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BEATRIZ DE OLIVEIRA GONÇALVES

AIRLINE HUB AND REGIONAL DEVELOPMENT: THE CASE OF RECIFE AIRPORT

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Dissertação apresentada ao programa de Pós-Graduação em Economia da Universidade Federal de Pernambuco, como requisito parcial para a obtenção do título de Mestre em Economia.

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Orientador: Prof. Dr. Raul da Mota Silveira Neto

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RESUMO

Aeroportos podem gerar efeitos positivos sobre o desenvolvimento econômico regional, atraindo firmas, através das melhores possibilidades de negócios, incentivando investimentos na localidade e levando a um aumento do emprego. Estudos recentes têm demonstrado que a ampliação dos serviços aéreos está associada a um crescimento no emprego e na renda, mas poucos estudos analisam estes efeitos em regiões em desenvolvimento. Esta pesquisa tem como objetivo principal avaliar os impactos econômicos da implementação de um hub aéreo da Azul Linhas Aéreas no Recife em 2016. Utilizando o método de controle sintético e dados para diferentes níveis regionais entre 2006 e 2023, constatou-se que a implementação do hub aéreo na cidade do Recife gerou efeitos significativos sobre o percentual de empregados no setor formal de Viagens e no número de guias turísticos na capital. Não foram obtidos resultados significativos para a economia como um todo, mas entende-se que essa intervenção trouxe impactos importantes para o setor de turismo no município onde foi implementada.

Palavras-chaves: Economia Urbana. Aeroporto. Hub. Controle Sintético. Emprego.

ABSTRACT

Airports may generate positive effects on regional economic development by attracting firms through better business opportunities, encouraging local investments, and leading to increased employment. Recent studies have shown that the expansion of air services is associated with growth in employment and income, but few studies analyze these effects in developing regions. The primary objective of this research is to assess the economic impacts of the implementation of an airline hub by Azul Linhas Aéreas in Recife in 2016. Using the synthetic control method and data for different regional levels between 2006 and 2023, it was found that the implementation of the airport hub in Recife had significant effects on the percentage of employees in the formal Travel sector and the number of registered tour guides in the capital. No significant results were obtained for the overall economy, but it is understood that this intervention had important impacts on the tourism sector in the municipality where it was implemented.

Keywords: Urban Economics. Airport. Hub. Synthetic Control. Employment.

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1 INTRODUCTION

Airports may generate positive effects on regional economic development. Air connections attract firms by offering better business opportunities, encouraging investments in the area, and leading to increased employment (BLONIGEN; CRISTEA, 2015; BRUECKNER, 2003; MCGRAW, 2020). However, obtaining unbiased estimates of these effects is not straightforward, as the relationship between airports and economic development may present endogeneity issues.

Recent studies using advanced econometric methods have shown that the expansion of air services is associated with employment and income growth (BLONIGEN; CRISTEA, 2015; SHEARD, 2014; SHEARD, 2019; MCGRAW, 2020). Most of these analyses consider airports of various sizes in the United States, but the effects on economic development may differ when focusing only on airport hubs. A hub is an airport that serves as a primary connection point within an airline's network, increasing passenger traffic and the number of flights at the location.

In 2016, the airline Azul Linhas Aéreas established a hub at Gilberto Freyre International Airport, located in Recife, the capital of the state of Pernambuco. Since its inception, this operational base has enabled greater connectivity among cities in Brazil's Northeast by increasing the number of available flights. According to data from the Agência Nacional de Aviação Civil [National Civil Aviation Agency] (ANAC), the total number of Azul flights in Recife increased from 16,157 in 2015 to 42,397 in 2019, more than doubling in just four years. In 2023, the total number of flights operated by the airline in Recife was 51,307.

Despite these impressive numbers, there is no evaluation of the economic impact of this regional hub in the literature. More broadly, studies linking urban economic development and air services in Brazil remain scarce, despite the importance of air transportation to the country.

According to the Instituto de Pesquisa Econômica Aplicada [Institute for Applied Economic Research] (IPEA, 2010), Brazil has significant potential for developing air transport due to factors such as its continental-scale territory and the high geographic and social mobility of its population. If airport infrastructure does influence local economic indicators in Brazil, the establishment and expansion of air services could be considered important instruments of urban economic development for the country.

Given these arguments, the primary objective of this research is to assess the economic impacts of implementing airport hubs in specific regions, focusing on the Azul Linhas Aéreas' hub, launched in Recife in 2016. This study analyzes both general and sector-specific effects on employment and income at three different geographic levels: the capital city, the metropolitan region, and the federative unit (state) level.

To conduct the analysis, the synthetic control method was employed. This approach allows for the estimation of what would have happened to the treated unit in the absence of the intervention by constructing a weighted combination of untreated units, providing a better comparison for the region exposed to the intervention. This identification strategy extends the traditional difference-in-differences method by allowing the effects of unobserved variables on the outcome to vary over time (ABADIE; DIAMOND; HAINMUELLER, 2010).

The panel data used in this study were constructed from several sources, including the Continuous National Household Sample Survey (PNADC), the Annual Social Information Report (RAIS), various datasets from the National Civil Aviation Agency (ANAC), and records of tourism service providers from the Ministry of Tourism. The constructed dataset covers different geographic regions over the period from 2006 to 2023.

The results indicate that the implementation of the airport hub in Recife had significant effects on the proportion of employees in the formal Travel Sector[1] and the number of registered tour guides in the capital city. No significant effects were found for the overall economy or other geographic regions, except for a notable increase in the number of registered tour guides in the state of Pernambuco. Therefore, the findings suggest that the airline hub had important impacts on the tourism sector in the municipality where it was implemented.

The remainder of this work is organized as follows. Section 2 presents a literature review on airports and economic development. Section 3 describes the context of the hub's implementation in Recife. Sections 4 and 5 describe the empirical strategy and data used in the study, respectively. Sections 6 and 7 present the initial results and robustness tests. Finally, Section 8 presents the conclusion.

[1] The Travel Sector, as defined in this study, corresponds to Division 79 of the National Classification of Economic Activities (CNAE), which comprises economic activities related to travel agencies, tour operators and reservation services. A more detailed description of this sector is presented in the Results Section.

2 LITERATURE REVIEW

2.1 THEORETICAL BASIS

An airport is a facility where aircraft can take off and land. With the increasing need for greater regional integration and enhanced speed and variety in economic activities, there has been an expansion in passenger and cargo flows due to the high speed and long-range characteristics of airplanes. From intercontinental travel to shorter trips, air transport has facilitated connections between people and places. As a result, pressure on the global airport system has grown significantly (RODRIGUE, 2024).

The variation in passenger and cargo traffic handled by airports can be explained by four main factors: demand patterns, network connectivity, competing airports, and physical capacity (RODRIGUE, 2024).

The demand pattern relates to the traffic an airport handles, which is directly influenced by the population, income, commercial intensity, and level of tourist activity in the city it serves (RODRIGUE, 2024).

Network connectivity is associated with the decisions made by airlines in selecting hubs within their networks, substantially impacting the traffic handled by airports.

A hub is an airport that serves as a primary connection point in an airline's flight network, increasing passenger circulation and the number of flights at the location. In a hub system, airlines benefit from economies of scale, scope, and density, increasing the economic efficiency of airline operations. Passengers also benefit from a greater number and frequency of flights and available travel options (BUTTON; LALL, 1999; MAYER; SINAI, 2003). Moreover, Mayer and Sinai (2003) point out that hub airlines are less likely to cancel flights to or from their hubs, providing even more benefits for passengers. Hubs offer more direct flights, significantly benefiting business travelers and facilitating long-distance travel (BUTTON; YUAN, 2013). It is important to note that the selection of a primary hub by an airline is based on a well-located airport with good infrastructure, rather than necessarily the one serving a large local passenger market (RODRIGUE, 2024).

Traffic is also determined by the presence of competing airports within the same metropolitan area, which can dilute passenger and cargo flows at a given facility, as well as by each airport's physical capacity (RODRIGUE, 2024). Furthermore, airports today compete more for business than in the past, making it essential to consider the growth of low-cost airlines.

This is because one dimension of these airlines' business model is providing services through lower-cost secondary airports (RODRIGUE, 2024).

Since airports require space for runways, terminal buildings, parking lots, and other facilities, they demand large areas within cities. Consequently, airports are generally located on the periphery of urban areas, where these locations offer a equilibrium between the cost of available land and accessibility to the urban core. According to Rodrigue (2024), this process has intensified over the years, meaning that the more recently an airport was built, the more likely it is to be located far from the center of the metropolitan area it serves.

Beyond influencing individual passenger decisions, the presence and location of airports can also affect firms' location decisions, as access to markets, raw materials, utilities, transportation, and labor is essential for businesses, and high-quality transportation facilitates the movement of production factors (BUTTON; YUAN, 2013). Thus, the possibility of using air transport, along with its speed, convenience, reliability, and service frequency, becomes an important criterion for business location (COOPER, 1990).

This idea is supported by Appold and Kasarda (2013), who argue that businesses may choose to locate near airports to improve operational efficiency through easy access to transportation infrastructure, much like early traders who positioned themselves near the quayside. Additionally, companies highly motivated by the need for quick access to air transport, as well as those that value proximity to other firms, may create employment clusters in areas surrounding airports. Thus, even companies that do not directly use air transport may choose to locate near airports to ensure greater convenience for customers and suppliers.

It is evident, then, that airports transform the communities in which they are located, being directly linked to urban economic development. As noted by Hakfoort, Poot and Rietveld (2001), airports serve as gateways to international markets, thereby promoting high-value import and export activities. According to Rodrigue (2024), air transport accounts for more than 35% of the value of global merchandise trade, being essential for transporting sensitive cargo, supporting just-in-time production and distribution strategies, and handling emergencies.

Appold and Kasarda (2013) argue that the shared infrastructure between air transport and automobile/truck transport can provide significant urbanization economies. Thus, as air transport becomes more prevalent, airports are expected to increasingly serve as functional urban anchors and symbolic reference points, even though the vast majority of metropolitan residents do not use air transport frequently.

In the view of Rodrigue (2024), aviation has also been a catalyst for economic growth.

The author explains that both passenger and cargo traffic have grown rapidly, as higher incomes translate into greater time valuation and a stronger preference for a faster mode of transportation. The economic impact of air transport is most pronounced near major airport hubs, but the catalytic effect of air accessibility extends throughout the economy, affecting entire sectors.

Rodrigue (2024) highlights that a major airport generates jobs both directly and through related activities. These connections take the form of businesses for which the airport is a supplier, such as local tourist attractions and logistics facilities, as well as businesses for which the airport is a customer, such as fuel suppliers and construction companies. Beyond the local dimension, major global corporate headquarters have increasingly concentrated in cities with good international air accessibility, catalyzing job creation in the region.

According to Rodrigue (2024), airports are substantial drivers of economic activity, with four main types of economic effects associated with airports: direct, indirect, induced, and catalytic effects.

Direct effects include economic activities conducted within the airport itself, such as services for passengers (check-in, security, boarding), cargo (loading and unloading), and aircraft (fueling, cleaning). Airlines pay airports landing fees, gate fees, parking fees, baggage handling fees, and other charges typically related to aircraft size. Airports also generate revenue from passenger fees, parking, and rental concessions. Rodrigue (2024) indicates that these and other non-aeronautical revenues account for about 40% of global airport revenues and are more significant at major hubs.

As Cooper (1990) explains, aviation-related service providers, such as airlines, airport concessions, and airport administration, spend their revenues to employ labor, pay fees and taxes, and purchase locally produced goods and services. According to Button and Yuan (2013), these effects, which they call secondary effects, are important for local economies in terms of employment, income, and, for local governments, tax revenue.

Indirect effects include economic activities driven by the "backward linkages" of the airport, directly attributable to it, such as fuel suppliers, electricity producers, and fresh food suppliers for airport restaurants. An airport requires many different inputs, and the flow of these inputs to the airport generates a counterflow of money into the local economy (RODRIGUE, 2024; COOPER, 1990).

Induced effects, in turn, encompass economic activities driven by the "forward linkages", especially the spending of airport employees and passengers passing through. The many restaurants and hotels surrounding airports also fall into this category (RODRIGUE, 2024).

Finally, catalytic effects include activities attracted by an airport through lower transportation costs and greater network accessibility, depending on its size. For example, the establishment of major corporate distribution centers near large airports (RODRIGUE, 2024). Cooper (1990) argues that these multiplier effects can be seen as changes in employment and income generated as initial direct and indirect expenditures trigger a chain reaction of spending throughout the local economy. The larger the area impacted by the airport, the more self-sufficient the local economy tends to be, and the more likely it is that each unit of value is spent on locally produced goods or services.

According to Cooper (1990), economic impact studies generally share the view that airport activity generates four types of impacts: business revenue, jobs, personal income, and taxes. These impacts are felt across five basic economic sectors: airline and airport services, cargo transportation, ground passenger transportation, construction and contracted consulting, and the tourism industry.

Considering, then, all the arguments presented, it is concluded that an airport is more than just a node in the flow of people and goods. It is a dynamic space through which the economy and identity of a place are shaped (RODRIGUE, 2024). Therefore, it is necessary to empirically measure the impact of airport hubs on the economies of the regions in which they are located.

2.2 EMPIRICAL EVIDENCE

Airports can be important instruments of economic development. Air connections facilitate access to inputs and enable personal meetings, potentially attracting firms and encouraging investments in the area, which can also lead to increased employment (BLONIGEN; CRISTEA, 2015; BRUECKNER, 2003; MCGRAW, 2020). However, estimating the causal effects of airports (or airport expansions) on a given region's economy is not simple, as there is a risk of reverse causality: airports can improve economic indicators, just as developing economies may invest more in their air services. Since airports are not randomly assigned to cities, endogeneity is an issue that must be considered (BLONIGEN; CRISTEA, 2015; BRUECKNER, 2003; GREEN, 2007; MCGRAW, 2020; SHEARD, 2019). Thus, it is necessary to choose an identification strategy that eliminates the possibility of reverse causality in estimation.

Brueckner (2003) is considered a seminal paper in studying the impact of air services on urban economic development. Using instrumental variables, the author confirms the hypothesis of air traffic influence on employment, being an important factor for economic development. The results show that a 10% increase in passenger boardings in a metropolitan area in the U.S. leads to approximately a 1% increase in employment in service-related industries. Following Brueckner (2003), Green (2007) also sought to analyze the relationship between airport activity and economic development, using panel data and instrumental variables. The author obtained similar results, finding that per capita passenger boardings and per capita passenger origins in the largest metropolitan areas of the United States have a strong relationship with population growth and employment growth.

The identification strategies adopted in the early works in the field are no longer considered the most adequate. However, even with the improvement of econometric techniques, more recent studies have pointed in the same direction as their precursors. Blonigen and Cristea (2015), for example, explore the 1978 U.S. Airline Deregulation Act to measure the relationship between air services and regional economic growth. Analyzing indicators for 263 Metropolitan Statistical Areas from 1969 to 1991, using the difference-in-differences strategy, the authors find that, on average, a 50% increase in a city's air traffic growth rate leads to a 1.65% to 3.45% increase in annual income growth rate and a 2.7% to 4.7% increase in annual employment growth rate. Additionally, they find that the service and retail sectors are the most affected by air services, experiencing significant employment growth.

McGraw (2020), in turn, employs a grouped synthetic control approach to find the causal effects of airport contributions on local economic indicators in the United States. The author estimates the treatment effect of an airport on outcomes such as employment, population, and income during the post-World War II period (1950-2010). Using synthetic control, McGraw (2020) generated counterfactual results for each airport city and then conducted an event study on the resulting case pairs. The author found that airports led to a 3.9% employment growth per decade. Additionally, airports increased personal income growth by 3.5% per decade from 1980 to 2010, corroborating the causal growth estimated in total employment and population.

Sectoral effects were also the subject of study in some works beyond Blonigen and Cristea (2015) and Brueckner (2003). Sheard (2014) aimed to estimate the effects of airport infrastructure on employment shares of specific sectors at the metropolitan area level, using the 1944 U.S. National Airport Plan as an instrument for airport sizes in 2007. The author found that airport size has a positive effect on employment shares in service sectors considered "tradable" but no measurable effect on industry or "non-tradable" services. According to Sheard (2014), the interpretation of these results is that air travel facilitates face-to-face contact, helping to provide tradable services. Thus, the production of these services tends to be located in metropolitan areas with larger airports and exported to other regions. These results were confirmed in Sheard (2019), in which the author found that airport size has a positive effect on local employment, with an elasticity of 0.04. This estimate is driven by positive effects on employment in some types of services and construction but with no measurable effect on employment in manufacturing, wholesale and retail trade, or transportation and utilities. Furthermore, the author found positive effects of airport size on a variety of other local outcomes, such as the number of businesses, population size, employment rate, and Gross Domestic Product (GDP).

Doerr et al. (2020) also investigated the effects of airport infrastructure on specific sectors, in this case, regional tourism. By analyzing the transformation of a military airbase into a regional commercial airport in the German state of Bavaria in 2007, using the synthetic control method, the authors found positive effects on tourism. With the dependent variable being guest arrivals from abroad, the results showed that the new commercial airport increased tourism in the Allgäu region, and the positive effect was especially pronounced in the county where the airport is located.

The effects on economic development may be even more interesting when analyzing airport hubs. A study conducted in China analyzed the spatial spillover effects of the country's major airport hubs on economic development. Using panel data, Chen, Xuan and Qiu (2021) found evidence that airport hubs have significant positive spatial spillover effects on economic development. The authors found that an increase in the number of air passengers, air cargo transport, or flight frequency at a given airport significantly benefits the overall economy of the city it serves, as well as producing larger positive spillover effects for other cities connected within the airport network.

There are not many studies linking urban economic development and air services for Brazil, despite the country having specific characteristics that could be well explored in analysis. According to the Instituto de Pesquisa Econômica Aplicada [Institute for Applied Economic Research] (IPEA, 2010), Brazil has great potential for air transport development due to a favorable combination of factors, such as the continental size of its territory, high geographic and social mobility of its population, and increasing consumer purchasing power. Thus, if airport infrastructure affects local economic indicators in Brazil, the installation and expansion of air services could significantly contribute to urban economic development in the country.

Based on both the theoretical framework and empirical evidence, it can be concluded that airports have served as important instruments for promoting urban economic development. By influencing firms' decisions, facilitating access to goods and people, airports promote investment and job creation in surrounding areas (BUTTON; YUAN, 2013; COOPER, 1990; APPOLD; KASARDA, 2013; BLONIGEN; CRISTEA, 2015; BRUECKNER, 2003; MCGRAW, 2020). The main economic effects are typically observed in the service sector (BLONIGEN; CRISTEA, 2015; SHEARD, 2014; BRUECKNER, 2003), particularly in the tourism sector (DOERR et al., 2020), with notable increases in annual employment and income levels in the countries analyzed, driven by the growth of air services and passenger traffic (BLONIGEN; CRISTEA, 2015).

