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The Impact of ICMS Tax Collection on State of Ceará after the Concession of Fortaleza Airport

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ABSTRACT

In Brazil, the concession of major airports to private entities aims to enhance infrastructure and operations, yet its fiscal impact on state revenues remains a critical question for policymakers. This study analyses this fiscal impact, with a specific focus on whether the 2017 privatization of Fortaleza Airport boosted the collection of the ICMS tax in the state of Ceará. We employ a dual-method approach. First, a panel data regression assesses the general impact of concessions on ICMS revenue across five northeastern states (2000–2022). Second, the Synthetic Control Method (SCM) isolates the specific causal effect of the Fortaleza concession by comparing Ceará to a weighted combination of similar untreated states. The panel regression reveals passenger movement as a key revenue driver, with the Fixed Effects model indicating a significant positive relationship from concessions. The SCM analysis shows a significant positive divergence emerging four years post-concession, suggesting a long-term positive impact on Ceará's ICMS collection. The findings confirm that airport concessions can generate significant, long-term fiscal benefits for state governments by stimulating the tax base. These benefits, however, materialize only after a prolonged operational stabilization period, providing crucial evidence for policymakers designing temporal planning and risk-sharing arrangements in future infrastructure privatization policy.

Keywords: Airport Concession; ICMS Tax Revenue; Synthetic Control Method; Panel Data; Fixed Effects; Fortaleza Airport.

INTRODUCTION

The aviation sector in Brazil has experienced notable changes in recent years, especially regarding the management and functioning of airport infrastructure. The rising participation of private firms in the oversight of major airports that were once managed by the Brazilian airport authority (Infraero) has ushered in a new phase of airport concessions in the country. This transition towards involving the private sector has led to enhancements in facilities, services, and connectivity, ultimately aiming to improve the overall passenger experience and foster economic growth. A prominent illustration of this shift is the concession of Fortaleza Airport, awarded to a private organization in 2017, which marked a crucial turning point in the airport's development and operations.

The concession of Fortaleza Airport signifies a strategic decision by the government to utilize private sector expertise and funding in airport infrastructure. By entrusting the management and operation of the airport to a private concessionaire, the goal is to enhance operational efficiency, attract new routes and airlines, and ultimately promote economic growth in the area. This move towards private management prompts significant inquiries regarding the effects of such concessions on state revenue, especially concerning tax collection, such as the State value added tax (*Imposto sobre Circulação de Mercadorias e Serviços*, in Portuguese, ICMS) in Ceará.

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Grasping the repercussions of airport concessions on state revenue is vital for policymakers and stakeholders engaged in infrastructure development and economic strategy. By examining the impact of the Fortaleza Airport concession on ICMS collection in Ceará, this study aims to offer valuable insights into the fiscal implications of airport privatization. Through a thorough analysis of the shifts in revenue trends following the concession, this research aspires to illuminate the broader economic consequences of airport infrastructure management in Brazil.

To delve into this issue, the paper unfolds as follows. Initially, we place the study within the wider context of literature on infrastructure concessions, emphasizing the frequently neglected fiscal duties of the state. Next, we outline our empirical approach, which adopts a dual-method strategy: a panel regression to evaluate the general connection between concessions and tax revenue across the Northeast, and the Synthetic Control Method (SCM) to pinpoint the specific causal influence of the Fortaleza concession on Ceará's ICMS. The following section presents our findings, which depict a nuanced landscape of delayed yet significant fiscal advantages. We conclude by discussing the policy implications of these results, particularly the necessity for long-term perspectives and robust fiscal risk management in planning concessions. The analysis reveals that while immediate impacts on ICMS collection may be subtle, the long-term benefits could significantly enhance the state's fiscal health.

AIRPORT CONCESSION AND FISCAL CONTEXT

The transition of infrastructure management via concessions introduces a new dynamic where the government's direct financial responsibility is replaced by complex financial and regulatory commitments. While concessions effectively mobilize private resources, the public sector remains critically involved in the financing structure, guarantee provision, and comprehensive risk-sharing arrangements. The literature cautions against reducing concessions to merely methods for bypassing state financial restrictions, highlighting that governments frequently neglect the issue of fiscal sustainability (Duarte 2020).

