was a notable equilibrium between movements, signifying enhanced efficiency in airports relative to flight operations.

To identify the regression analysis of airports where passengers incur the highest transportation expenses, Table 6 presents the values in Brazilian Real (BRL) corresponding to the governance structure of the small airports, the passenger's car travel cost to the airport (*D*), airport parking daily rate (*P*), passenger’s flight cost (*A*), and total travel expenses (*U*), ranked by the highest total travel expenses.

Table 6
Costs related to transportation to the airport. (Source: research data).

Airport	Governance structure	D	P	A	U
SBSI	Private	6,12	40,00	460,48	506,60
SSKW	Infraero	31,40	*	339,03	370,43
SBCJ	State	34,20	*	280,68	314,88
SBKG	State	3,81	*	153,93	307,74
SBJI	Infraero	5,32	*	294,55	299,88
SNBR	Private	7,38	25,00	230,64	263,02
SBAT	Private	9,12	*	252,94	262,06
SBML	State	1,26	*	241,07	242,32
SBAE	State	7,54	30,00	194,22	231,75
SBMA	Infraero	2,35	*	216,40	218,75
SBAU	State	5,02	35,00	178,69	218,72
SBHT	Infraero	3,20	*	208,73	211,93
SBUR	Infraero	1,42	22,00	187,67	211,09
SBDO	Infraero	6,08	10,00	192,01	208,09
SBMK	Municipal	2,84	20,00	183,68	206,53
SBZM	State	30,52	25,00	149,56	205,08
SBIP	Private	3,18	*	187,95	191,12
SBPF	State	6,08	*	162,98	169,06
SBCM	Infraero	25,84	20,00	118,81	164,65
SBTT	Municipal	4,70	*	151,05	155,75
SBJE	Municipal	5,27	*	148,67	153,94
SBCA	State	3,42	*	142,77	146,19
SBCX	Private	2,19	28,00	114,11	144,31
SBVC	Private	6,09	48,00	56,03	110,12
SBCN	Private	10,06	30,00	64,38	104,44

* No fees applied, such as public parking, or not enough data for this measurement.

The findings presented in Table 6 suggest that the cost of the passenger's flight plays a predominant role in shaping the total travel expenses. Nevertheless, in certain instances, other factors also wield significant influence over the cost outcomes. Specifically, the cost of the passenger's car travel to airports located farther from the population centers amplifies the travel expenses. This phenomenon is evident in the cases of Carajás Aiport - Parauapebas/PA (SBCJ), Cacoal/RO (SSKW), and Forquilhinha-Criciúma/SC (SBCM) airports, whose cities are 17.2, 10.6, and 10.2 kilometers away, respectively.

From the applied regression, a moderate relationship between the variables is indicated, as shown in Table 7. The Pearson's coefficient, which signifies the degree of correlation, approaches 1, indicating a strong association. The multiple R or Pearson's coefficient, calculated at 0.741, suggests a robust correlation among the variables. The R-squared value, representing the proportion of the variation in efficiency explained by the regression, stands at 55%, indicating a moderate level of explanatory power. In terms of significance level α, which signifies the threshold for statistical significance, values less than or equal to 0.05 are considered significant. In this regression, the coefficient that best fits this relationship is the attraction index for airports. However, considering a less stringent α of 0.1, other factors such as GDP per capita, city attraction index, and nearest distance to the airport also exhibit significant influence on airport efficiency. These results underscore the relevance of regional factors in explaining airport efficiency using DEA. In line with the findings of Khadaroo and Seetanah (2010), variables such as market size, human capital, openness, and infrastructure quality emerge as key determinants not only in transport infrastructure, but also in manufacturing and tourism industries, thereby enhancing the attractiveness to foreign investors.

Table 7
Results of Multiple Linear Regression Analysis (Source: research data).