However, the existing literature does not provide any analysis conducted in the context of a developing country such as Brazil, where labor market characteristics include wage rigidity and a high degree of informality. Therefore, it is crucial to assess whether the expansion of air services in an important urban region of the country can generate positive effects on local employment and income levels.

3 LOCAL BACKGROUND

In Brazil, three major airlines dominate the market: Azul, GOL, and LATAM. In 2023, these three companies accounted for 88.9% of all flights operated in the country, as shown in Table 11 in Appendix A. Since the beginning of the analyzed series in 2006, these airlines have collectively held the majority of the Brazilian air travel market. Since 2014, Azul, GOL, and LATAM each have a larger market share than the sum of all other airlines combined.

The need for domestic and international connectivity requires Azul, GOL, and LATAM to designate certain airports as primary connection centers, known as hubs. The selection of these hubs is based on business decisions made by the airlines themselves, with no official records from the Agência Nacional de Aviação Civil [National Civil Aviation Agency] (ANAC). However, this information was obtained through direct contact with the press offices of each airline.

LATAM Airlines has two hubs in Brazil: São Paulo - Guarulhos International Airport and Brasília International Airport, in the Federal District. According to the company's press office, both hubs began operations in 2012 (LATAM PRESS, 2025).

GOL Linhas Aéreas did not respond to email inquiries regarding its hubs in Brazil. However, the air network provided on the company's website leads to the assumption that its primary hubs are in São Paulo, Rio de Janeiro, Brasília, and Salvador. In August 2022, GOL announced the establishment of a hub at Salvador International Airport, stating that it would progressively increase its flight offerings (GOL INFORMA, 2022). Additionally, in 2018, GOL signed an agreement with the State Government of Ceará to establish a hub at Fortaleza International Airport (GOVERNO DO ESTADO DO CEARÁ, 2018). However, this hub did not develop as planned (DIÁRIO DO NORDESTE, 2023), and the expected increase in flights did not materialize significantly in the following years. The variation in GOL's flight numbers in Fortaleza can be seen in Table 1.

Table 1 – Variation in the number of GOL flights in Fortaleza

Year	Total Number of Flights	Variation (%)
2006	9,502	
2007	15,113	59.05
2008	14,152	-6.36
2009	14,646	3.49
2010	17,576	20.01
2011	18,098	2.97
2012	16,882	-6.72
2013	18,128	7.38
2014	19,259	6.24
2015	17,538	-8.94
2016	13,172	-24.89
2017	12,549	-4.73
2018	14,668	16.89
2019	16,758	14.25
2020	8,715	-47.99
2021	11,108	27.46
2022	13,235	19.15
2023	9,294	-29.78

Azul Linhas Aéreas Brasileiras operates three hubs in Brazil: Viracopos International Airport in Campinas, São Paulo; Belo Horizonte International Airport in Confins, a neighboring city of the capital of Minas Gerais; and Recife International Airport in Pernambuco. According to Azul's press office, the Campinas hub was established in December 2008, and the Belo Horizonte hub in August 2009. The Recife hub was established in February 2016 (AZUL PRESS, 2025).

The decision to elevate Recife's airport to a hub was made by Azul to "expand interregional connections and links to other parts of the country from Recife, enabling greater connectivity between northeastern capitals" (PREFEITURA DO RECIFE, 2016). With the formalization of the agreement between Azul and the Recife City Hall, it was expected that the municipal economy would be stimulated, generating more jobs and income for the city, especially in the tourism sector. It was also expected that there would be a reduction in airfare prices, with a higher number of direct and cheaper flights.

According to then-president of Azul Linhas Aéreas, Antonoaldo Neves, the company planned a long-term relationship, aiming to double the number of its flights within four to five years

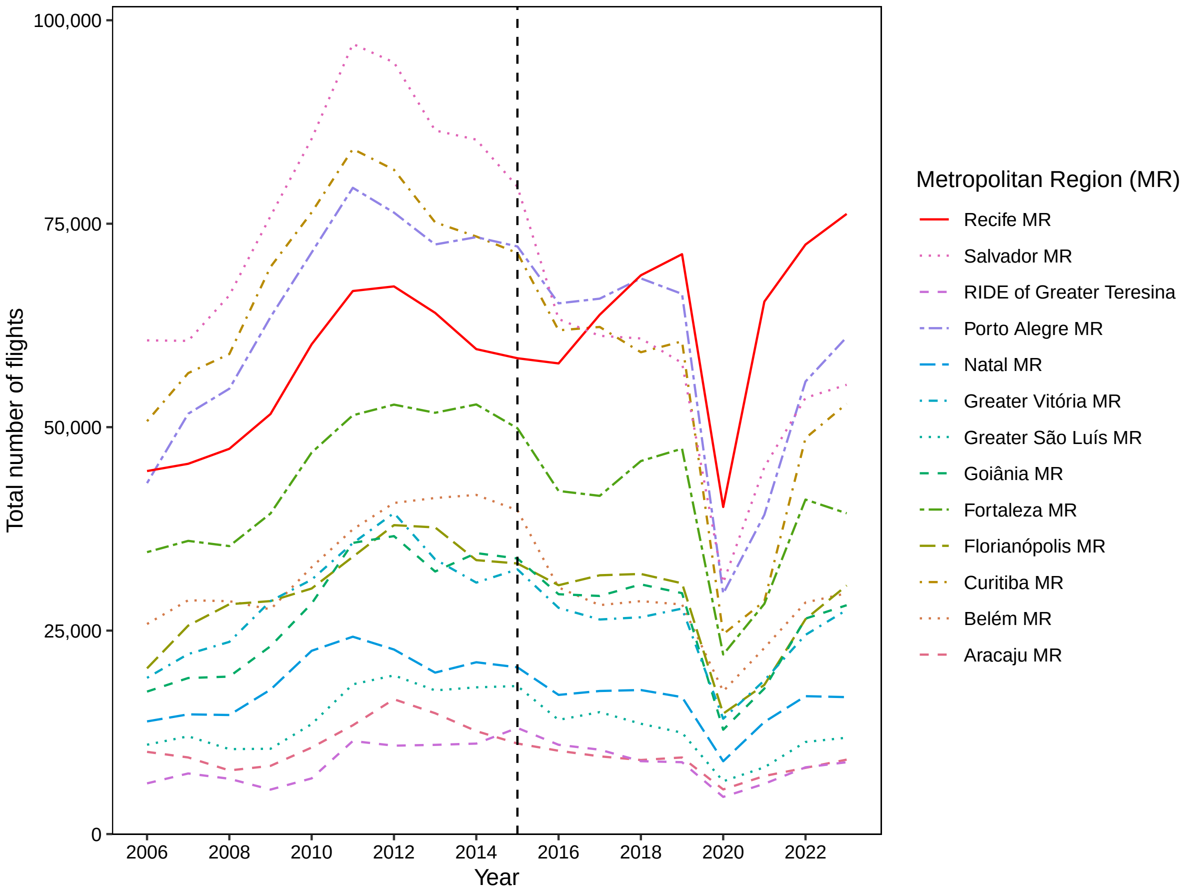
(PREFEITURA DO RECIFE, 2016). This increase occurred as expected, as shown in Table 2. It is also possible to observe the change in the number of flights in Recife by comparing the total number of flights per year and metropolitan region used in the study, as shown in Figure 1.

This study will analyze whether the establishment of the Recife airport hub, and the resulting sharp increase in total flights in the region, led to significant economic changes in the city.

Table 2 – Variation in the number of Azul flights in Recife

Year	Total Number of Flights	Variation (%)
2009	1,344	
2010	2,428	80.65
2011	5,510	126.94
2012	7,289	32.29
2013	9,728	33.46
2014	14,713	51.24
2015	16,157	9.81
2016	22,959	42.10
2017	30,032	30.81
2018	34,556	15.06
2019	42,397	22.69
2020	25,332	-40.25
2021	45,386	79.16
2022	47,585	4.85
2023	51,307	7.82

Figure 1 – Total flights by metropolitan region (MR) and year



Notes: The annual data refers to the total values for each complete year. Therefore, the 2016 data already include the effects of the changes after the hub implementation. For that reason, the vertical line, which indicates the year of the intervention, is positioned over 2015 in the figures, allowing for the visualization of the hub's impact. The figure includes only the treated unit, the Recife Metropolitan Region, and the units in the donor pool, which constitute the group of potential metropolitan regions that may be used as contributing units in the synthetic control.

4 EMPIRICAL STRATEGY

In this section, the theory of the identification strategy employed is described, in addition to the inference methods used to assess the significance of the results obtained through synthetic control.

4.1 SYNTHETIC CONTROL METHOD

Airports, and specifically hubs, are not randomly established in cities. There is a financial interest on the part of firms, considering that their allocation in a certain region will bring the greatest possible economic return. Consequently, estimating the effects of hubs on local economic indicators is not straightforward, as such estimations may be subject to endogeneity issues, particularly due to reverse causality. Therefore, a robust identification strategy must account for the possibility of endogeneity and adequately address this issue. In this study, the Synthetic Control Method (SCM) was chosen, as it can construct appropriate counterfactuals for the group of localities benefiting from the introduction of airport hubs, thereby generating an estimate of what the outcomes would have been for the treated units in the absence of the intervention.

Athey and Imbens (2017) described the Synthetic Control Method as the most important innovation in policy evaluation literature in the fifteen years preceding their publication. This identification strategy allows for the estimation of the treatment effect on the treated unit by generating a counterfactual with observable characteristics similar to those of the treated unit in the pre-treatment period. This counterfactual is constructed from a weighted combination of units that did not receive the treatment, providing a more suitable comparison for the unit exposed to the intervention (ABADIE; DIAMOND; HAINMUELLER, 2010). The synthetic control method was originally proposed to estimate the effects of interventions implemented at an aggregate level that impact a small number of large units (such as cities, regions, or countries) on some aggregate variable of interest (ABADIE, 2021).

This model extends the traditional difference-in-differences approach by allowing the effects of unobservable variables on the outcome to vary over time (ABADIE; DIAMOND; HAINMUELLER, 2010). Unlike the difference-in-differences method, synthetic control moves away from using a single control unit or a simple average of control units, instead employing a weighted average of the control group that more closely resembles the treated unit than any single control (ATHEY; IMBENS, 2017). Moreover, the synthetic control methodology formalizes the selection of comparison units through a data-driven procedure, avoiding reliance on informal statements of affinity between treated units and the set of control units (ABADIE, 2021).

Beyond these reasons, the use of the synthetic control method is particularly interesting for several factors. First, it makes the difference between the treated unit and the combination of control units transparent. Second, it does not require access to post-treatment outcomes while computing the synthetic control, providing greater protection against specification searches and undesirable manipulations. Third, the method explicitly reveals the contribution of each comparison unit to the counterfactual of interest (ABADIE, 2021).

According to Abadie, Diamond and Hainmueller (2010), the model is obtained from panel data for $J+1$ regions over a period of T years, with only one region exposed to the intervention of interest (in this study, the introduction of an airport hub in the locality). Thus, J regions serve as potential controls. Let Y_{it}^N be the outcome of the variable of interest (employment, GDP, among others) that would be observed for region i in period t in the absence of the intervention, for units $i = 1, ..., J+1$, and time periods $t = 1, ..., T$. Let T_0 be the number of pre-intervention periods, with $1 \leq T_0 < T$. Let Y_{it}^I be the outcome that would be observed for unit i in period t if this unit were exposed to the intervention in periods $T_0 + 1$ to T. Also, let $\alpha_{it} = Y_{it}^I - Y_{it}^N$ be the effect of the intervention for unit i in period t, and D_{it} an indicator that takes the value of one if unit i is exposed to the intervention in period t, and zero otherwise. Then, the observed outcome for unit i in period t is:

$$Y_{it} = Y_{it}^N + \alpha_{it} D_{it} \tag{4.1}$$

For $t > T_0$,

$$\alpha_{1t} = Y_{1t}^I - Y_{1t}^N = Y_{1t} - Y_{1t}^N \tag{4.2}$$

α_{1t} represents the effect of the intervention for unit 1, the only treated unit, for the post-treatment periods, which is precisely what is sought to be estimated. Since Y_{1t}^I is observable, it is only necessary to find Y_{1t}^N to estimate α_{1t}.

Abadie, Diamond and Hainmueller (2010) define Y_{it}^N is given by a factor model such that:

$$Y_{it}^N = \delta_t + \boldsymbol{\theta_t Z_i} + \boldsymbol{\lambda_t \mu_i} + \varepsilon_{it} \tag{4.3}$$

where δ_t is an unknown factor that is common and constant across units, $\boldsymbol{Z_i}$ is a vector of observable covariates (not affected by the intervention), $\boldsymbol{\theta_t}$ is a vector of unknown parameters, $\boldsymbol{\lambda_t}$ is a vector of unobserved common factors, $\boldsymbol{\mu_i}$ is a vector of unknown factor loadings, and the term ε_{it} represents unobserved transitory shocks at the regional level with zero mean.

Consider a weight vector $\boldsymbol{W} = (w_2, ..., w_{J+1})'$ such that $w_j \geq 0 \quad$ for $\quad j = 2, ..., J+1 \quad$ and $\quad w_2 + ... + w_{J+1} = 1$. Each specific value of the vector $\boldsymbol{W}$ represents a potential synthetic control, that is, a particular weighted average of the available control regions. The outcome variable for each synthetic control indexed by $\boldsymbol{W}$ is:

$$\sum_{j=2}^{J+1} w_j Y_{jt} = \delta_t + \boldsymbol{\theta_t} \sum_{j=2}^{J+1} w_j \boldsymbol{Z_j} + \boldsymbol{\lambda_t} \sum_{j=2}^{J+1} w_j \boldsymbol{\mu_j} + \sum_{j=2}^{J+1} w_j \varepsilon_{jt} \tag{4.4}$$

The objective, under the appropriate conditions, is to find a weight vector $\boldsymbol{W}^*$ such that $Y_{1t}^N = \sum_{j=2}^{J+1} w_j^* Y_{jt}$. Thus,

$$\hat{\alpha}_{1t} = Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt} \quad \text{for } t \in \{T_0 + 1, ..., T\} \tag{4.5}$$

can be used as an estimator of α_{1t}. A synthetic control satisfying $\sum_{j=2}^{J+1} w_j^* \boldsymbol{Z_j} = \boldsymbol{Z_1}$ and $\sum_{j=2}^{J+1} w_j^* \boldsymbol{\mu_j} = \boldsymbol{\mu_1}$ provides an unbiased estimator of Y_{1t}^N.

The weight vector $\boldsymbol{W}^*$ is chosen to minimize the distance between $\boldsymbol{X_1}$ and $\boldsymbol{X_0 W}$, subject to $w_j \geq 0$ for $j = 2, ..., J+1$ and $w_2 + ... + w_{J+1} = 1$, where $\boldsymbol{X_1}$ represents the pre-intervention characteristics vector for the treated region, and $\boldsymbol{X_0}$ represents the same vector for the control regions. The discrepancy between$\boldsymbol{X_1}$ and $\boldsymbol{X_0 W}$ is measured using:

$$\|\boldsymbol{X_1} - \boldsymbol{X_0 W}\| \boldsymbol{V} = \sqrt{(\boldsymbol{X_1} - \boldsymbol{X_0 W})' \boldsymbol{V} (\boldsymbol{X_1} - \boldsymbol{X_0 W})} \tag{4.6}$$

where $\boldsymbol{V}$ is a symmetric and positive semidefinite matrix, although other choices are also possible. An optimal choice of $\boldsymbol{V}$ assigns weights to linear combinations of the variables in $\boldsymbol{X_0}$ and $\boldsymbol{X_1}$ to minimize the mean squared error (MSE) of the synthetic control estimator. That is, $\boldsymbol{V}$ is chosen such that the MSE of the outcome variable prediction is minimized for the pre-intervention periods (ABADIE; DIAMOND; HAINMUELLER, 2010).

Abadie, Diamond and Hainmueller (2010) explain that, in practice, it may not always be possible to obtain a weighted combination of untreated units that satisfies the equations above. Therefore, in each application, the analyst must assess whether the characteristics of the treated unit are sufficiently matched by the synthetic control. In some cases, the fit may be inadequate, in which case the use of a synthetic control is not recommended.

Furthermore, Abadie, Diamond and Hainmueller (2010) argue that even when a synthetic control provides a good fit for the treated units, interpolation biases may be substantial if the model is not valid for the entire set of regions in a given sample. To mitigate these biases, the donor pool — the group of possible contributing units — can be restricted to regions with characteristics similar to those of the unit exposed to the intervention of interest, reducing biases arising from interpolation across regions with significantly different characteristics.

An important observation is that the traditional difference-in-differences model can be obtained by imposing that $\boldsymbol{\lambda}_t$ in equation (4.3) remains constant for all periods t, so that it is eliminated through temporal differencing. In contrast, the synthetic control model allows the effects of unobservable characteristics on the outcome variable to vary over time (ABADIE; DIAMOND; HAINMUELLER, 2010).

4.2 INFERENCE

To assess the significance of the estimates generated by the synthetic control method, Abadie, Diamond and Hainmueller (2010) propose different inference methods. The authors explain that large-sample inferential techniques are not suitable for comparative case studies when the number of units in the comparison group is small. Therefore, the recommended approach is to use inference techniques similar to permutation tests, which do not require a large number of comparison units in the donor pool.

Permutation tests, or placebo studies, allow for the evaluation of the synthetic control method's ability to replicate the trajectory of the treated unit in the absence of treatment by applying the same method to a control unit. According to Abadie, Diamond and Hainmueller (2010), the distribution of a test statistic is computed under random permutations of the assignment of sample units to the treatment and control groups. The synthetic control method is then applied to each possible control unit in the sample, allowing an assessment of whether the estimated effect for the affected region is large relative to the estimated effect for a randomly chosen region. The treatment effect on the affected unit is considered significant when its magnitude is extreme relative to the permutation distribution (ABADIE, 2021).

According to Athey and Imbens (2017), in a placebo analysis, the primary analysis is replicated by replacing the outcome variable with a pseudo-outcome that is not affected by the treatment. In this case, the true value of the estimand for this pseudo-outcome is zero, and the goal of the supplementary analysis is to assess whether the adjustment methods used in the primary analysis yield estimates close to zero when applied to the pseudo-outcome.

Abadie (2021) explains that even if a synthetic control successfully reproduces the trajectory of the outcome variable for the treated unit before the intervention, this may not hold for all units in the donor pool. Therefore, the proposed test statistic measures the ratio between post-intervention fit and pre-intervention fit, defined as the root mean squared prediction error (RMSPE) of the synthetic control estimator.