The failure to systematically assess the complete impact of concessions on public accounts—specifically, the potential for accumulating unobserved or contingent liabilities—represents a significant exposure. In scenarios of fiscal contingencies or extreme economic hypotheses, this exposure may necessitate involuntary public sector intervention or the assumption of additional costs to sustain project viability. Therefore, effective fiscal risk management is essential, requiring a comprehensive perspective that incorporates not only the concessionaire's construction and operating costs but also the net tax revenues indirectly generated by the project to inform resource allocation and validate the potential return on public investment.

The fundamental role of transport infrastructure in driving regional economic development mandates that concession strategies extend beyond simple cost recovery (Frischtak 2013). The promotion of regional economic growth is often viewed as a prerequisite for ensuring a concession's long-term success (Aragão *et al.* 2019). The Fortaleza Airport concession, formalized on July 28, 2017, and effective for a 30-year term, established defined fiscal commitments to the Federal Granting Authority (Union).

These obligations include an initial fixed contribution (R$ 425 million) and subsequent structured payments: a schedule of annual fixed contributions commencing in the sixth year (subject to predefined adjustment formulae, as shown in Table 1) and an annual variable contribution corresponding to 5% of the concessionaire's gross revenue. Fraport effectively assumed operations in January 2018, undertaking significant initial investment, exceeding R$ 1 billion, in infrastructure modernization.

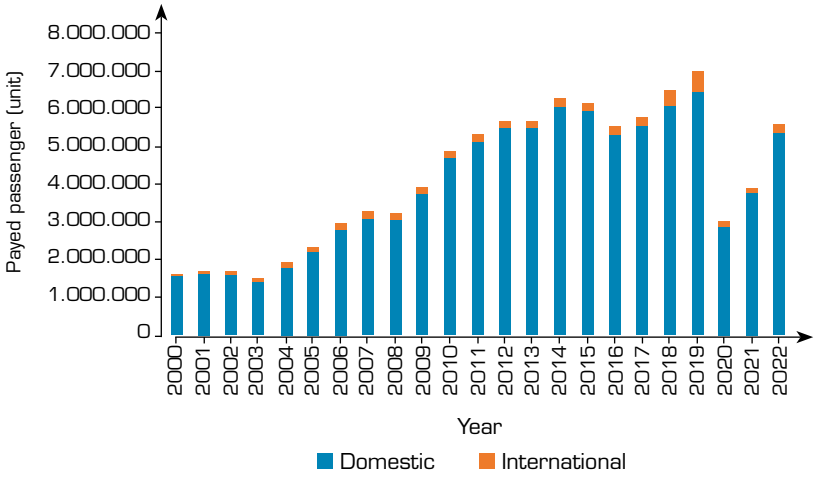
Table 1. Fix annual payment to Federal Government of Brazil by concessions.

Period	Value (R$)
First to fifth year	-
Sixth year	9,397,313
Seventh year	18,794,627
Eight year	28,191,940
Nineth year	37,589,253
Tenth and following years	46,986,567

Source: ANAC (2024).

At the subnational level, the ICMS acts as the primary consumption tax, falling on goods and services, and is crucial for state revenue generation (Complementary Law No. 87/1996). To foster regional connectivity, the state of Ceará utilizes tax incentives, such as a special tax regime, to reduce the tax base on aviation kerosene—a major operational cost—for airlines maintaining regular international routes, effectively lowering the tax burden to 12% on refuelling operations. However, despite the concessionaire's substantial investment, the post-concession operational period exhibited a discrepancy between state policy goals and market outcomes.

As shown in Fig. 1, which illustrates the total annual passenger traffic from 2010 to 2022, the sharp decline in 2020–2021 due to the COVID-19 pandemic significantly altered the traffic trajectory. Furthermore, even after the initial recovery, the preestablished growth conditions for the air hub were not met by 2022, leading to the permanent discontinuation of several flights. This outcome, despite the tax incentives, highlights the limitations of state fiscal policy in fully mitigating commercial risks and maintaining targeted connectivity, directly influencing the projected ICMS revenue derived from the airport ecosystem.