Dependent variable = efficiency measured by DEA			**Dependent variable = efficiency measured by EATWOS**	
Regression statistics			**Regression statistics**	
R-multiple		0,740811	R-multiple	0,815518
R-Square		0,5488	R-Square	0,66507
Adjusted R-square		0,226515	Adjusted R-square	0,425835
Standard error		0,226907	Standard error	0,131114
Observations		25	Observations	25
Variable	**Coefficients**	**p-value**	**Coefficients**	**p-value**
Intersection	0,507526	0,076358*	0,076246	0,626569
GDP per capita of the population Arrangement	0,195396	0,112236*	0,149488	0,041529**
People at the population arrangement	0,085728	0,228092	0,045047	0,270903
Population arrangement city	-0,21223	0,132466*	-0,0488	0,53518
Attraction index for airport	0,157103	0,034968**	0,107589	0,015131***
The closest distance to the airport of the same population arrangement	-0,18909	0,141683*	0,039771	0,579752
Distance from the airport to the city of influence	-0,00177	0,987048	-0,0056	0,929234
Canceled flights	-0,01085	0,375127	-0,00394	0,573912
Flights delayed by more than 30 minutes	-0,00884	0,441632	-0,00794	0,238554
Flights delayed by more than 60 minutes	0,032763	0,385526	0,033775	0,132348*
Total travel cost	0,082979	0,685274	-0,11369	0,343124

Notes: *, **, and *** indicate that the explanatory variables have significance levels of 0.10, 0.05, and 0.01, respectively.

Also presented in Table 7, the results reveal an R-multiple value of 0.816, indicating a strong relationship as indicated by Pearson's coefficient. The R-square value of 0.67 signifies that 67% of the efficiency results are explained by this model. The significance level underscores the relevance of flights delayed by more than 60 minutes, the attraction index for airports, and GDP per capita in determining efficiency. These findings are consistent with those reported in Caetano et al. (2022), which examine technical-operational and socioeconomic indicators associated with Brazilian public general aviation aerodromes and their impact on regional development. Additionally, they align with the results of Grubesic et al. (2017), who investigated the development of the reliever airport network in the Phoenix metropolitan area in the United States.

The results obtained through input-oriented DEA concerning the governance structure in 2014 and 2019 did not yield significant findings. Table 8 illustrates the values concerning the relationship between EATWOS efficiency and governance structure in 2014. The airports under state and Infraero governance exhibited the highest R-multiples, indicating significant efficiency. This trend persisted in 2019, when state and Infraero airports continued to demonstrate the highest R-multiples and utmost significance.

Table 8
The correlation between efficiencies derived from EATWOS and the distinct governance structures (Source: survey data).

Small Airports in 2014				Small Airports in 2019		
Dependent variable = efficiency measured by EATWOS						
Variable (0-1)	**R-multiple**	**R-Square**	**p-value**	**R-multiple**	**R-Square**	**p-value**
State	0,307	0,094	0,145*	0,097	0,009	0,645
Infraero	0,356	0,126	0,088*	0,311	0,057	0,131*
Municipal	0,131	0,017	0,543	0,040	0,002	0,848
Granted/Private	0,123	0,015	0,568	0,239	0,057	0,250

Note: * indicates that the explanatory variable has a significance level of 0.10.

As presented in Table 8, these findings should be juxtaposed with those observed in Nascimento and Caetano (2020), which reveal negative financial performance indices among small public airports. This underscores the necessity for a distinct approach towards this governance structure, particularly concerning airports, despite their operational efficiency.

To validate the regressions and to comprehensively analyze all dependent variables simultaneously, the Tobit method was employed in this study. The most recent efficiency data were juxtaposed with the independent variables utilized in the multiple regression approach, alongside various forms of management. Table 9 delineates this association, utilizing data assessed through DEA and EATWOS for the year 2019.

The results obtained in 2019 using DEA, as presented in Table 9, indicate significant relationships with GDP, the city attraction index, and airports, mirroring findings from the multiple linear regression analysis. Similarly, the analysis using the EATWOS method reveals relationships with GDP, population, attraction rates for both city and airport, nearest distance to the airport within the same population arrangement, as well as flights delayed by more than 30 and 60 minutes, and the type of management (granted/private). However, the results obtained from the Tobit analysis using the EATWOS efficiency slightly deviate from those obtained through linear regressions.

Private management shows a negative impact, albeit relatively low (-0.212), on airport efficiency in the Tobit efficiency measured by EATWOS in 2019, with significance levels at 0.01. This contrasts with the findings of linear correlation analyses. Despite the prevailing notion in the literature that private management leads to improved performance (Caetano et al., 2021; Halpern et al., 2021), this study demonstrates that, in the case of small airports, private management does not necessarily guarantee efficiency.