For $0 \leq t_1 \leq t_2 \leq T$ and $j = \{1, ..., J+1\}$, let

$$R_j(t_1, t_2) = \left(\frac{1}{t_2 - t_1 + 1} \sum_{t=t_1}^{t_2} (Y_{jt} - \hat{Y}_{jt}^N)^2 \right)^{1/2} \tag{4.7}$$

where $\hat{Y}_{jt}^N$ represents the outcome in period t produced by a synthetic control when unit j is considered treated, and all other J units are used to construct the donor pool. According to Abadie (2021), this is the root mean squared prediction error (RMSPE) of the synthetic control estimator for unit j over the time periods $t_1, ..., t_2$. The ratio between post-intervention RMSPE and pre-intervention RMSPE for unit j is

$$r_j = \frac{R_j(T_0 + 1, T)}{R_j(1, T_0)} \tag{4.8}$$

That is, r_j measures the quality of the fit of a synthetic control for unit j in the post-treatment period relative to the fit in the pre-treatment period. The permutation distribution of r_j is used by Abadie, Diamond and Hainmueller (2010) for inference.

A p-value for the inferential procedure based on the permutation distribution of r_j is given by

$$p = \frac{1}{J+1} \sum_{j=1}^{J+1} I_+(r_j - r_1) \tag{4.9}$$

where $I_+(\cdot)$ is an indicator function that returns one if the argument is non-negative and zero otherwise. Abadie (2021) argues that, although p-values are often used to summarize the results of testing procedures, the permutation distribution of the test statistics, r_j, or of the placebo differences, $Y_{jt} - \hat{Y}_{jt}^N$, are easy to visualize and provide additional information (for example, on the magnitude of the differences between the estimated treatment effect in the treated unit and the placebo differences in the donor group).

4.3 BIAS CORRECTION

Abadie (2021) argues that, in some scenarios, the predictor values for treated units may not be accurately reproduced by a synthetic control. Alternatively, they may be accurately reproduced only by combinations of units that exhibit large discrepancies in the predictor values relative to the treated unit. In such cases, there may be concerns about potential biases introduced by the discrepancies between the predictor values of the treated units and those of the respective synthetic controls.

Therefore, it is important to perform bias corrections in the estimations. The modifications to the synthetic control estimator proposed by Abadie and L'Hour (2021) and Ben-Michael, Feller and Rothstein (2021) use regression adjustments to attenuate the bias of synthetic control estimators in scenarios where the counterfactual is constructed using untreated units whose predictor values do not accurately reproduce the predictor values of the treated unit.

For $t = T_0{+}1, \ldots, T$, let $\hat{\mu}_{0t}$ be a sample regression function (parametric or nonparametric) estimated by regressing the outcomes of the untreated units $Y_{I+1,t}, \ldots, Y_{I+J,t}$ on the predictor values for the untreated units $X_{I+1}, \ldots, X_{I+J}$. The bias-corrected synthetic control estimator for unit i is

$$\hat{\tau}_{it} = \left(Y_{it} - \sum_{j=I+1}^{I+J} w_{ij}^{*} Y_{jt} \right) - \sum_{j=I+1}^{I+J} w_{ij}^{*} \left(\hat{\mu}_{0t}(X_i) - \hat{\mu}_{0t}(X_j) \right) \tag{4.10}$$

The first term on the right-hand side of equation 4.10 is the original synthetic control estimator. The second term, according to Abadie (2021), uses a regression adjustment to correct for discrepancies between the predictor values for the treated unit and the predictor values for the units contributing to the synthetic control.

Alternatively, the estimator in equation 4.10 can be expressed as

$$\hat{\tau}_{it} = \left(Y_{it} - \hat{\mu}_{0t}(X_i) \right) - \sum_{j=I+1}^{I+J} w_{ij}^{*} \left(Y_{jt} - \hat{\mu}_{0t}(X_j) \right). \tag{4.11}$$

Equation 4.11 provides an interpretation of the bias-corrected synthetic control estimator as a synthetic control estimator applied to the residuals of the regression. In the Robustness section of this study, analyses are conducted to ensure the significance of the results after the correction for potential biases.

5 DATA

To analyze the effects of the Recife airport hub on the local economy, a panel dataset was constructed using various sources. This section describes the data used in the research.

5.1 PNADC

Data were obtained from the Continuous National Household Sample Survey (PNADC), conducted by the Instituto Brasileiro de Geografia e Estatística [Brazilian Institute of Geography and Statistics] (IBGE). This dataset provided information on income and employment (both formal and informal), aggregated and by sector, education level, and other population characteristics. The data produced by PNADC allow for an analysis of the hub's effects at the levels of capital cities, metropolitan regions, and federative units.

PNADC was permanently implemented nationwide in 2012. As of the publication date of this study, the most recent data available from IBGE pertain to the year 2023. Therefore, the annual panel data from PNADC used in this study cover capital cities, metropolitan regions, and states from 2012 to 2023.

5.2 ECONOMIC DATA

Abadie (2021) argues that a small number of pre-intervention periods can hinder the construction of an accurate counterfactual. This issue can be mitigated by including strong predictors of post-intervention values for the variable of interest, which was a priority in this study. Additionally, efforts were made to extend the number of pre-intervention years by incorporating other data sources.

Data from the Annual Social Information Report (RAIS), provided by the Ministry of Labor and Employment, were gathered regarding formal employment relationships in Brazil. The RAIS data span from 2006 — ten years before the Recife hub was implemented — until 2023, the most recent available year. RAIS data used as predictors include the percentage of formal employment contracts under the Consolidation of Labor Laws (CLT) and the proportion of employees with a high school or college degree. Another RAIS variable analyzed was the percentage of formal employees in specific sectors, though this was used as a dependent variable. With RAIS data, the analysis period could be extended to obtain a more accurate estimation of the airport hub's effects in Recife after its implementation in 2016.

Additionally, Gross Domestic Product (GDP) data for municipalities were obtained from IBGE. However, the latest available data in this series refer to 2021. The collected dataset also includes information on GDP *per capita*.

5.3 AIRPORTS DATA

Data on flights and Brazilian airports were obtained from the Agência Nacional de Aviação Civil [National Civil Aviation Agency] (ANAC). The microdata contain detailed annual information, including the number of flights departing from or arriving at a given airport, the airline operating the flight, the number of paying passengers, the volume of paid cargo, and other relevant details.

5.4 TOURISM DATA

Finally, data on tourism service providers in Brazil were obtained from the Ministry of Tourism. These data pertain to the registry of individuals and companies operating in the tourism sector, including mandatory registration for tour guides, a category analyzed in this study. It is important to note that, according to the Ministry of Tourism, reports released before 2016 serve only as references and do not attest to the formal registration of service providers. This is because, before 2016, registrations in the Cadastur system were not fully digital, and information validation relied on manual processes, which made ensuring registration regularity difficult (MINISTÉRIO DO TURISMO, 2024; MINISTÉRIO DO TURISMO, 2025).

5.5 ANALYSIS

As mentioned earlier, the analysis will be conducted at the levels of capital cities, metropolitan regions, and federative units (states). The primary analysis will focus on the metropolitan region, considering Recife's geography and characteristics, as well as prior studies on airports and labor markets that have also been based on metropolitan areas (RATTSØ; SHEARD, 2024; BRUECKNER; LEE; SINGER, 2014).

PNADC provides estimates for 27 capitals, 20 metropolitan regions, 1 integrated development administrative region, and 27 federative units. However, to determine the effect of an airport hub in a specific location using the synthetic control method, it is necessary to exclude other regions that also implemented hubs during or before the analyzed period. Thus, São Paulo, Rio de Janeiro, Minas Gerais, and the Federal District were excluded, as their hubs were implemented in or before 2012, making them unsuitable as control units. Fortaleza, in Ceará, was not excluded from the donor pool since, as demonstrated in the Local Background section, its hub was not effectively implemented.

Additionally, the donor pool was restricted to units with characteristics similar to the treated unit (ABADIE, 2021). Therefore, the regions of Amazonas, Amapá, and Mato Grosso were removed due to significant demographic and socioeconomic differences from Pernambuco. Units that could be influenced by the intervention in the treated unit, such as geographically close regions, were also excluded to prevent biased estimates of the counterfactual outcome (ABADIE, 2021). As a result, the states of Paraíba and Alagoas were removed. Finally, the capital and state-level analyses consider the same units used in the metropolitan region evaluation. Thus, the analysis includes 12 capitals, 11 metropolitan regions, 1 integrated development administrative region, and 12 federative units for the period from 2006 to 2023.

The variables of interest are the total number of paid passengers, GDP *per capita*, the proportion of formal employees in specific sectors, real income in these sectors, and the total number of registered tour guides. Each variable will be analyzed separately to achieve the best pre-intervention fit for each.

Predictor variables used to construct synthetic regions include the proportion of formal employees under the CLT regime, the proportion of formal employees with completed secondary or higher education, the total number of flights, the proportion of residents of brown and black colors/races, the average habitual monthly earnings from all jobs, the unemployment rate, the proportion of residents aged 25 to 54, and lagged observations of the variable of interest. The first four variables are calculated as averages from 2006 to 2015, while the others use the period from 2012 to 2015 — the last year before the intervention in Recife (PE) — for their averages. The variable of interest, however, uses data starting from 2011.

Using the method described in the Empirical Strategy section and the predictor variables, synthetic locations were constructed to reflect the variables of interest in the treated unit before the Recife airport hub's implementation. The hub's effect on the dependent variables is estimated as the difference between the actual and synthetic regions in the post-implementation years. Robustness tests and placebo studies are also conducted to confirm the statistical significance of the estimated effects, following the methodology proposed by Abadie, Diamond and Hainmueller (2010).

6 RESULTS

In this section, the synthetic control results are presented for the Recife Metropolitan Region, for the city of Recife alone, and for its state, Pernambuco. The results for passenger traffic, overall economic activity, and activity in sectors related to tourism are considered for each region of analysis.

6.1 PASSENGER TRAFFIC

The main objective of the analysis is to measure the impact of the implementation of the airport hub in Recife on the local economy as a whole and by sector. However, it is important to verify whether the increase in the number of flights resulted in a higher flow of paid passengers at Recife International Airport. Figure 2 displays the number of paid passengers who embarked or disembarked in the Metropolitan Region of Recife, also considering its synthetic version, between 2006 and 2023. Table 3 compares the pre-intervention characteristics for the treated region, its synthetic version, and the simple average of the control units. It is evident that the synthetic unit approximates the treated unit much more closely than the simple average of the controls. Table 4 presents the weights used in each region for constructing the synthetic unit.

Figure 2 – Number of paid passengers: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region

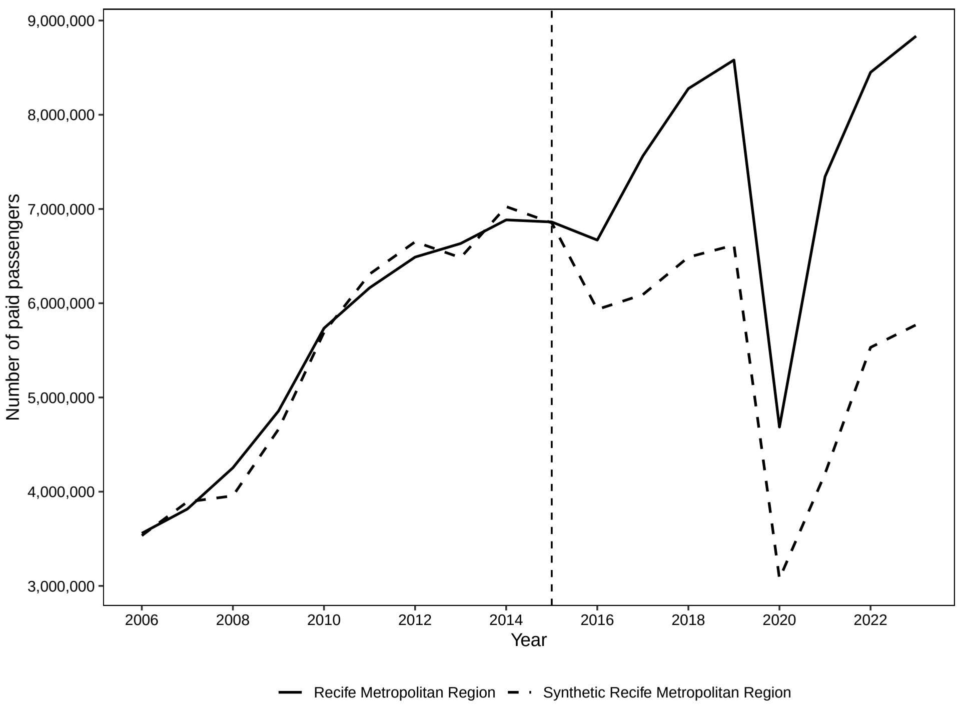


Table 3 – Predictors of paid passengers

	Treated	Synthetic	Sample Mean
Formal Employees CLT (%)	78.10	77.95	73.92
High School Completed (%)	44.90	48.86	44.03
Bachelor's Degree Completed (%)	17.66	17.03	19.36
Total Number of Flights	56,537	56,437	36,478
Total Number of Passengers	6,606,566	6,664,542	4,084,155
Brown-Skinned Workers (%)	61	60	49
Black-Skinned Workers (%)	06	14	09
Real Monthly Salary (R$)	3,221.19	2,692.13	2,948.78
Unemployment Rate (%)	10	10	09
Population Aged 25 to 54 (%)	45	46	46

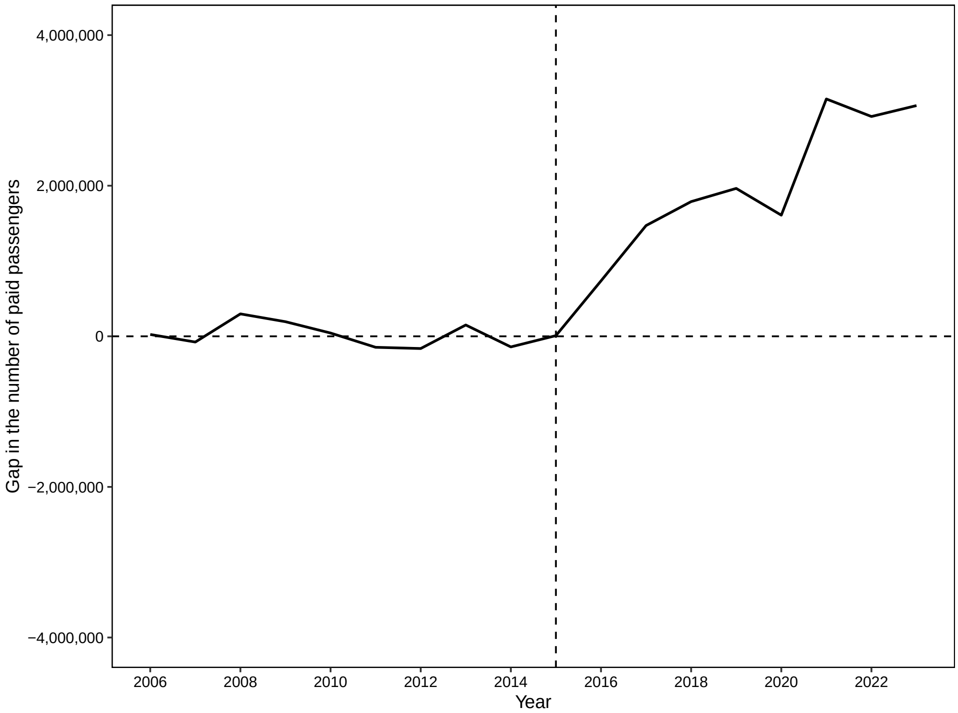
Note: The variables Formal Employees CLT, High School Completed, Bachelor's Degree Completed, and Total Number of Flights are averaged over the 2006–2015 period. The variables Brown-Skinned Workers, Black-Skinned Workers, Real Monthly Salary, Unemployment Rate, and Population Aged 25 to 54 are averaged over the 2012–2015 period. The dependent variable, in this case, Total Number of Passengers, is averaged over the 2011–2015 period. The other predictor tables in this study follow the same approach. The Real Monthly Salary is adjusted for inflation and deflated to December 2023.

Table 4 – Metropolitan Region weights in the Synthetic Recife Metropolitan Region: paid passengers

Weight	Region
0.01	Belém Metropolitan Region
0.00	Greater São Luís Metropolitan Region
0.11	Integrated Administrative Region for the Development of Greater Teresina
0.03	Fortaleza Metropolitan Region
0.00	Natal Metropolitan Region
0.46	Aracaju Metropolitan Region
0.00	Salvador Metropolitan Region
0.00	Greater Vitória Metropolitan Region
0.01	Curitiba Metropolitan Region
0.00	Florianópolis Metropolitan Region
0.00	Porto Alegre Metropolitan Region
0.36	Goiânia Metropolitan Region

It can be seen in Figure 3 that there was a considerable increase in passenger traffic compared to the counterfactual without the implementation of the airport hub in Recife. On average, between 2016 and 2023, the number of passengers increased by more than 2 million, a growth of approximately 38% compared to the period prior to the implementation of the hub.

Figure 3 – Paid passengers gap between Recife Metropolitan Region and Synthetic Recife Metropolitan Region



The annual gaps suggest that the increase in the number of passengers was significant. This assumption is corroborated in Figures 4 and 5.

Figure 4 shows the results for the placebo test. The gray lines show the difference in the number of paid passengers between each unit in the control group and its respective synthetic version. The black line represents the estimated difference for the Metropolitan Region of Recife. As shown, the estimated difference for the treated unit after the implementation of the hub is substantially higher compared to the distribution of differences for the regions in the control group.