Source: Elaborated by authors with data retrieved from ANAC.

Figure 1. Annual passenger traffic at Fortaleza Airport (2010-2022).

METHODOLOGY

The methodology is designed to rigorously estimate the causal effect of the Fortaleza Airport concession on subnational fiscal outcomes. This is achieved through a dual-methodological framework: initially utilizing standard panel data econometrics—pooled Ordinary Least Squares (OLS) and Fixed Effects—to control for observed and unobserved heterogeneity, followed by the SCM to isolate the unit-specific causal impact.

Data Structure and Research Variables

The study employs an unbalanced longitudinal panel data set covering Ceará (the treated state) and four control states over the period 2000–2022. The primary objective is to monitor the ICMS tax revenue of Ceará following the 2017 concession, utilizing the data structure to identify the treatment effect (τ).

The dependent variable is the logarithm of the annual state-level ICMS revenue (ln(ICMS)). The independent variables used in the panel regression are outlined in Table 2, aiming to control for the main drivers of airport-related commercial activity.

Isolating the specific causal impact of the concession requires constructing a robust counterfactual scenario—the trajectory that Ceará's ICMS revenue would have followed without the privatization event.

The selection of Piauí, Rio Grande do Norte, Paraíba, and Pernambuco to form the donor pool for the control group is a critical methodological decision based on the following criteria, ensuring both internal and external validity for the panel and SCM analyses:

Table 2. Research variables.

Dependent Variable	Definition
ICMS (tax)	ICMS revenue (R$) for Ceará and control states.
Independent Variables	**Definition**
Passenger	passenger movements (arrivals/departures).
Cargo	cargo movements (in tonnes)
Movement	flight movements (landings/take-offs)
Concession	Binary variable (1 for post-concession period in each airport, 0 otherwise)

Source: Elaborated by authors.

- Airport comparability (traffic and infrastructure): The airports in these four control state capitals exhibit a high degree of similarity to Fortaleza Airport (prior to its concession) in terms of traffic volume, infrastructure scale, and operational scope. Furthermore, they all operated under federal administration (Infraero) for the majority of the study period, ensuring a common operational and ownership baseline against which the effect of private concession in Ceará can be clearly measured.
- Regional and macroeconomic homogeneity: The control states belong to the same geopolitical region, exposing them to similar macroeconomic shocks, regulatory environments, and socioeconomic trends. This homogeneity helps the Fixed Effects model effectively mitigate the risk of omitted variable bias by controlling for common, unobserved time-varying confounders.
- Fiscal and structural comparability: Crucially, all entities utilize the ICMS as the primary state-level value-added tax. This common fiscal structure ensures that the dependent variable is fully comparable across the treated (Ceará) and control states.

This configuration will allow for an assessment not only of the relationship between airport movements and ICMS revenue but also of whether airport concessions have a significant impact on revenue, while controlling for other relevant factors. The inclusion of control variables related to airport activities will provide a comprehensive analysis of the impact of airport concessions on state revenue, considering the specific context of the state of Ceará post-concession.

Econometric Models for Causal Inference

The analysis begins by estimating the effect of the concession using the general panel data specification, according to Wooldridge (2006):

$$Y_{it} = X'_{it}\beta + c_i + u_{it} \quad (1)$$

In this expression, the subscript i ($i = 1, 2, ..., N$) denotes the different cross-sectional units (northeastern states) and the subscript t ($t = 1, 2, ..., T$) indicates the time period being analysed. Y_{it} is the dependent variable for unit i in period t; X'_{it} is the transposed vector of independent variables for unit i in period t; while β is the vector of coefficients associated with the independent variables.

The latent variable c_i is responsible for capturing the unobservable characteristics between the northeastern states that are immutable over time, such as natural characteristics. Equation 1 is a general representation that can be used in both pooled and fixed effects models, depending on the interpretation of c_i. If c_i is assumed constant for all units, then a pooled model will be specified, where the units share the same fixed effects. If, instead, c_i is considered a different constant for each unit over time, then a Fixed Effects model will be specified.