Table 9
The Tobit regression results for small airports in 2019 (Source: research data).

Dependent variable = efficiency measured by DEA in 2019				Dependent variable = efficiency measured by EATWOS in 2019		
Variable	**Coefficients**	**Error**	**p-value**	**Coefficients**	**Error**	**p-value**
Constant	0,567	0,225	0,012**	0,238	0,101	0,019**
GDP per capita of the population arrangement	0,201	0,090	0,026**	0,130	0,041	0,002***
People at the population arrangement	0,078	0,052	0,137	0,057	0,024	0,015**
Population arrangement attraction index	-0,206	0,101	0,041**	-0,086	0,045	0,059*
Attraction index for airport	0,164	0,056	0,003***	0,111	0,025	0,000***
Nearest distance to the airport of the same population arrangement	-0,167	0,114	0,143	0,103	0,051	0,044**
Distance from the airport to the city of Influence	0,003	0,082	0,969	-0,046	0,037	0,217
Canceled flights	-0,010	0,009	0,282	-0,000	0,004	0,932
Flights delayed by more than 30 minutes	-0,012	0,009	0,169	-0,010	0,004	0,011**
Flights delayed by more than 60 minutes	0,042	0,029	0,139	0,035	0,013	0,007***
Total travel cost	0,062	0,160	0,699	-0,104	0,072	0,150
Granted/Private	-0,101	0,151	0,503	-0,212	0,068	0,002***
State	-0,021	0,183	0,908	-0,104	0,083	0,208
Infraero	-0,107	0,177	0,543	-0,042	0,080	0,596
Municipal****	-	-	-	-	-	-

Notes: *, **, and *** indicate that the explanatory variables have significance levels of 0.10, 0.05, and 0.01, respectively.

5 FINAL CONSIDERATIONS

This study provides insights into the weights of variables on small airport efficiency through different analytical methods. Multiple linear regression revealed that GDP per capita, the closest distance to the airport within the same population arrangement, the closest distance to the airport of the city of influence, and flights delayed by more than 60 minutes significantly influenced positively the efficiency of small airports. Additionally, the airport attraction index showed a strong correlation with efficiency, indicating its utility as a reliable indicator of airport usage. The observed relationships between GDP per capita and distance may suggest that regions with higher economic performance tend to exhibit better airport efficiency.

While this study did not demonstrate a clear evolution in efficiency information, it contributed to enhancing our understanding of the relationships involved. By employing the Tobit regression method, this study expanded upon the variables identified by multiple linear regression, incorporating population arrangement variables, and flight delays exceeding 30 minutes. Consistent with prior research, the regression analysis revealed that many variables exerted distinct impacts on efficiency. Furthermore, the numerical disparities between the results obtained via DEA and EATWOS shed light on the effects of input weights in the study.

The relationship between efficiency and governance structure can also be verified when considering the variables and research methods employed in this study. It is possible to note that airports such as Cascavel/PR (SBCA), Caxias do Sul/RS (SBCX), and Marabá/PA (SBMA), each governed by municipal, state, and Infraero authorities, respectively, rank among the most efficient small airports. This underscores the diverse governance structures observed among highly efficient airports. Conversely, airports privatized in 2019, like Alta Floresta/MT (SBAT), exhibit lower efficiency levels. Interestingly, airports like Jaguaruna/SC (SBJA), established in 2014 and under private management since inception, demonstrate commendable efficiency results. While Brazil's ongoing transition toward varied governance structures across state, municipal, and federal levels reflects evolving strategies in upgrading airport operations, private airports tend to be considered more efficient compared to publicly managed ones. Future research endeavors could further explore financial factors to corroborate these findings.

The findings of this study, focused on some public airports at the time of analysis, offer valuable insights that can serve as a reference for future efficiency analyses of airports that have recently transitioned to private initiative through concessions. By highlighting potential managerial and infrastructure issues that may require optimization, these results provide a solid foundation for evaluating the performance of newly privatized airports. Leveraging this reference, stakeholders involved in airport management and oversight can effectively assess the impact of privatization on efficiency and identify areas for improvement to enhance overall operational performance and contributions to regional development.

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