Figure 4 – Paid passengers gaps in Recife Metropolitan Region and placebo gaps in all 12 control units

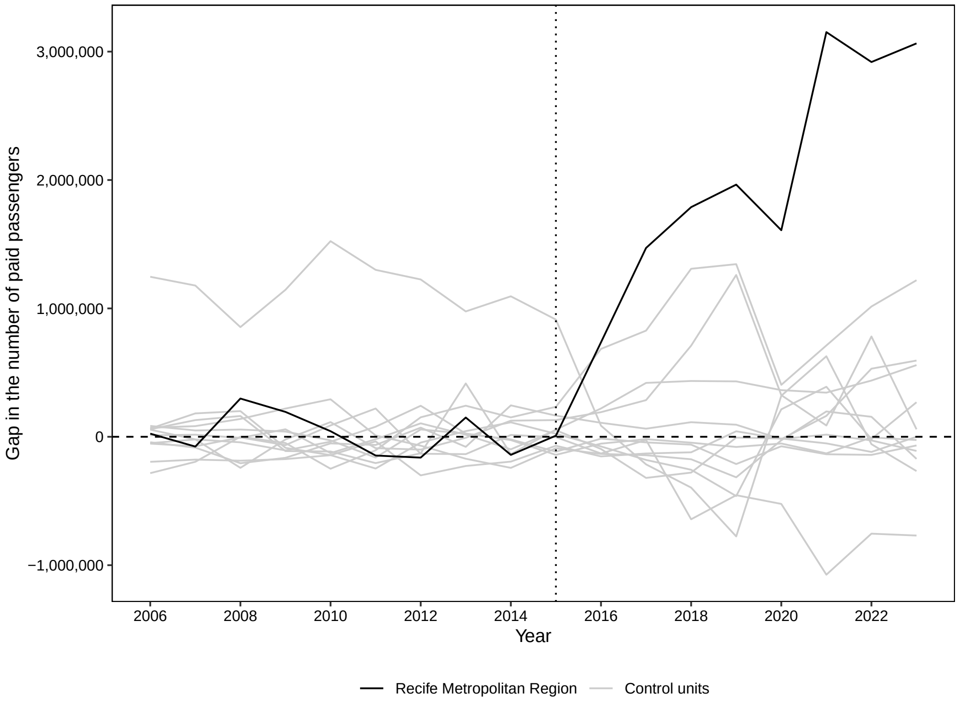
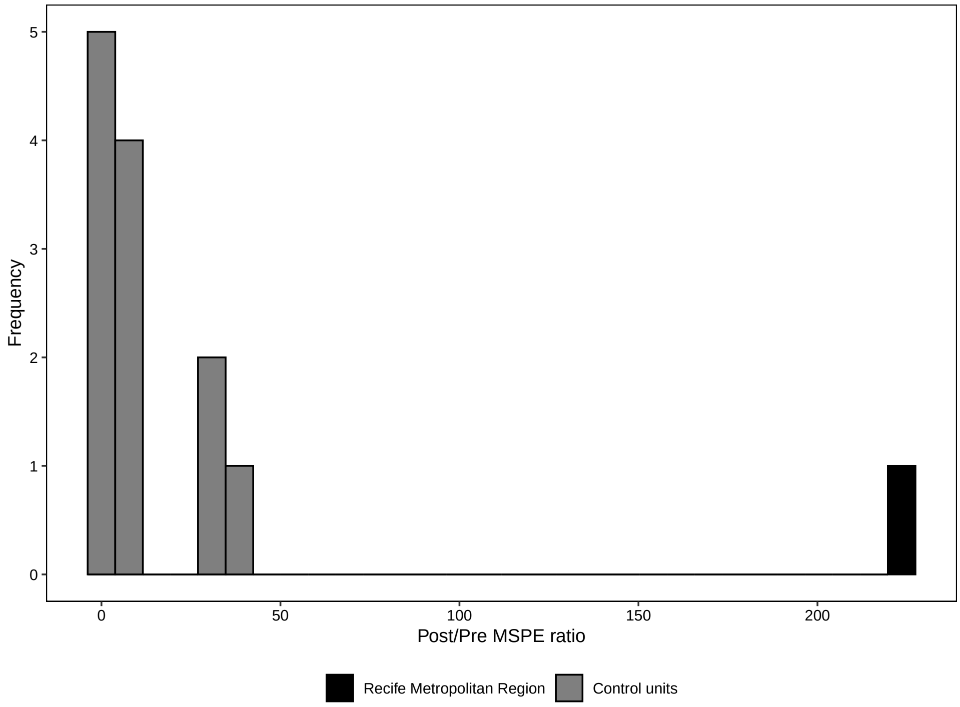


Figure 5 shows the distribution of the ratios between the mean squared prediction errors (MSPE) for the post/pre-implementation period of the airport hub in Recife for the treated region and the other units tested in the placebo test. It can be observed that the Recife Metropolitan Region stands out, with the MSPE for the post-implementation period being approximately 220 times greater than the MSPE for the pre-implementation period. This test verifies that, if the intervention had been randomly assigned in the data, the probability of obtaining a post/pre-implementation MSPE ratio as large as Recife's would be $1/13 = 0.077$, lower than the conventional 10% significance level used in statistical tests.

Figure 5 – Ratio of post-hub and pre-hub MSPE for paid passengers: Recife Metropolitan Region and 12 control units



6.2 OVERALL ECONOMIC ACTIVITY

Having concluded that there was a significant increase in the number of flights and passengers at Recife International Airport starting in 2016, the next step is to analyze whether this change had significant impacts on the economy of the Recife Metropolitan Region.

The first variable analyzed was the GDP *per capita* at constant prices. Figure 6 shows that the variable had a good fit in the pre-intervention period. However, Figures 7 and 8 show that the implementation of the airport hub did not have a significant effect on the GDP *per capita* of the Metropolitan Region of Recife, with a placebo MSPE test p-value of 0.846.

Figure 6 – GDP *per capita*: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region

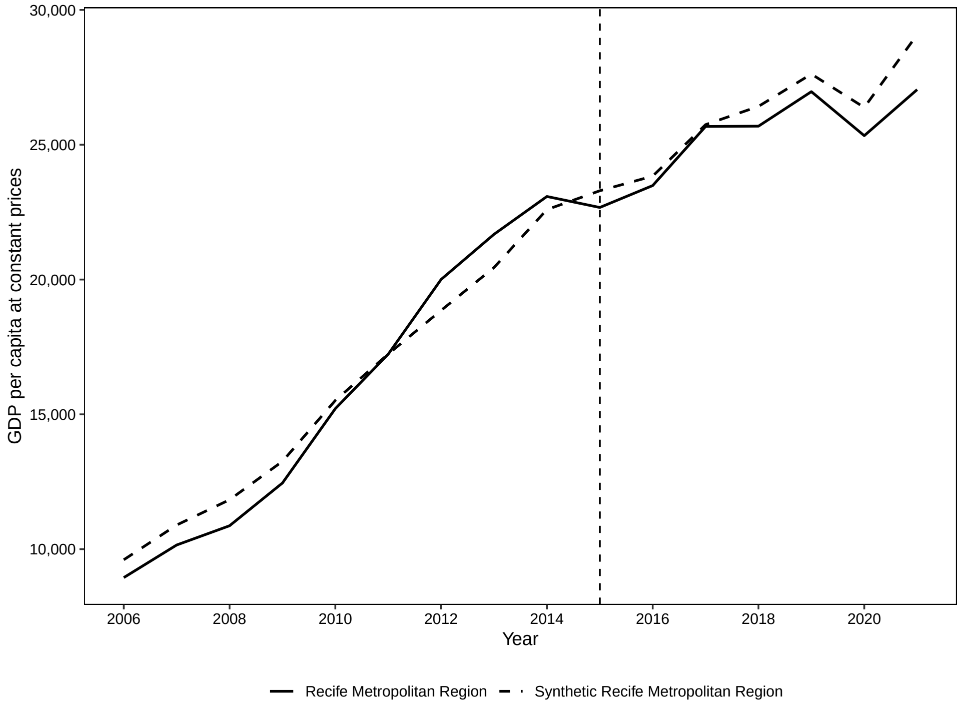


Figure 7 – GDP *per capita* gaps in Recife Metropolitan Region and placebo gaps in all 12 control units

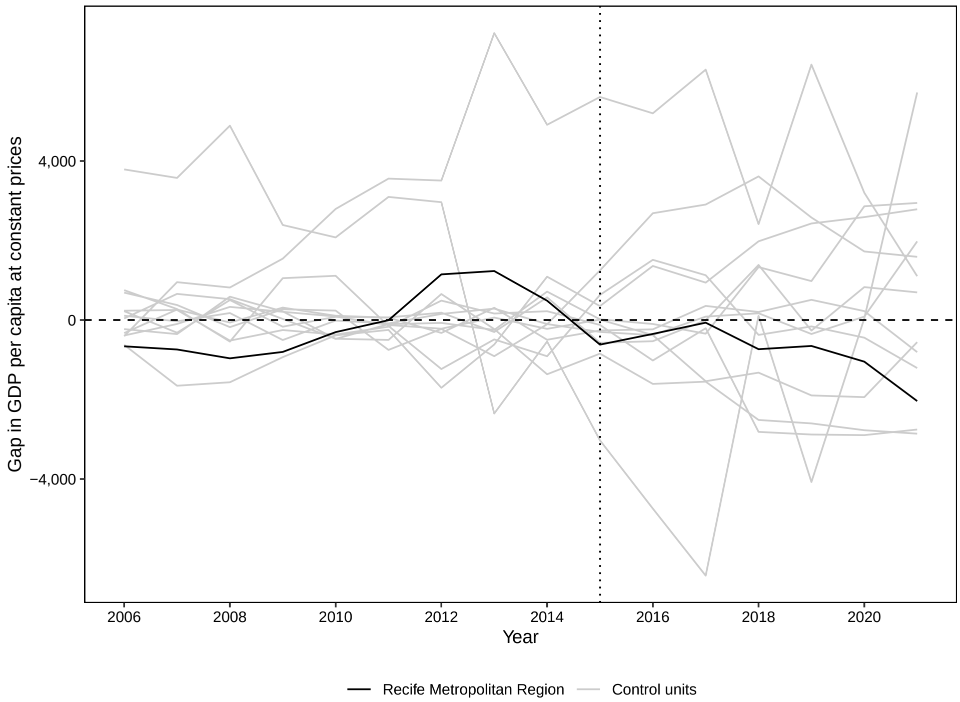
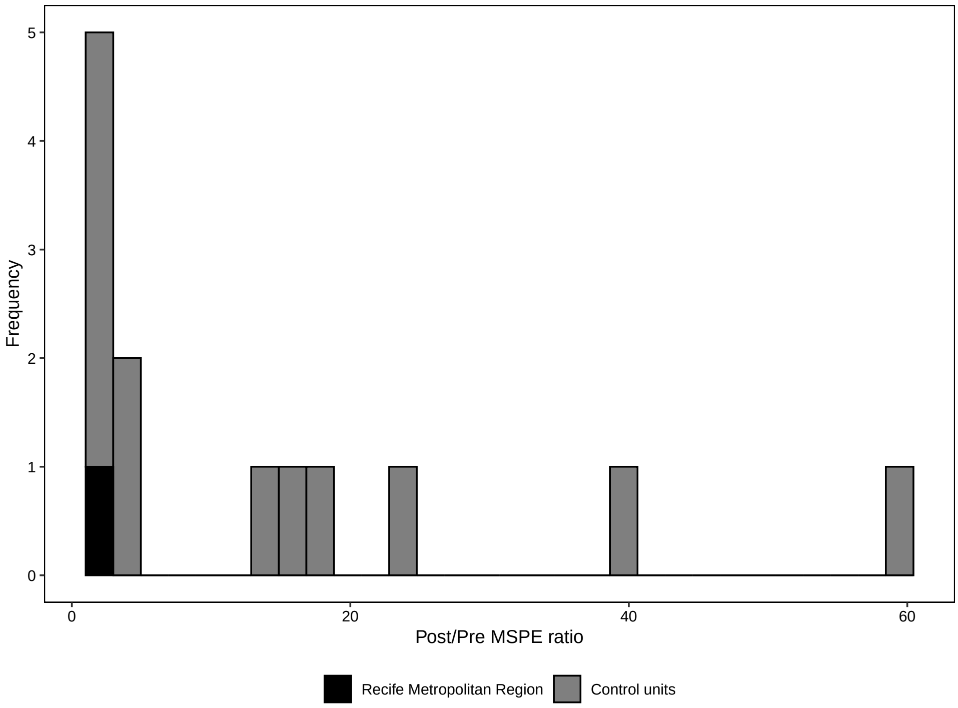


Figure 8 – Ratio of post-hub and pre-hub MSPE for GDP *per capita*: Recife Metropolitan Region and 12 control units



6.3 TOURISM SECTOR ACTIVITY

6.3.1 Employment Travel Sector

Although no significant effects were found on the overall economy, it was observed that the airport hub had important impacts on certain sectors, particularly the "Travel Agencies, Tour Operators and Reservation Services" sector described in RAIS.

This sector represented in the RAIS database is associated with Division 79 of the National Classification of Economic Activities (CNAE), which is the official system adopted by Brazil for the production of statistics based on economic activity (IBGE, 2007). Division 79 specifically comprises classes of economic activities related to travel agencies, tour operators and reservation services and other travel-related services not elsewhere classified. Throughout this study, the sector described will be referred to as the "Travel Sector" for the sake of clarity and simplification.

As shown in Figure 9, the percentage of employees in the formal sector of Travel Agencies, Tour Operators, and Reservation Services in the Metropolitan Region of Recife substantially increased after the implementation of the airport hub in Recife. Tables 5 and 6 display the comparison between the units and the weights used for the synthetic control, respectively.

Figure 9 – Proportion of formal employees in the Travel sector: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region

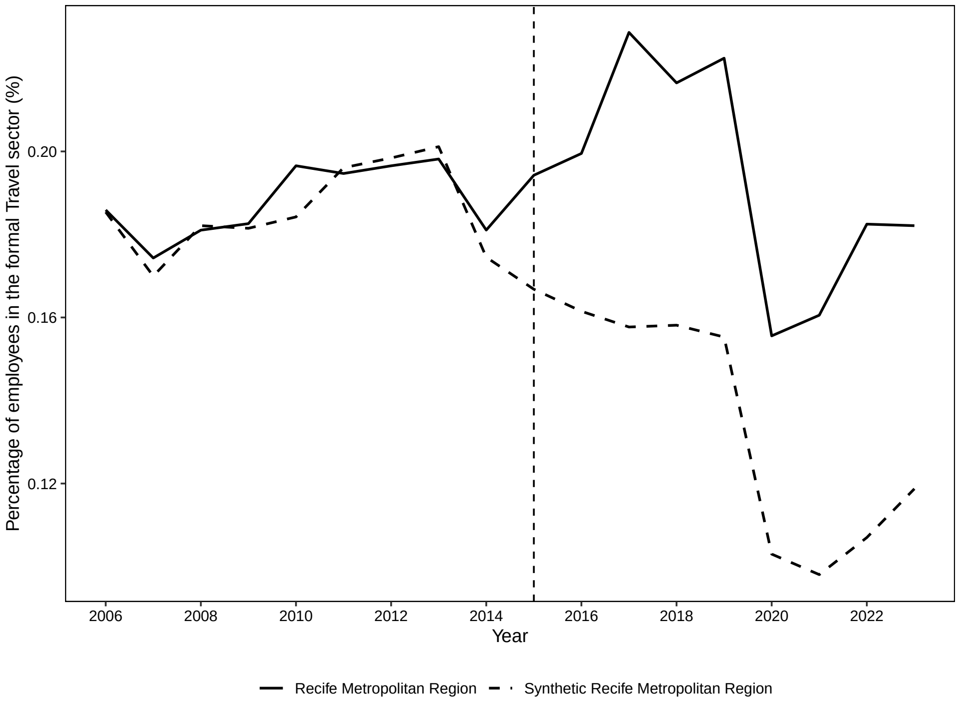


Table 5 – Predictors of the proportion of formal employees in the Travel sector

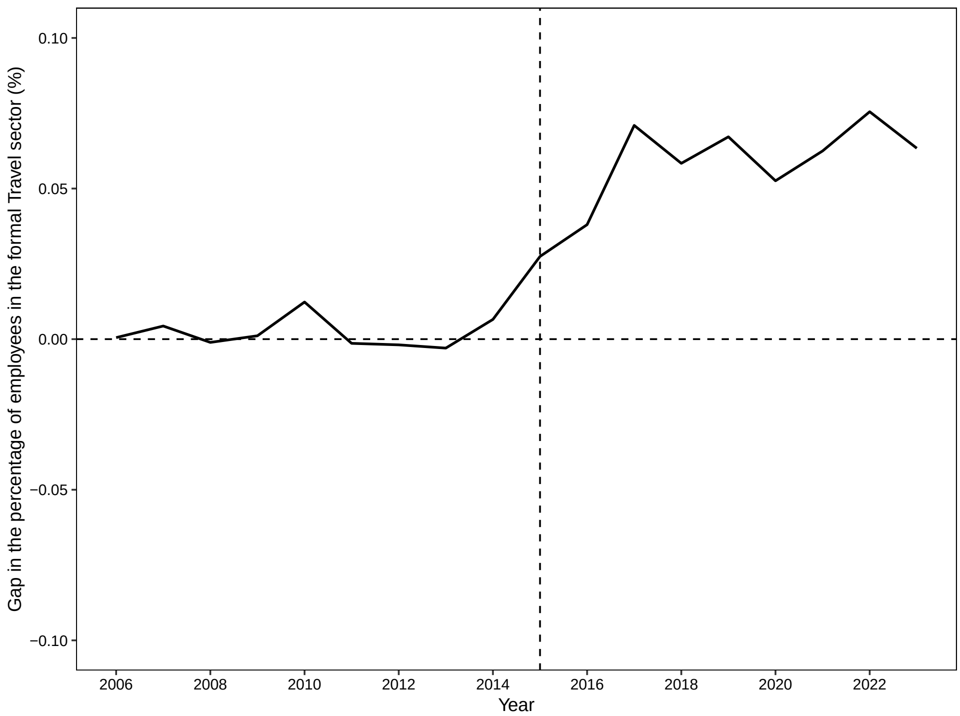
	Treated	Synthetic	Sample Mean
Formal Employees CLT (%)	78.10	77.57	73.92
High School Completed (%)	44.90	44.10	44.03
Bachelor's Degree Completed (%)	17.66	18.98	19.36
Total Number of Flights	56,537	52,986	36,478
Employees in Travel Sector (%)	0.19	0.19	0.16
Brown-Skinned Workers (%)	61	36	49
Black-Skinned Workers (%)	06	10	09
Real Monthly Salary (R$)	3,221.19	3,139.09	2,948.78
Unemployment Rate (%)	10	08	09
Population Aged 25 to 54 (%)	45	46	46

Table 6 – Metropolitan Region weights in the Synthetic Recife Metropolitan Region: proportion of employees in the Travel sector

Weight	Region
0.00	Belém Metropolitan Region
0.03	Greater São Luís Metropolitan Region
0.00	Integrated Administrative Region for the Development of Greater Teresina
0.04	Fortaleza Metropolitan Region
0.13	Natal Metropolitan Region
0.20	Aracaju Metropolitan Region
0.00	Salvador Metropolitan Region
0.00	Greater Vitória Metropolitan Region
0.00	Curitiba Metropolitan Region
0.12	Florianópolis Metropolitan Region
0.29	Porto Alegre Metropolitan Region
0.20	Goiânia Metropolitan Region

This result can also be observed through the difference between the Recife Metropolitan Region and its synthetic counterpart, as demonstrated in Figure 10. This difference represents an increase of more than 32% compared to the period before 2016.

Figure 10 – Proportion of employees in the Travel sector gap between Recife Metropolitan Region and Synthetic Recife Metropolitan Region



Through placebo tests and MSPE predictions, shown in Figures 11 and 12, it is observed that the result for the percentage of employees in the Travel sector is significant, with a p-value of 0.077.