The Pooled OLS is an approach in econometric analysis that combines cross-section and time series data to perform estimations. According to Wooldridge (2006), the pooled model assumes that all available data are used together, ignoring any systematic differences between cross-section units. Ordinary Least Squares is often used to estimate the parameters of this model. The objective is to minimize the sum of squared residuals (u_{it}) to obtain estimates of the coefficients (β and c_i) that best fit the observed data.

The Fixed Effects model uses a transformation to control the effects of unobserved heterogeneity that is constant over time. The within transformation subtracts the time average from each variable for each unit, eliminating the unobserved effect c_i. The fixed effects estimator is obtained by applying OLS to the transformed model.

The SCM is deployed as the primary methodology for robust causal inference in the context of a single, localized intervention (Abadie *et al.* 2010). This data-driven procedure constructs a comparison group (the Synthetic Ceará) as a weighted average of the control units that best resembles Ceará's characteristics prior to the intervention (2000–2017). The synthetic control estimator of the treatment effect for the post-intervention period (i.e., $t \geq T_o$) is represented in Eq. 2.

$$Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt} \tag{2}$$

In this expression, Y_{1t} is the value of the variable for the treated unit at post-intervention time t. While $\sum_{j=2}^{J+1} w_j^* Y_{jt}$ is the weighted sum of the values of the variable for the untreated units ($j = 2,...,J + 1$). Here, w_j^* is the vector of optimal weights. The estimated causal effect would therefore be the difference between the observed value for the treated unit and the estimated contribution of the untreated units in the synthetic control group.

The estimation of the treatment effect for the state of Ceará at time t after the intervention is calculated as the difference between the actual revenue of the treated Ceará and the estimated revenue of the untreated Ceará for the same period. Therefore, the post-treatment effect, which is the estimated interest, can be expressed as Eq. 3.

$$\hat{\alpha}_{Ceará,t} = ICMS_{Ceará,t}^{treated} - \widehat{ICMS}_{ceará,t}^{control} \text{ for } (t \geq T_0) \tag{3}$$

Furthermore, a pre-treatment estimate can be obtained, serving as an indirect test of the synthetic control's validity. It is expected that pre-treatment differences are close to zero, indicating that the synthetic control group adequately replicates Ceará's behaviour before the intervention, providing a good representation of the trajectory Ceará would have followed in the absence of the intervention. This difference is estimated as follows in Eq. 4.

$$\hat{\alpha}_{Ceará,t} = ICMS_{Ceará,t}^{treated} - \widehat{ICMS}_{ceará,t}^{control} \text{ for } (t < T_0) \tag{4}$$

This dual-methodology ensures a comprehensive analysis of the ICMS revenue impact, controlling for both time-invariant factors and the construction of a reliable counterfactual for the specific concession event.

RESULTS AND DISCUSSION

The quantitative analysis utilizes a dual-methodological approach—Panel Data Regression (Pooled OLS and Fixed Effects) and the SCM—to rigorously estimate the causal effect of the Fortaleza Airport concession on the logarithm of state-level ICMS revenue (ln(ICMS)).

The initial estimation via Pooled OLS (Table 3) was performed to establish a baseline. As anticipated, this model failed to detect a statistically significant impact of the concession, with the Concession Dummy coefficient being positive but nonsignificant ($\beta = 0.17$, p-value = 0.26, greater than 10%). This result is expected because Pooled OLS is unable to control for unobserved, time-invariant heterogeneity across states, which is necessary for valid causal inference in this setting.

Table 3. Pooled model: dependent variable ln(ICMS).

Variables	Coefficient	Standard error	t-ratio	p-value
constant	14.7116***	0.76	19.16	<0.0001
Concession Dummy	0.17	0.13	1.31	0.26
ln(passenger)	0.531283**	0.220635	2.408	0.0185
ln(cargo)	–0.0657083	0.158072	–0.4157	0.6788
ln(movement)	–0.00128550	0.281952	–0.004559	0.9964
R^2	0.88		R^2 adjusted	0.84

Source: Elaborated by the authors. *statistical significance 10%; **statistical significance 5%; ***statistical significance 1%.