Figure 11 – Proportion of employees in the Travel sector gaps in Recife Metropolitan Region and placebo gaps in all 12 control units

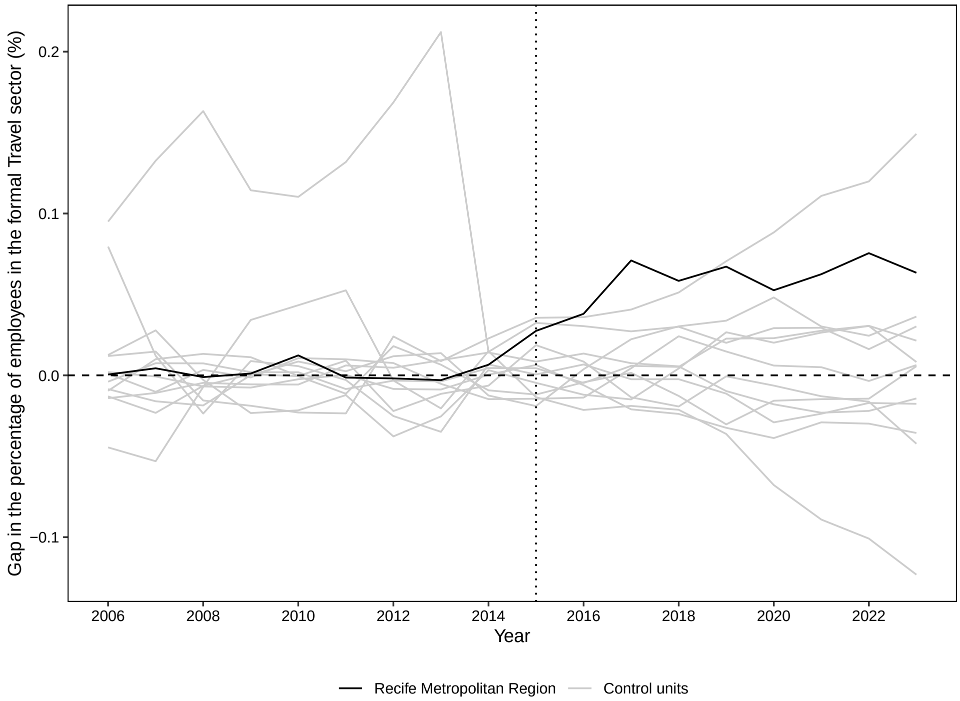
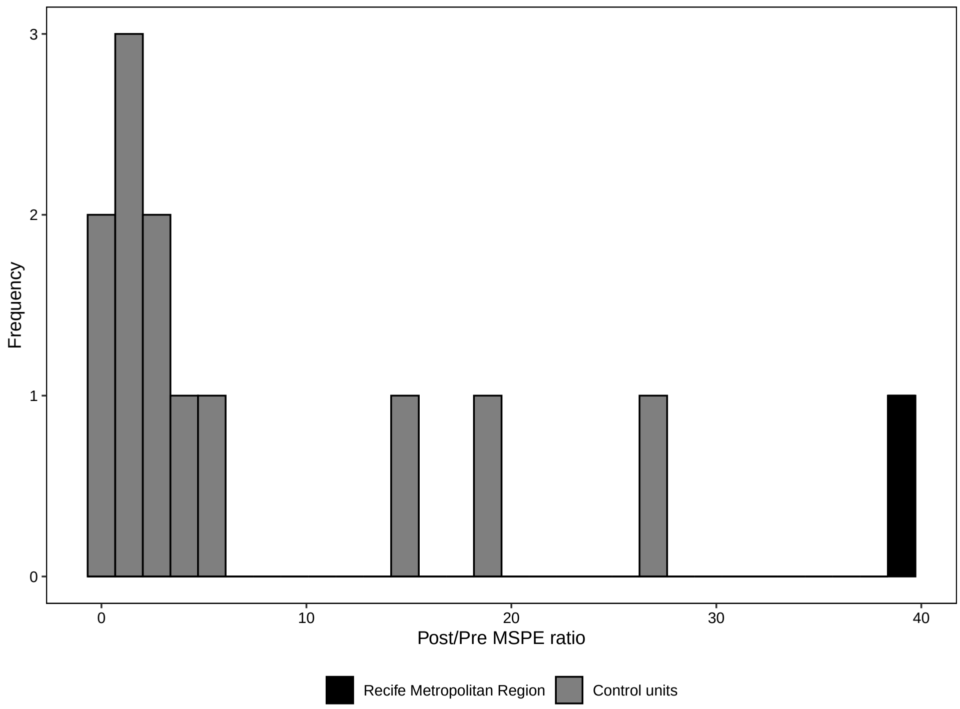


Figure 12 – Ratio of post-hub and pre-hub MSPE for the proportion of employees in the Travel sector: Recife Metropolitan Region and 12 control units



An attempt was made to verify whether these results have economic significance or are merely the result of reallocations among different sectors. Therefore, the next variable analyzed was the number of employees in the same sector. As observed in Figures 13, 14 and 15, the effect was also positive and significant for this variable, with a p-value of 0.077.

Figure 13 – Number of formal employees in the Travel sector: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region

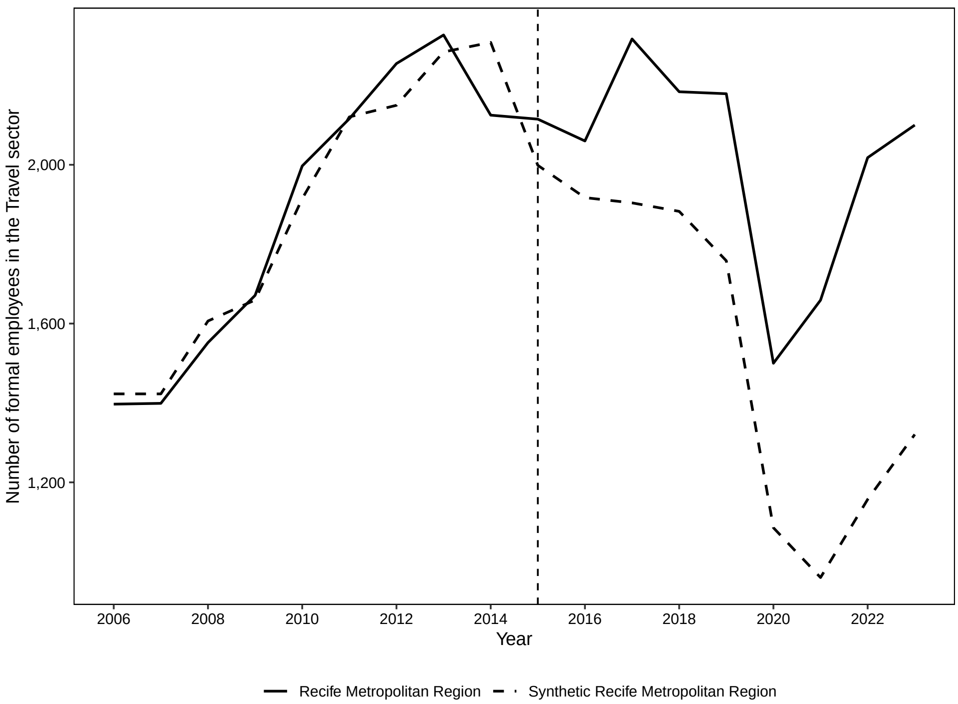


Figure 14 – Number of employees in the Travel sector gaps in Recife Metropolitan Region and placebo gaps in all 12 control units

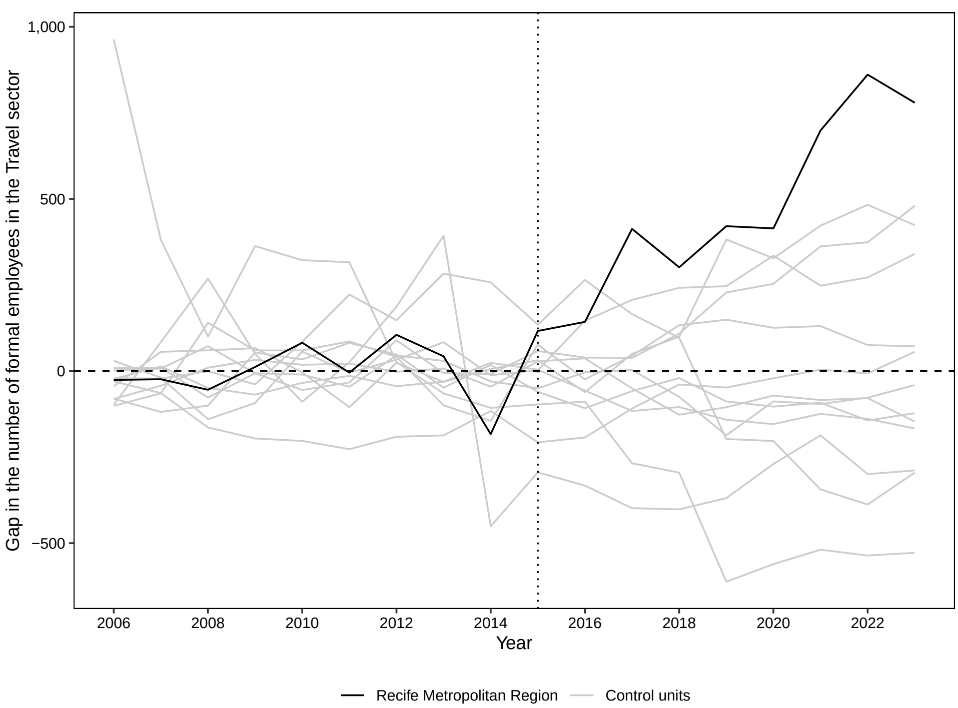
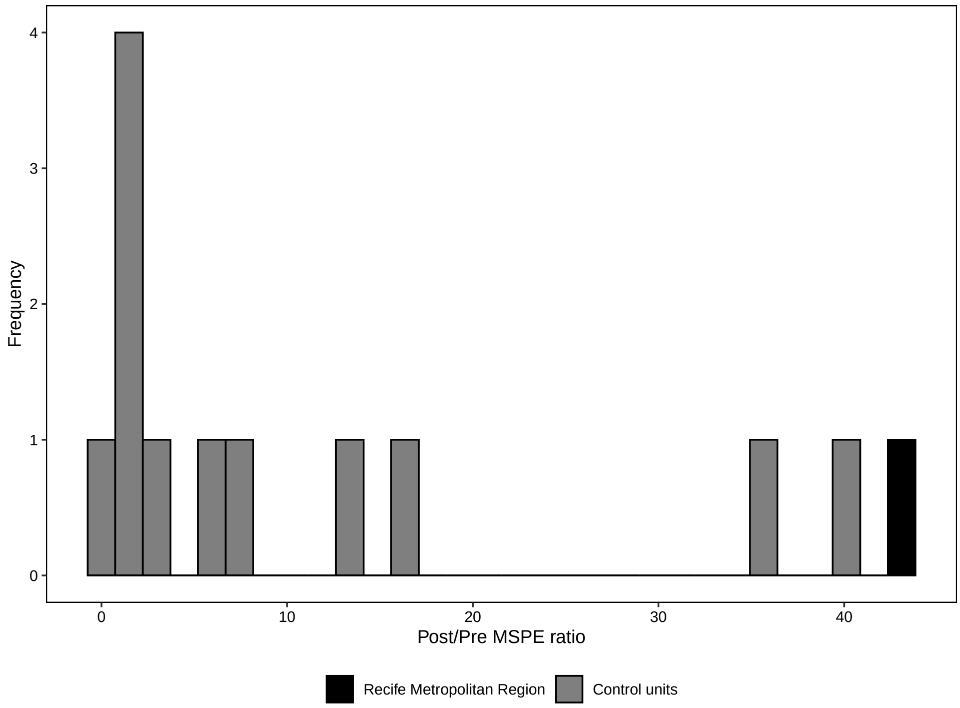


Figure 15 – Ratio of post-hub and pre-hub MSPE for the number of employees in the Travel sector: Recife Metropolitan Region and 12 control units



6.3.2 Employment Tour Guides

Despite the results described above, they are not corroborated by the findings regarding the number of tour guides registered in the Ministry of Tourism. Taking the number of guides as the dependent variable, it is observed that the implementation of the airline hub in Recife is associated with an increase in the number of registered tour guides in the Metropolitan Region of Recife. In Figures 16 and 17, it is possible to verify the difference between the actual region and its synthetic counterpart. However, the results are not statistically significant, with a p-value of 0.154, as can be observed in Figures 18 and 19.

Table 7 – Predictors of tour guides in Recife Metropolitan Region

	Treated	Synthetic	Sample Mean
Formal Employees CLT (%)	78.10	78.20	73.92
High School Completed (%)	44.90	42.77	44.03
Bachelor's Degree Completed (%)	17.66	18.04	19.36
Total Number of Flights	56,537	45,294	36,478
Total Number of Guides	275	275	182
Brown-Skinned Workers (%)	61	35	49
Black-Skinned Workers (%)	06	08	09
Real Monthly Salary (R$)	3,221.19	3,215.14	2,948.78
Unemployment Rate (%)	10	08	09
Population Aged 25 to 54 (%)	45	45	46

Table 8 – Metropolitan Region weights in the Synthetic Recife Metropolitan Region: total of tour guides

Weight	Region
0.00	Belém Metropolitan Region
0.00	Greater São Luís Metropolitan Region
0.00	Integrated Administrative Region for the Development of Greater Teresina
0.05	Fortaleza Metropolitan Region
0.00	Natal Metropolitan Region
0.00	Aracaju Metropolitan Region
0.00	Salvador Metropolitan Region
0.17	Greater Vitória Metropolitan Region
0.33	Curitiba Metropolitan Region
0.00	Florianópolis Metropolitan Region
0.44	Porto Alegre Metropolitan Region
0.00	Goiânia Metropolitan Region

Figure 16 – Number of tour guides: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region

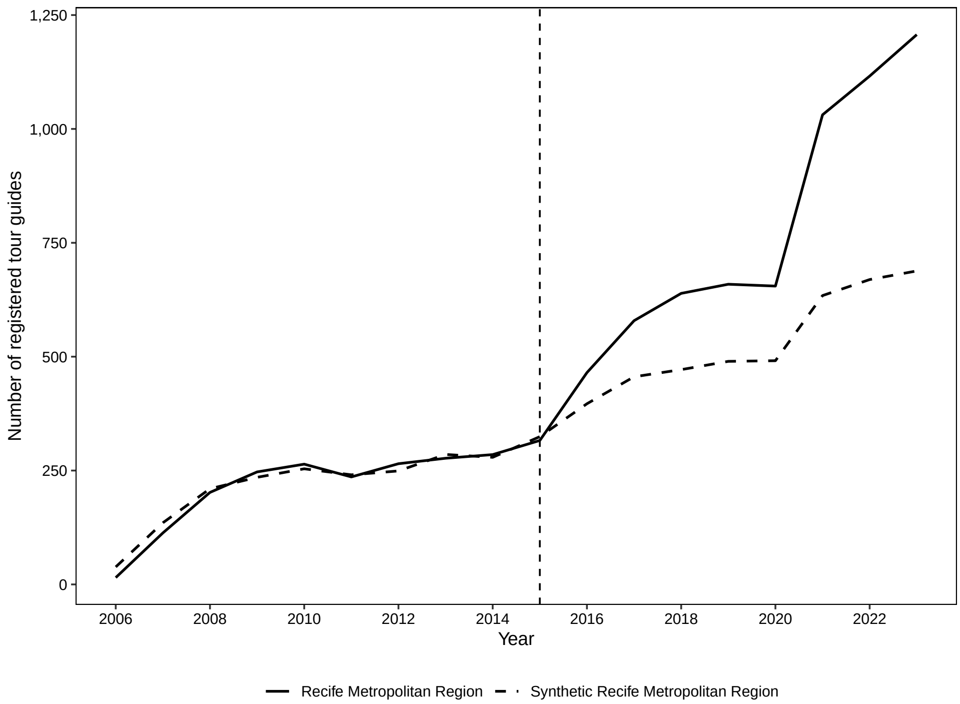


Figure 17 – Number of tour guides gap between Recife Metropolitan Region and Synthetic Recife Metropolitan Region

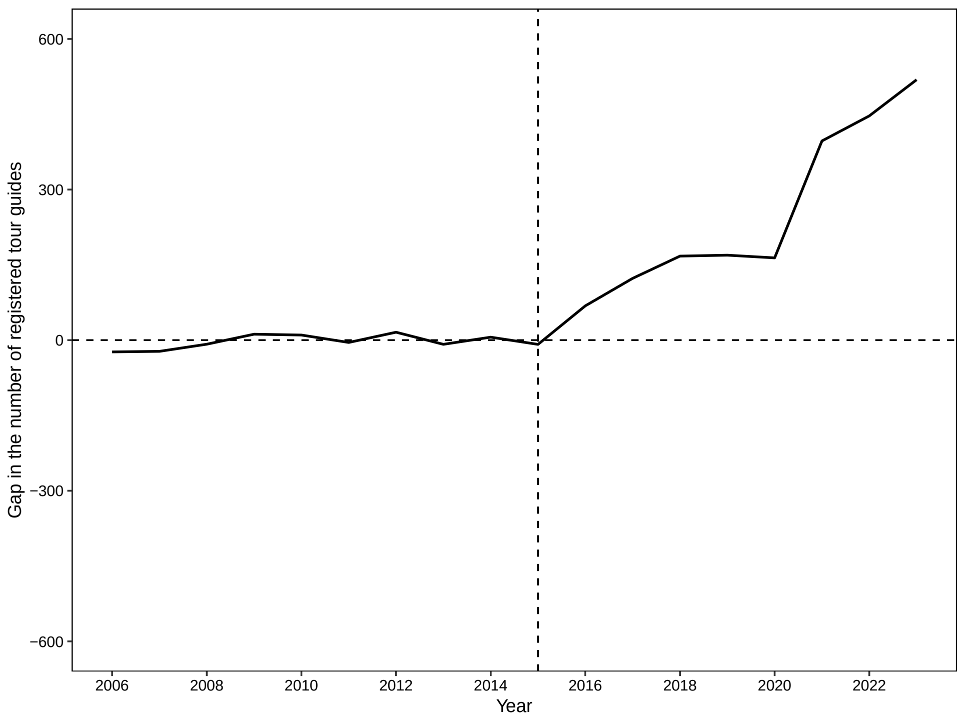


Figure 18 – Number of tour guides gaps in Recife Metropolitan Region and placebo gaps in all 12 control units

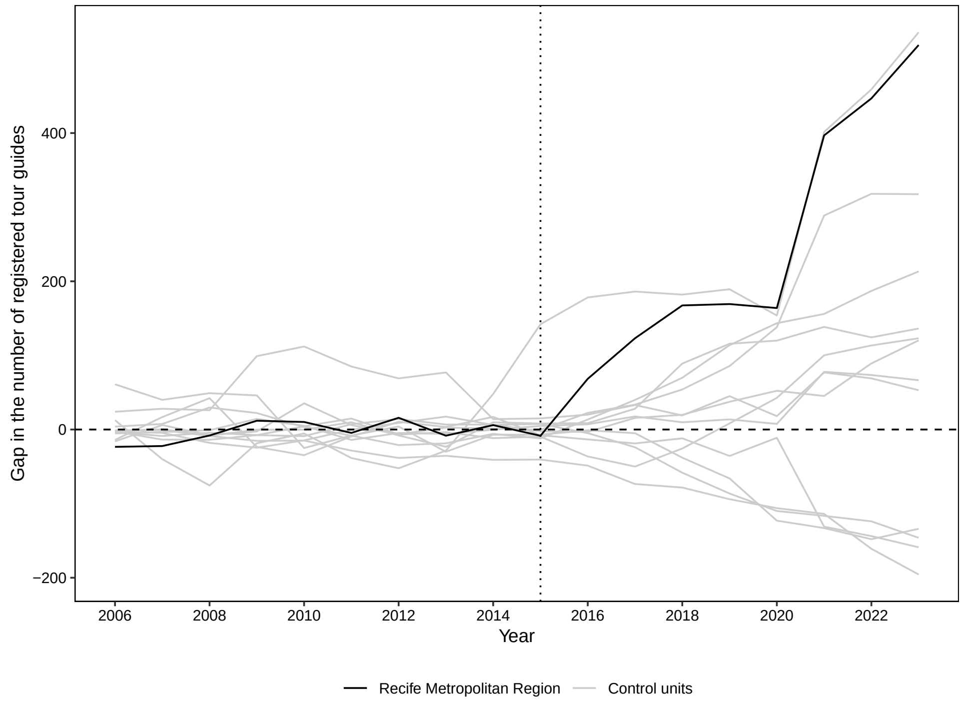
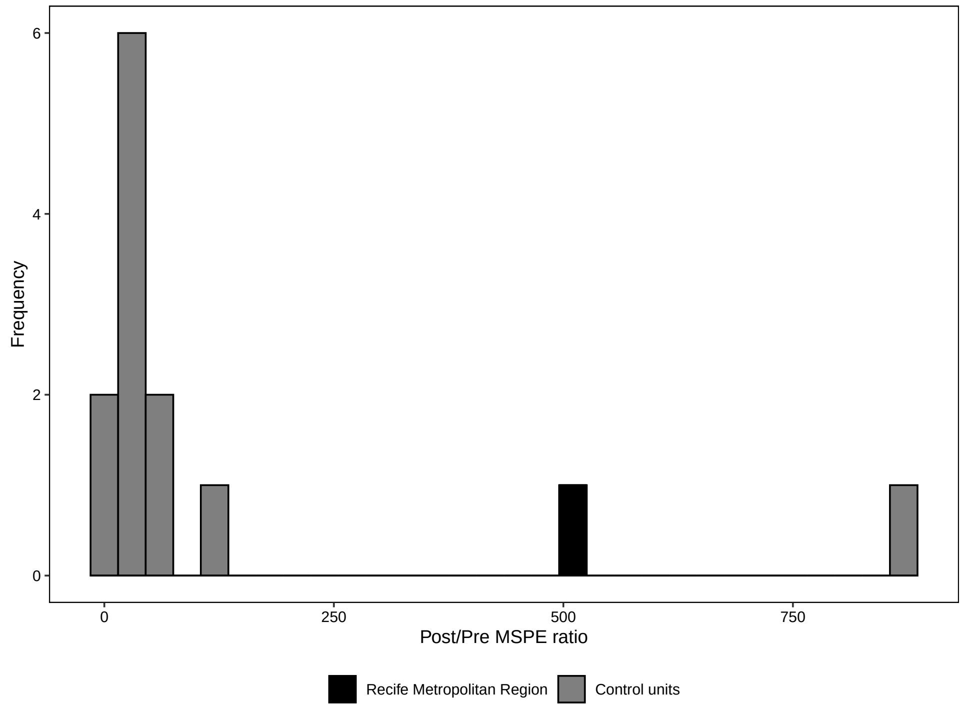


Figure 19 – Ratio of post-hub and pre-hub MSPE for tour guides: Recife Metropolitan Region and 12 control units



Thus, it is concluded that, although the implementation of Azul's airline hub at Recife International Airport did not generate significant effects on the local economy as a whole, it did have positive and significant effects on the sector of Travel Agencies and Tour Operators, despite the statistically insignificant results regarding the number of employees registered as tour guides in the region.

6.3.3 Employment Other Tourism-Related Sectors

Despite showing good fits, no significant results were found for other tourism-related sectors, such as Accommodation, Food Services, and Arts and Culture, as seen in Figures 20, 21 and 22. Their respective p-values are 0.385, 0.692, and 0.692.

Figure 20 – Proportion of formal employees in the Accommodation sector: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region

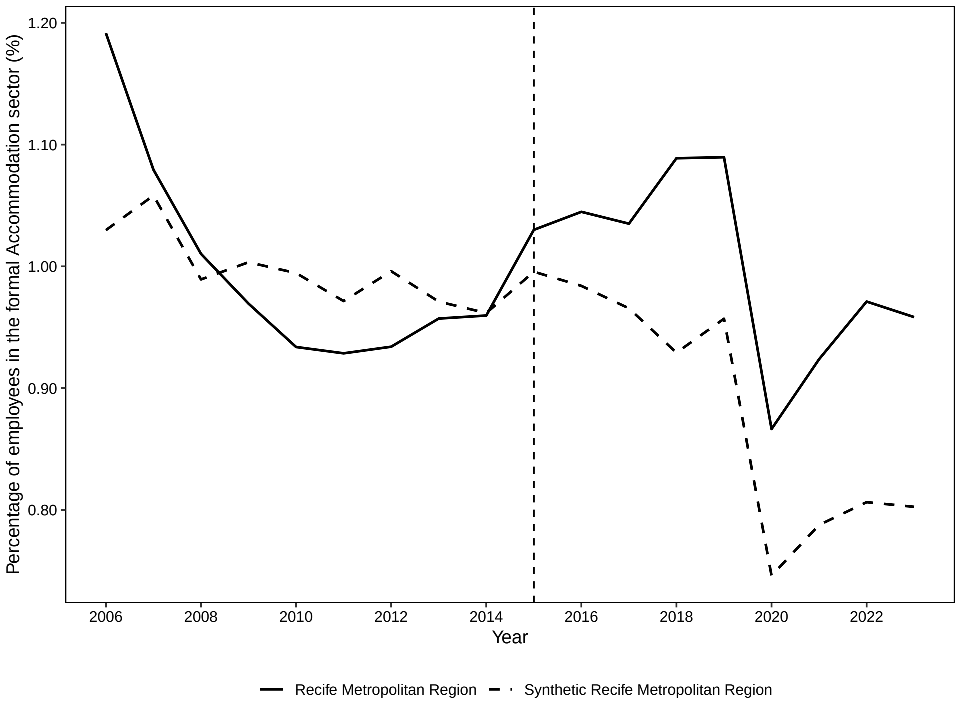


Figure 21 – Proportion of formal employees in the Food Service sector: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region

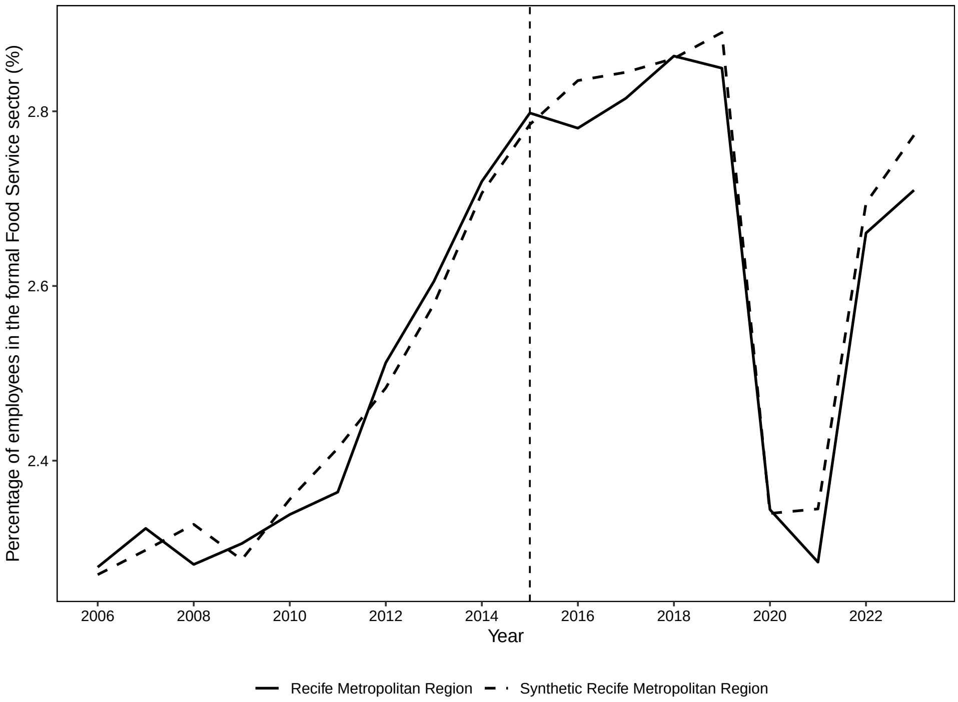
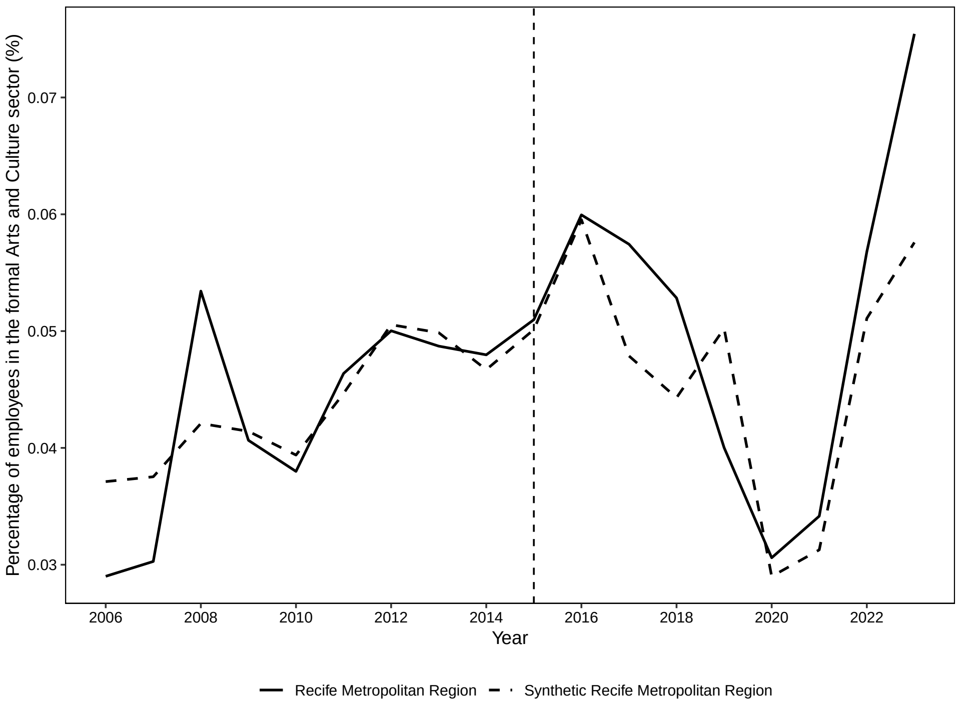


Figure 22 – Proportion of formal employees in the Arts and Culture sector: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region



6.3.4 Real Earnings Tourism-Related Sectors

Real earnings in tourism-related sectors were also analyzed. The only variable that showed statistical significance was income in the Accommodation sector, with a placebo test p-value of 0.077. The trajectories of real and synthetic earnings can be seen in Figure 23. The comparison between the versions and the contribution of each control unit can be found in Tables 9 and 10. Despite showing good fits, no significant results were found for the other tourism-related sectors, namely Travel, Food Services, and Arts and Culture, as seen in Figures 24, 25 and 26. Their respective p-values are 0.385, 0.231, and 0.385.

Table 9 – Predictors of the real income in the formal Accommodation sector (R$)

	Treated	Synthetic	Sample Mean
Formal Employees CLT (%)	78.10	73.37	73.92
High School Completed (%)	44.90	44.19	44.03
Bachelor's Degree Completed (%)	17.66	19.74	19.36
Total Number of Flights	56,537	35,731	36,478
Real Income Accommodation Sector (R$)	1,761.86	1,764.33	1,825.02
Brown-Skinned Workers (%)	61	57	49
Black-Skinned Workers (%)	06	07	09
Real Monthly Salary (R$)	3,221.19	2,951.81	2,948.78
Unemployment Rate (%)	10	10	09
Population Aged 25 to 54 (%)	45	45	46

Table 10 – Metropolitan Region weights in the Synthetic Recife Metropolitan Region: real income in the formal Accommodation sector (R$)

Weight	Region
0.00	Belém Metropolitan Region
0.38	Greater São Luís Metropolitan Region
0.26	Integrated Administrative Region for the Development of Greater Teresina
0.20	Fortaleza Metropolitan Region
0.00	Natal Metropolitan Region
0.12	Aracaju Metropolitan Region
0.00	Salvador Metropolitan Region
0.00	Greater Vitória Metropolitan Region
0.00	Curitiba Metropolitan Region
0.00	Florianópolis Metropolitan Region
0.00	Porto Alegre Metropolitan Region
0.04	Goiânia Metropolitan Region

Figure 23 – Real income in the formal Accommodation sector: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region

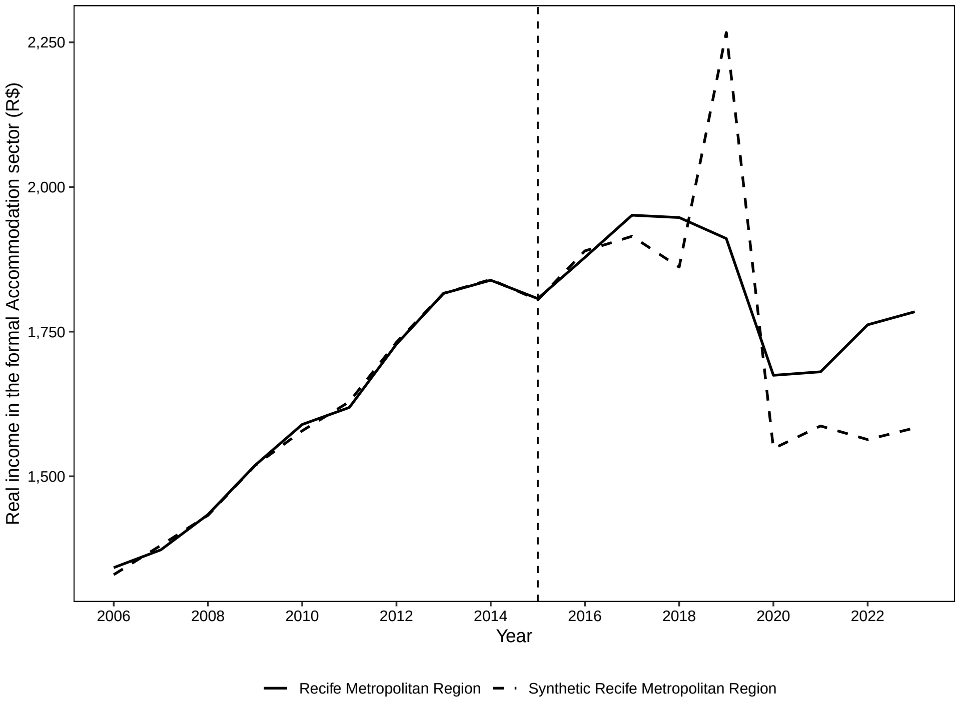


Figure 24 – Real income in the formal Travel sector: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region

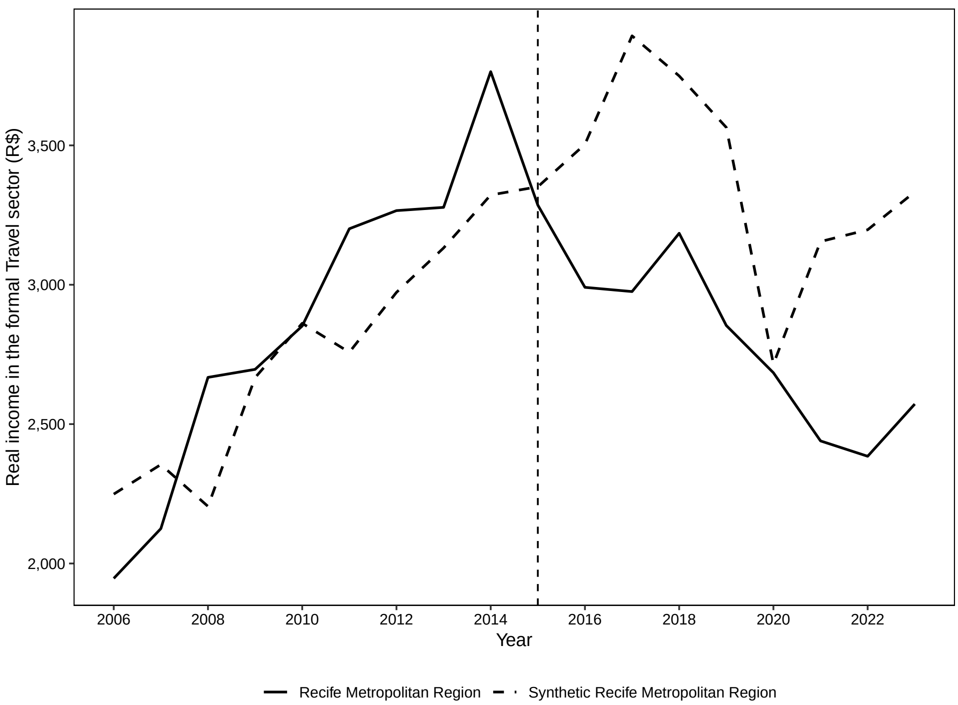


Figure 25 – Real income in the formal Food Service sector: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region