Among the control variables ("passenger," "cargo," and "flight"), only passenger movements showed statistical significance. The coefficient for this variable was 0.531, indicating that a 1% increase in passenger movements leads to a 0.531% rise in ICMS revenue in these states. This highlights the importance of passenger traffic in influencing state revenue. The Fixed Effects model will further explore the nuanced effects of airport concessions on revenue, considering specific state characteristics and potential time-related variations.

The analysis of panel data allows for a more robust examination of the relationship between airport activities and state revenue over time, providing a comprehensive understanding of the dynamics at play. The results obtained from the pooled model lay the foundation for deeper investigations into the impact of airport concessions on state finances, setting the stage for a more detailed exploration in the subsequent Fixed Effects model analysis.

The Fixed Effects model (Table 4) corrects this limitation by absorbing all stable, state-specific factors (α_i). This provides the key econometric estimate for the policy impact:

Table 4. Fixed effect model: dependent variable ln(ICMS).

Variables	Coefficient	Standard Error	t-ratio	p-value
constant	17.7639***	44.416	39.99	0.0001
Concession Dummy	0.58883***	93.475	6.299	0.0032
ln(passenger)	1.57829***	868.763	18.17	0.0001
ln(cargo)	–0.550605***	983.076	-5.601	0.005
ln(movement)	–0.960223***	138.506	-6.933	0.0023
R^2 LSDV	0.940		R^2 within	0.900

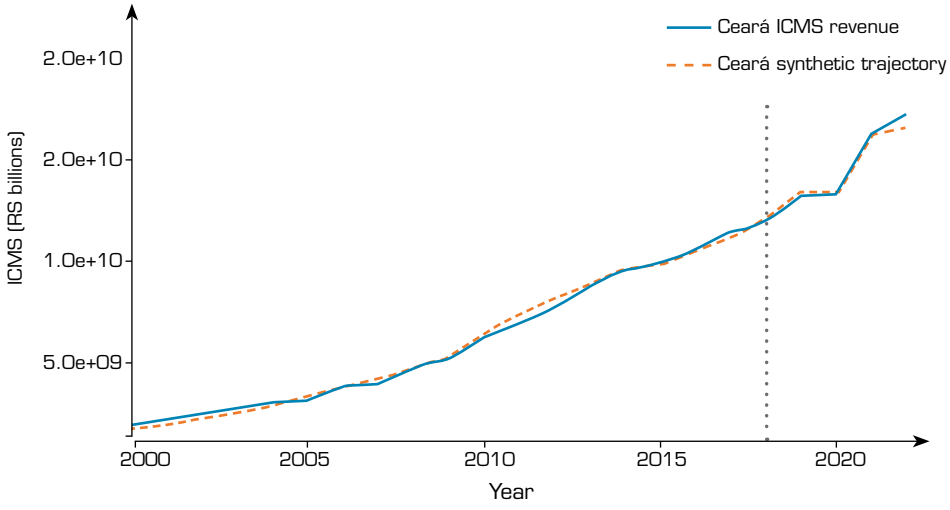
Source: Elaborated by authors. *statistical significance 10%; **statistical significance 5%; ***statistical significance 1%; LSDV: Least Squares Dummy Variable.

- Concession effect: The Concession Dummy is positive and highly significant at the 1% level ($\beta = 0.588$, $p = 0.0032$). This confirms that, after controlling for stable structural differences, the concession induced a substantial positive shift in Ceará's ICMS revenue relative to the control group.
- Elasticity of passenger traffic: The elasticity of ICMS revenue with respect to passenger movements (ln(passenger)) is notably high ($\beta = 1.578$, $p < 0.0001$). This underscores the pronounced role of passenger-related commerce, services, and tourism in expanding the state's sales tax base.
- Asymmetric control variable effects: Both ln(cargo) ($\beta = -0.550$) and ln(flight) ($\beta = -0.960$) movements were found to be statistically significant with negative coefficients. This suggests that increases in non-passenger aviation activity do not translate into immediate positive ICMS revenue growth in the same manner as passenger traffic, pointing toward complex fiscal mechanisms or current state tax structures.