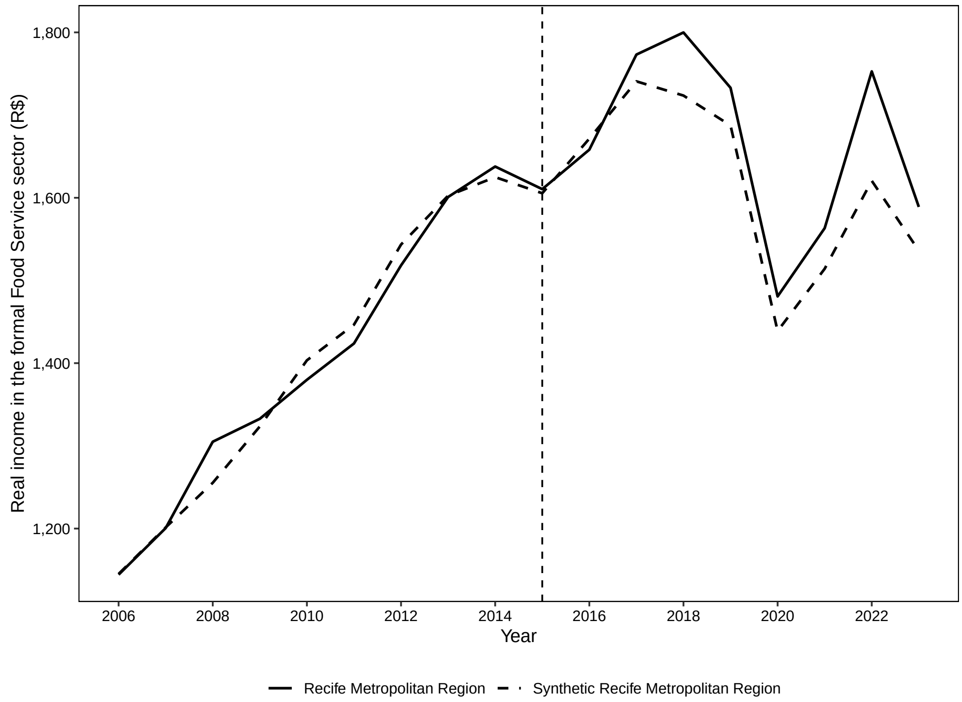
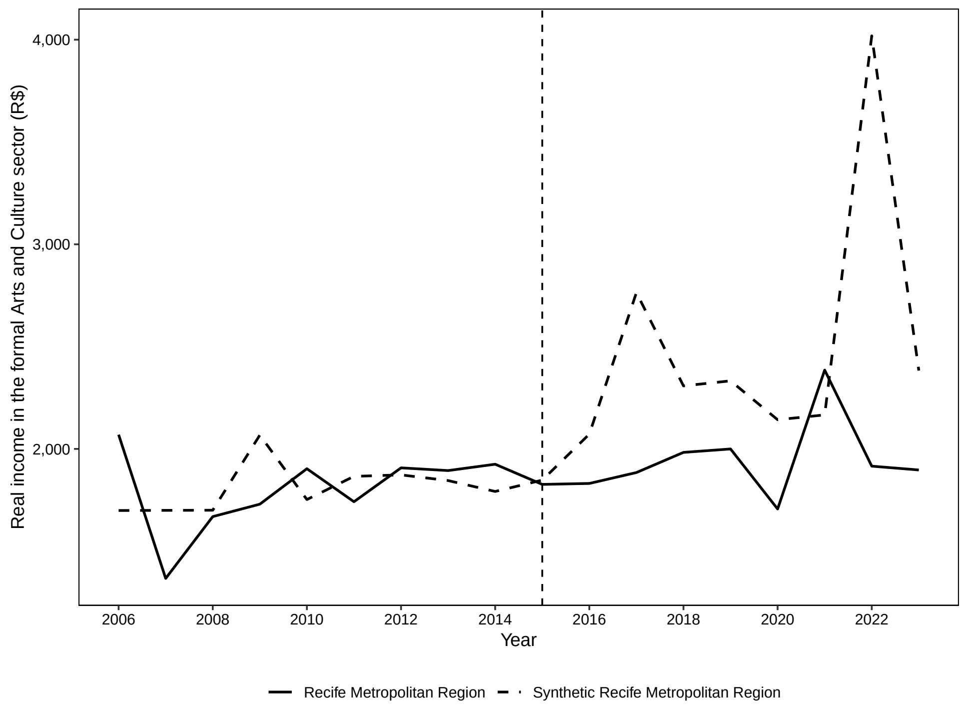


Figure 26 – Real income in the formal Arts and Culture sector: Recife Metropolitan Region vs. Synthetic Recife Metropolitan Region



6.3.5 Employment Capital

The results found for the capital city level remained the same as those obtained for the metropolitan region, with the difference that the income result was not significant for any of the tourism-related sectors, and the result for the number of registered tour guides was significant here, with a p-value of 0.077, as observed in Figures 27, 28 and 29. The comparison table for the synthetic unit and the table with the weights used in the calculation, 12 and 13, considering tour guides as the dependent variable, are available in Appendix B.

Figure 27 – Number of tour guides: Recife vs. Synthetic Recife

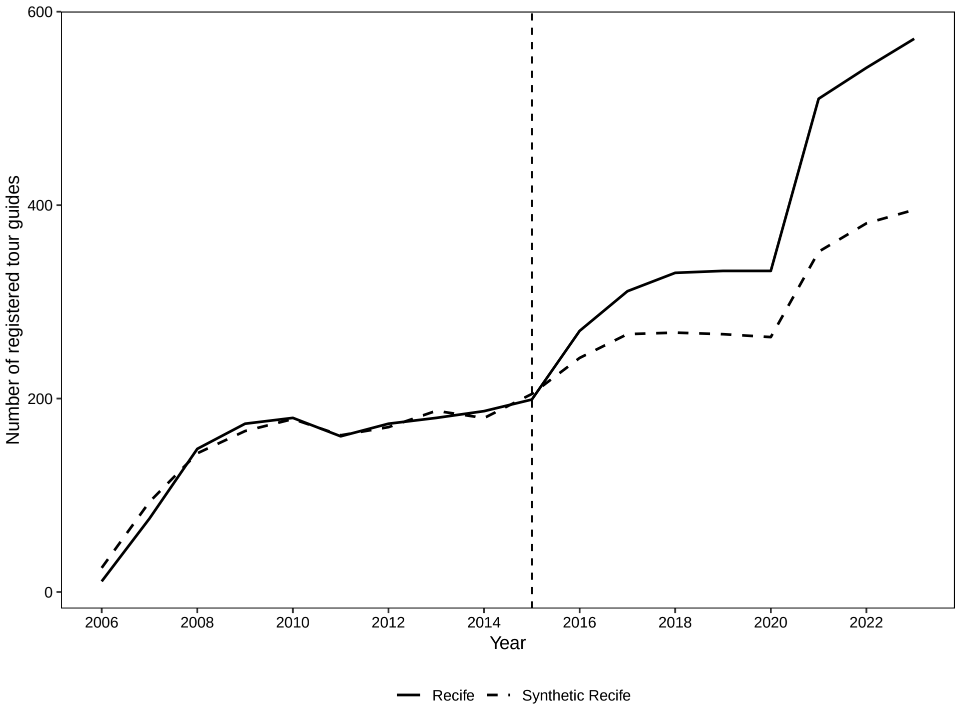


Figure 28 – Number of tour guides gaps in Recife and placebo gaps in all 12 control units

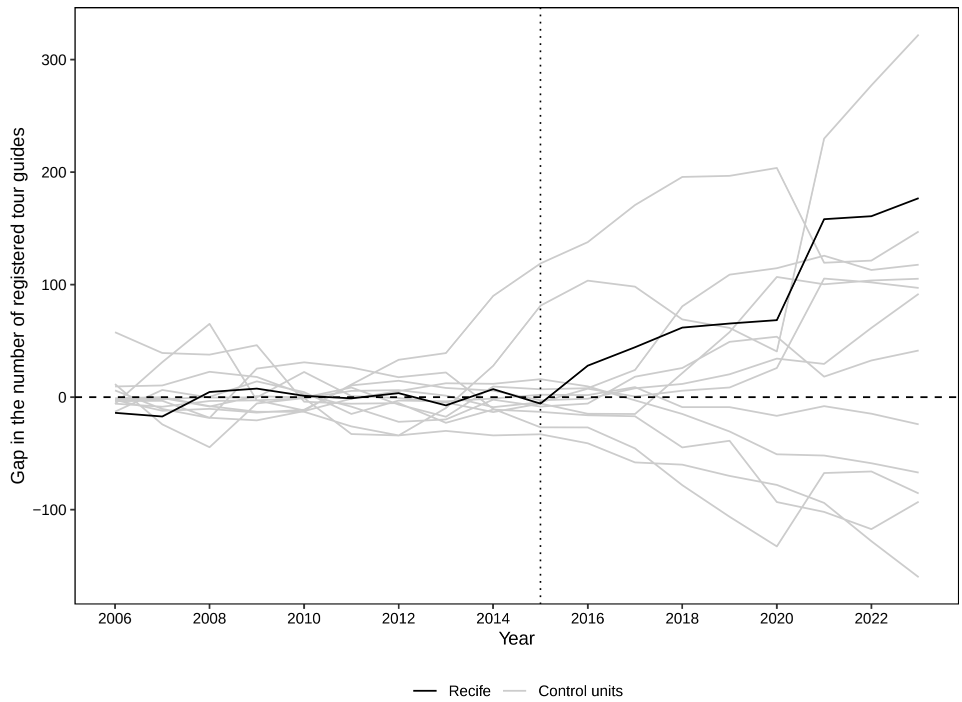
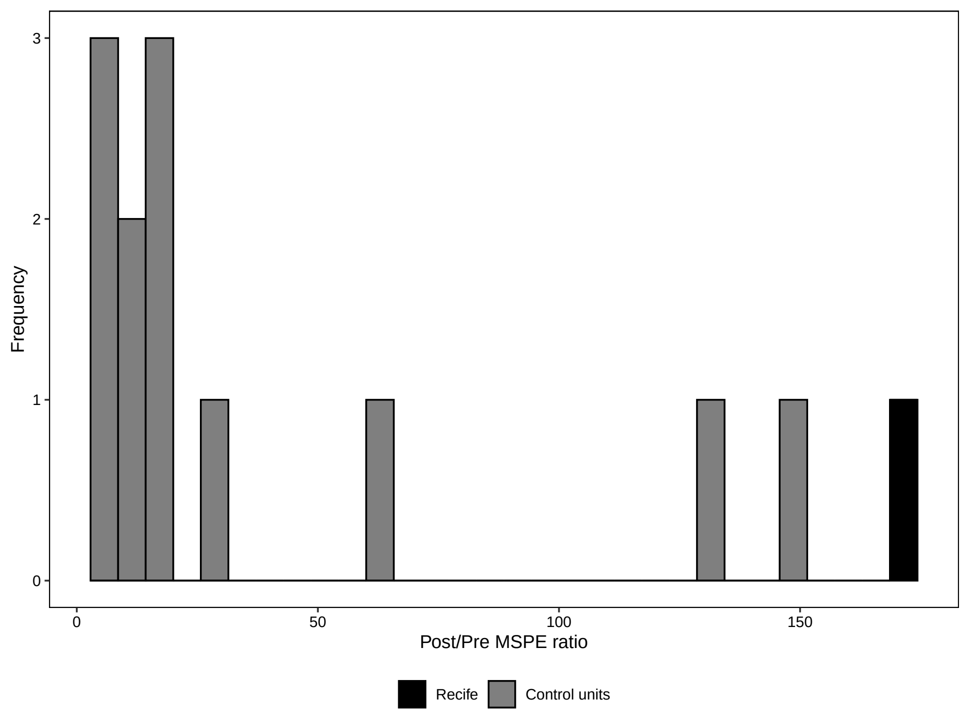


Figure 29 – Ratio of post-hub and pre-hub MSPE for tour guides: Recife and 12 control units



6.3.6 Employment Federative Unit

Analyzing at the federative unit level, important differences were found regarding the significance of the airport hub's effect on the percentage of employees in the Travel sector. Although the effect remained positive, the result was not statistically significant as observed in Figures 30 and 31, with a p-value associated with the placebo test of 0.154. The same applies to the total number of employees in this sector. On the other hand, the effect of the airport hub on the number of registered tour guides was positive and significant, with a p-value of 0.077, as seen in Figures 32 and 33. Tables 14 and 15, which present characteristics related to the tour guides' results for the state, are available in Appendix C.

Figure 30 – Proportion of formal employees in the Travel sector: Pernambuco vs. Synthetic Pernambuco

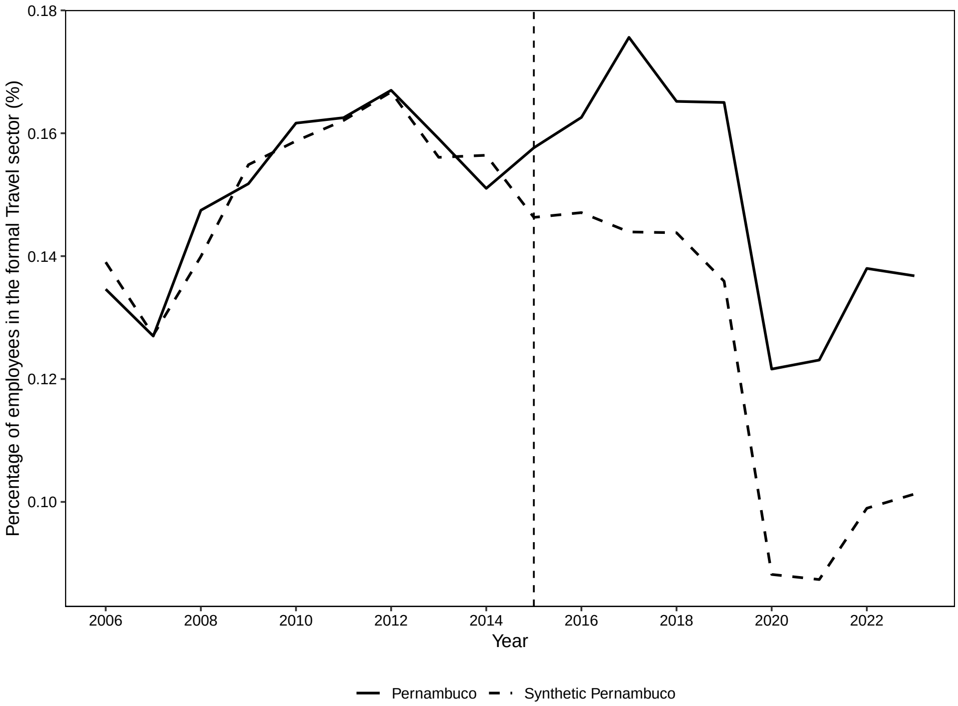


Figure 31 – Ratio of post-hub and pre-hub MSPE for the proportion of employees in the Travel sector: Pernambuco and 12 control units

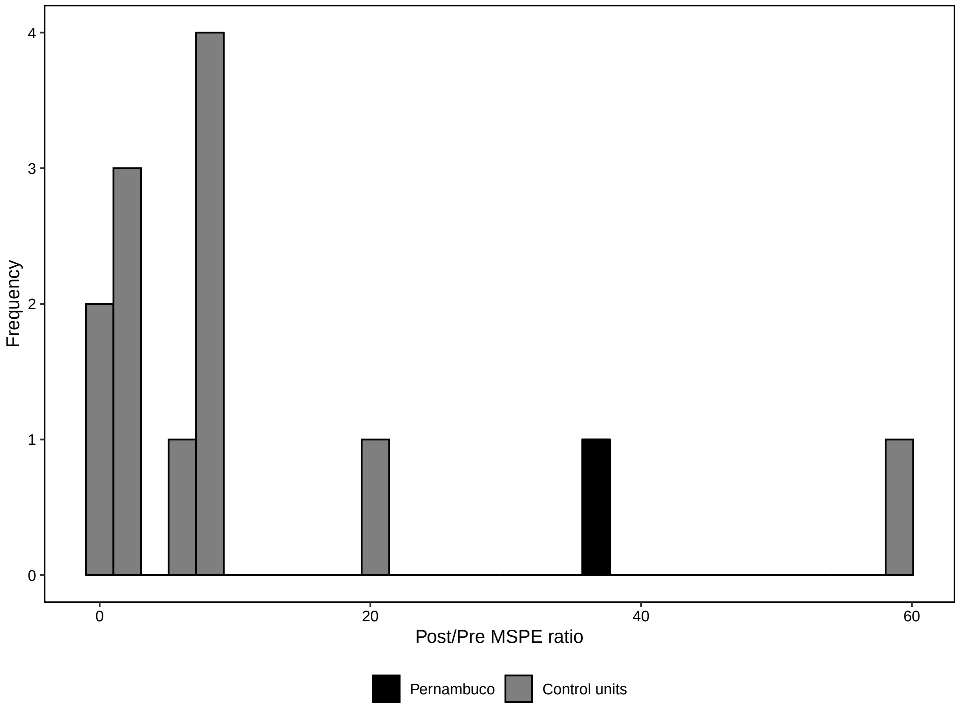


Figure 32 – Number of tour guides: Pernambuco vs. Synthetic Pernambuco

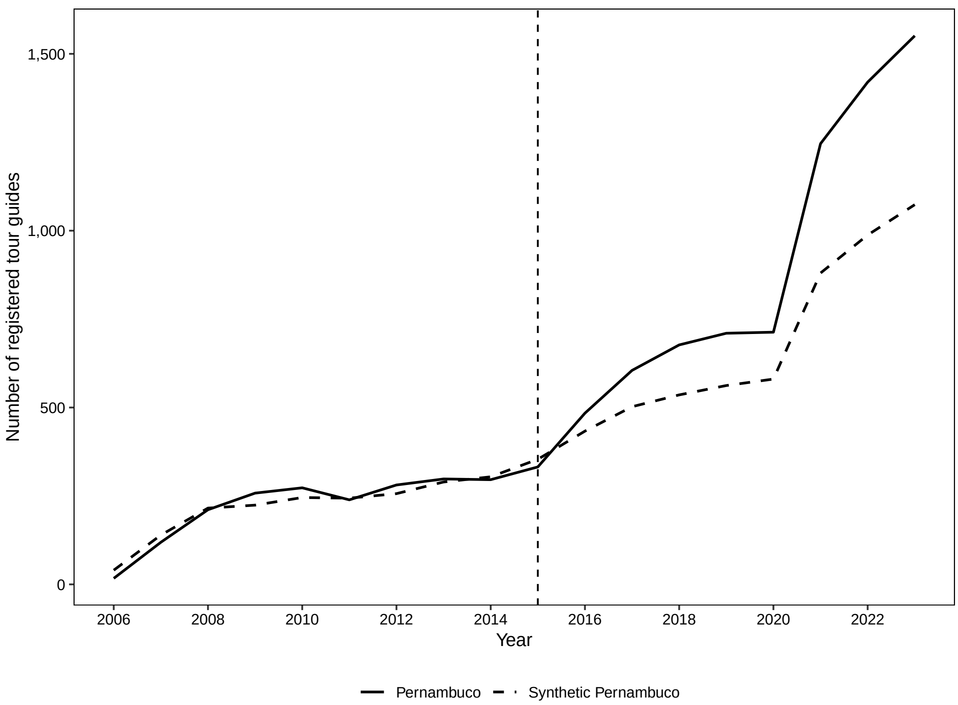
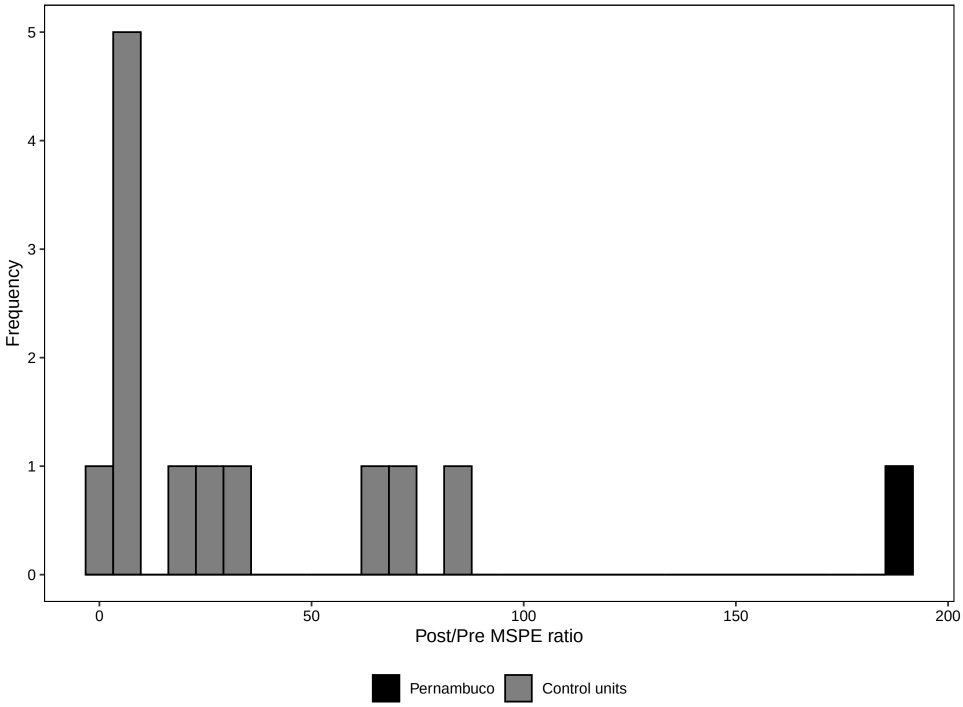