Additionally, the SCM was applied to assess the causal effect of the intervention, specifically the concession of Fortaleza Airport, on ICMS revenue in Ceará. This methodological choice aligns our work with advanced policy evaluation literature, where SCM

is recognized as a powerful tool for constructing a statistically valid counterfactual when evaluating localized, large-scale policy changes (Kleimann *et al.* 2020). This approach is particularly relevant given the work done within the Brazilian context. The SCM has been applied to evaluate the broader Brazilian airport privatization policy on value generation and efficiency, thus providing a methodological precedent for its use here (Resende 2017). Internationally, SCM has proven effective in transport economics to assess the fiscal impacts of policies, such as the German aviation tax (Borbely 2019) or the effects of large railway projects on surrounding demographics and land prices (Kunimi and Seya 2021; Renzy and Artzer 2025).

Pre-treatment validation: The SCM results (Fig. 2) demonstrate a high fidelity fit between Ceará's actual ICMS revenue (solid line) and the synthetic control trajectory (dashed line) during the pre-intervention period (2000–2017). The small, consistent difference, rarely exceeding R$ 0.4 billion, confirms the synthetic control's robustness in modelling the counterfactual revenue path that Ceará would have followed had the concession not occurred.



Source: Elaborated by authors.

Figure 2. Synthetic Control Estimation of the Concession's Effect on Ceará's ICMS Revenue.

Post-treatment effect: The analysis of the post-intervention period (2018 onwards) reveals the treatment's temporal dynamics:

- Initial transition (2018–2021): There was no immediate or statistically observable treatment effect on ICMS revenue. The two trajectories remained closely aligned, indicating a fiscal neutrality during the first years of private management.
- Lagged positive divergence (2022 onwards): A significant positive divergence emerged starting in 2022. Ceará's actual ICMS revenue trajectory began to grow substantially more than the Synthetic Ceará. In 2022, the estimated treatment effect—the gap between actual and synthetic revenue—exceeded R$ 0.62 billion. This positive, emerging gap provides strong causal evidence of a lagged positive impact of the airport concession on state revenue.

Discussion and Policy Implications

The convergence of findings from the robust Fixed Effects model and the causal SCM provides compelling evidence regarding the fiscal impact of the airport concession. The Fixed Effects model ascertains the existence of a significant positive effect, while the SCM meticulously reveals its delayed manifestation.

The pattern of a negligible immediate effect followed by a positive divergence four years post-intervention (2022) is highly informative. This finding is intrinsically consistent with the nature of large-scale infrastructure privatization, where the early post-concession years are typically characterized by front-loaded capital expenditures, project planning, and the operational stabilization required before new economic activity is stimulated. This temporal lag aligns with empirical evidence from other transport infrastructure studies, such as the analysis of the Ferrovia Norte-Sul in Brazil, where the full socioeconomic benefits, including the impact on formal employment, were similarly observed only after a sustained period of operational maturity (Oliveira *et al.* 2023).

This study makes a significant contribution by shifting the focus of the privatization debate. Existing literature often concentrates on the efficiency gains of privatized airports or the direct fiscal benefits derived by the Federal Government from concession fees. This work, by contrast, rigorously quantifies the secondary, subnational fiscal benefits (ICMS revenue), providing essential evidence on the cascading effects of private management.

Furthermore, by utilizing SCM, we position our analysis within the methodological frontier of transport economics (Kunimi and Seya 2021; Renzy and Artzer 2025). The estimated positive effect confirms the hypothesized role of private airport management in stimulating regional commerce and expanding the state's tax base. The counter-intuitive negative coefficients for cargo and flight movements warrant further investigation, potentially indicating the need for policymakers to adjust tax incentive structures to maximize the commercial translation of these activities into taxable ICMS revenue.

The robust empirical findings necessitate a strategic recalibration of governance models for subnational entities engaging in infrastructure concessions, particularly concerning temporal planning and fiscal sustainability. The identification of a four-year fiscal lag before the positive ICMS revenue effect emerged is critical for setting budgetary expectations; therefore, future concession contracts and public financial planning must integrate a lagged fiscal return model. This approach justifies revisiting risk-sharing arrangements to ensure the public sector is adequately compensated for the temporal risk borne during the initial operational stabilization phase. Simultaneously, the high revenue elasticity with respect to passenger movements ($\beta = 1.578$) exposes state ICMS revenue to substantial volatility from exogenous shocks. To secure fiscal sustainability, policymakers must proactively develop mechanisms, such as establishing counter-cyclical reserve funds, to hedge against this heightened revenue exposure.

Furthermore, the statistically significant, but counter-intuitive, negative correlation of cargo and flight movements with ICMS revenue indicates a structural inefficiency in the current state-level tax framework. While the concession promotes overall operational efficiency, existing ICMS regulations may not effectively translate high-volume logistics and non-passenger activities into taxable commerce. Consequently, a targeted review of ICMS regulations related to air cargo and international flight operations is warranted. The policy goal is to optimize tax incidence and incentives to ensure that the concessionaire's operational efficiency is maximally converted into diversified and sustainable state-level tax base expansion.

CONCLUSION

The empirical analysis using panel data models, specifically pooled and fixed effects models, did not yield statistically significant evidence of a direct impact of airport concessions on the ICMS revenue of northeastern states. However, the results suggest that passenger movements have a positive and significant influence on state tax revenues. This underscores the importance of maintaining and growing airport passenger traffic to support state finances.

The SCM was employed to further evaluate the causal effect of the Fortaleza Airport concession on ICMS revenue in Ceará. This approach allowed for a more nuanced analysis, comparing the observed revenue trajectory of Ceará with a synthetic control group constructed from similar untreated states. The synthetic control estimator provided an estimate of the treatment effect, enabling a robust assessment of the impact of the concession on state revenue while considering the specific context and characteristics of Ceará.

The key findings are:

- The Concession Dummy is highly significant in the Fixed Effects model (β=0.588), confirming a positive revenue effect when controlling for unobserved state heterogeneity.
- The SCM reveals that this positive impact is lagged, manifesting significantly from 2022 onwards, four years after the concession commenced, and quantifying the effect at over R$ 0.62 billion in 2022.
- Passenger traffic is identified as a critical, highly elastic driver of state tax revenue ($\beta = 1.578$).

The findings emphasize the need for comprehensive fiscal risk management by the government when engaging in infrastructure concessions. By developing a thorough understanding of the financial implications of concession projects, including construction costs, operating expenses, and potential tax revenues, policymakers can make informed decisions about resource allocation and expected returns. This knowledge is crucial for ensuring the success and sustainability of concession projects.

The case of Fortaleza Airport underscores the complexity of infrastructure transitions. The observed delayed positive fiscal impact should inform policymakers regarding temporal expectations for returns on future concession projects. This knowledge is crucial for developing refined fiscal risk management strategies that account for multiyear lags and ensuring that concession policies are effectively calibrated to maximize the long-term, subnational fiscal benefits of private infrastructure management.

The policy implications derived from this analysis emphasize the necessity of managing budget expectations based on the observed time lag, establishing mechanisms to manage passenger-driven revenue volatility, and reviewing tax policy to maximize the commercial benefit derived from all airport activities. Future research should focus on utilizing spatial econometric techniques, such as the generalized SCM, to precisely map the geographical extent of these fiscal benefits to the surrounding municipalities.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHORS' CONTRIBUTION

Conceptualization: Silva FGF; **Methodology:** Silva FGF; Bezerra EHF; **Analysis:** Falcão V; **Writing – Original Draft:** Bezerra EHF; **Writing – Review and Editing:** Falcão V; **Supervision:** Silva FGF; Final approval: Falcão V.

DATA AVAILABILITY STATEMENT

The data will be available upon request.

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DECLARATION OF USE OF ARTIFICIAL INTELLIGENCE TOOLS

In the preparation of this manuscript, AI tools were utilized to support language refinement. Gemini (Google) was employed for translation, and Scispace (Typeset) was used for grammatical correction and proofreading. No AI tool was involved in the conceptualization, methodology, data analysis, or interpretation of results.

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