Figure 33 – Ratio of post-hub and pre-hub MSPE for tour guides: Pernambuco and 12 control units



7 ROBUSTNESS TESTS

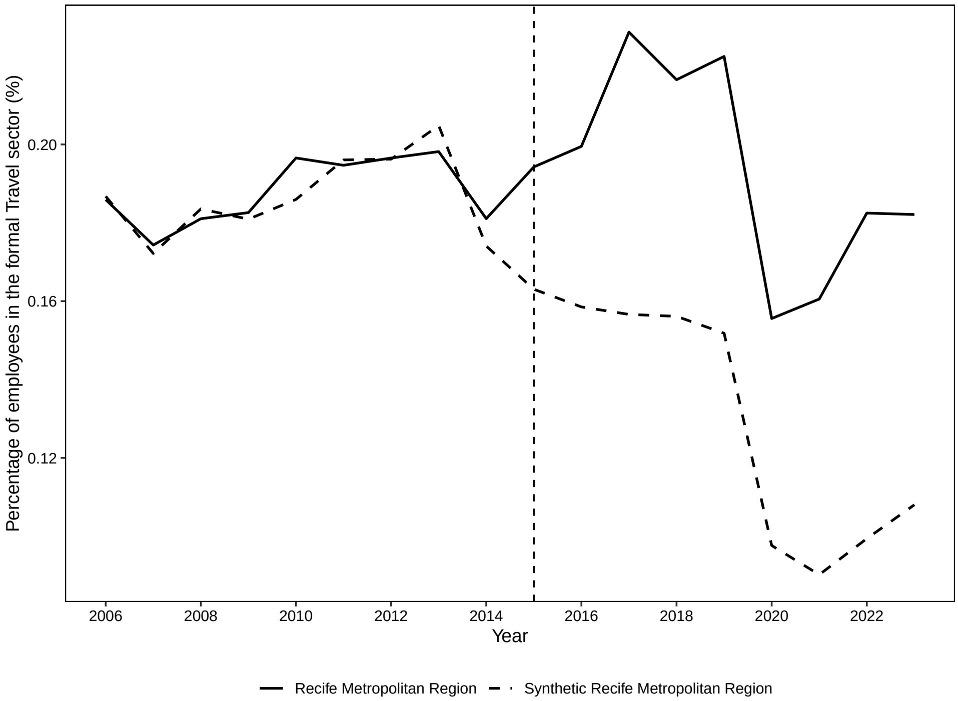
As explained by Abadie (2021), certain diagnostic checks can be used to assess the credibility of synthetic control counterfactuals, as well as robustness exercises to evaluate the sensitivity of results to changes in study design. Therefore, in this section, additional tests are conducted to demonstrate that the significant results found through the main specification are not sensitive to some of the choices made in its design, ensuring the credibility of synthetic controls. Two examples will be presented to illustrate the backdating and leave-one-out exercises. The main robustness analyses, nevertheless, will be based on the estimation of the synthetic control with bias correction.

7.1 BACKDATING

The first exercise proposed by Abadie (2021) is backdating. According to the author, this is a way to address anticipation effects on the outcome variable before an intervention occurs. In the absence of anticipation effects, this test can be applied to evaluate the credibility of a synthetic control.

Figure 34 shows the estimated effect of the airline hub implementation in 2016, backdated to 2010, on the percentage of employees in the formal Travel sector. Some variables used in the main specification for pre-intervention adjustment could not be used here because they begin in 2012, after the placebo year of hub implementation; yet the good fit remained. It is observed that the synthetic control estimator follows the main variable in the period after the placebo intervention and before the start of the actual intervention, as desired.

Figure 34 – Backdating the 2016 hub implementation specification to 2010



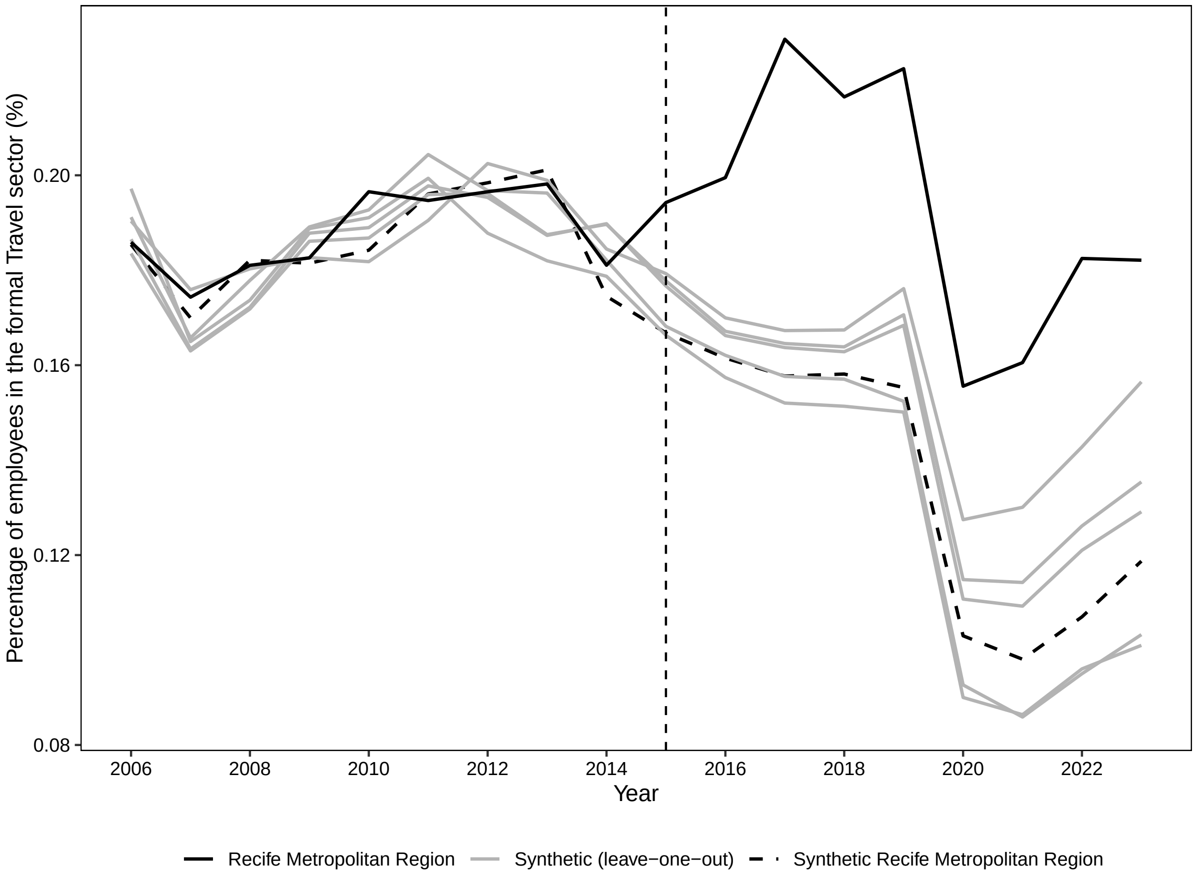
Moreover, as explained by Abadie (2021), the absence of estimated effects before the intervention, with the test behaving similarly to the main specification, strengthens the credibility of the synthetic control estimator, as it demonstrates that the synthetic control can reproduce the trajectory of the outcome variable for the treated unit before the intervention occurs. The results for the real and synthetic metropolitan region begin to diverge around the time of the actual intervention, even when the implementation is backdated and the procedure does not use any information about the real intervention timing. Thus, the credibility of the synthetic control estimator is reinforced.

7.2 LEAVE-ONE-OUT

The second robustness exercise described by Abadie (2021) proposes the removal of each unit contributing to the main synthetic control one at a time, to verify the validity of the results obtained in the main specification. This method is called leave-one-out.

Figure 35 presents the results of this analysis. It can be observed that all leave-one-out estimates follow the series obtained with the main synthetic control for the percentage of employees in the Travel sector. After the implementation of the airline hub, all resulting estimates remain below the actual result for the metropolitan region and revolve around the result obtained through the main synthetic control. Thus, the conclusion that the implementation of the airline hub had a positive impact on the proportion of employees in the Travel sector is robust to the exclusion of any specific control unit.

Figure 35 – Leave-one-out estimates of the effect of the 2016 hub implementation

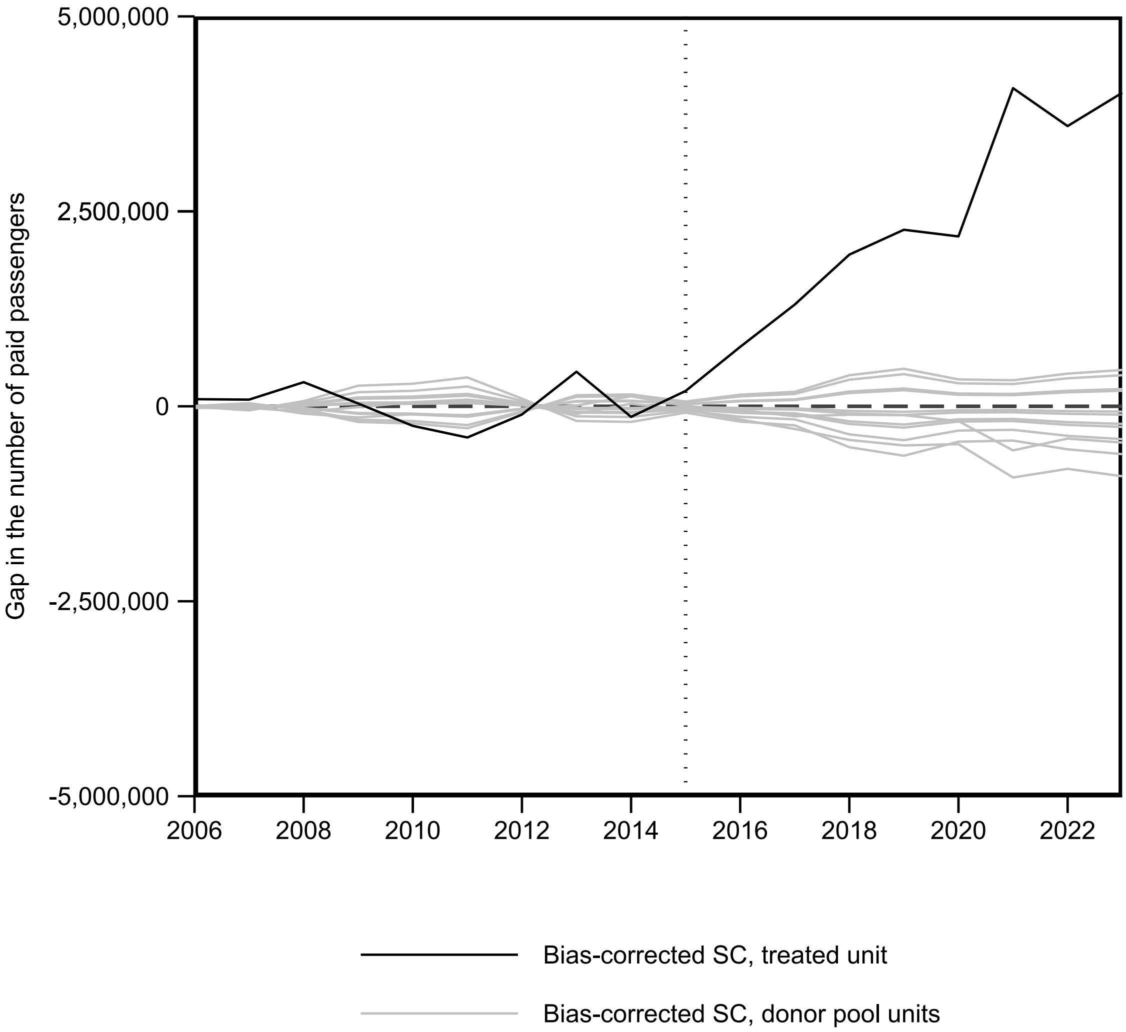


7.3 BIAS CORRECTION

The final proposed exercise is the robustness analysis through the estimation of synthetic control with bias correction. The goal is to assess whether the result remains significant after removing potential biases.

Starting with the number of paid passengers, it is observed that the result no longer reaches statistical significance, although the estimated effect remains positive. The data can be seen in Figure 36 and Table 16 in Appendix D. Its p-value changed from 0.077 to 0.154 in all post-treatment years.

Figure 36 – Bias-corrected gaps in Recife Metropolitan Region and control units: Number of paid passengers



Now considering the proportion of employees in the Travel sector, it is possible to observe in Figure 37 and Table 17 that, after bias correction, the results do not hold. When the bias is eliminated, the effect of the hub on the percentage of formal employees in the Travel sector is no longer significant. The same occurs with the number of employees in this sector, as shown in Figure 38. The lowest p-value for this variable after correction was also 0.923.

Figure 37 – Bias-corrected gaps in Recife Metropolitan Region and control units: Proportion of employees in the formal Travel sector (%)

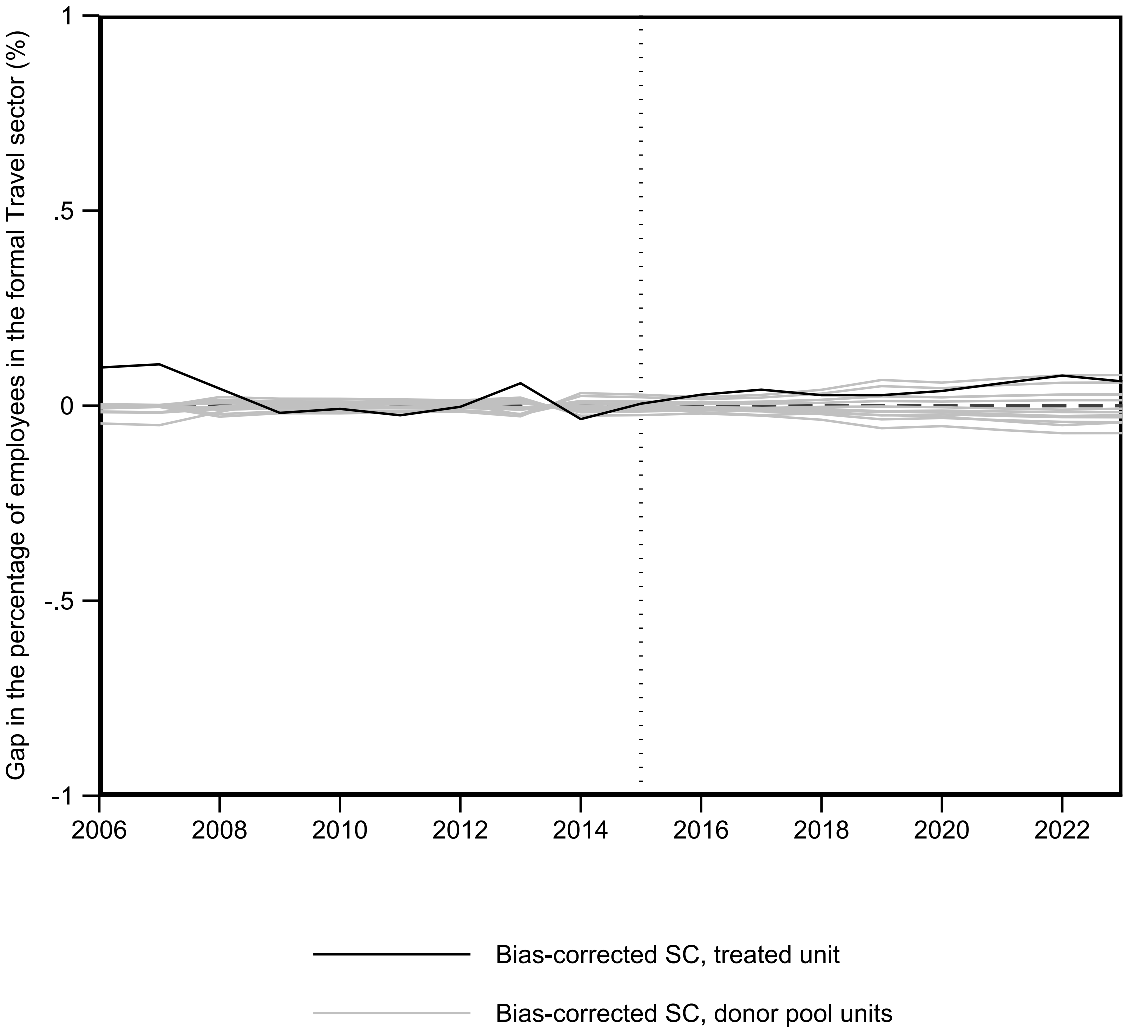
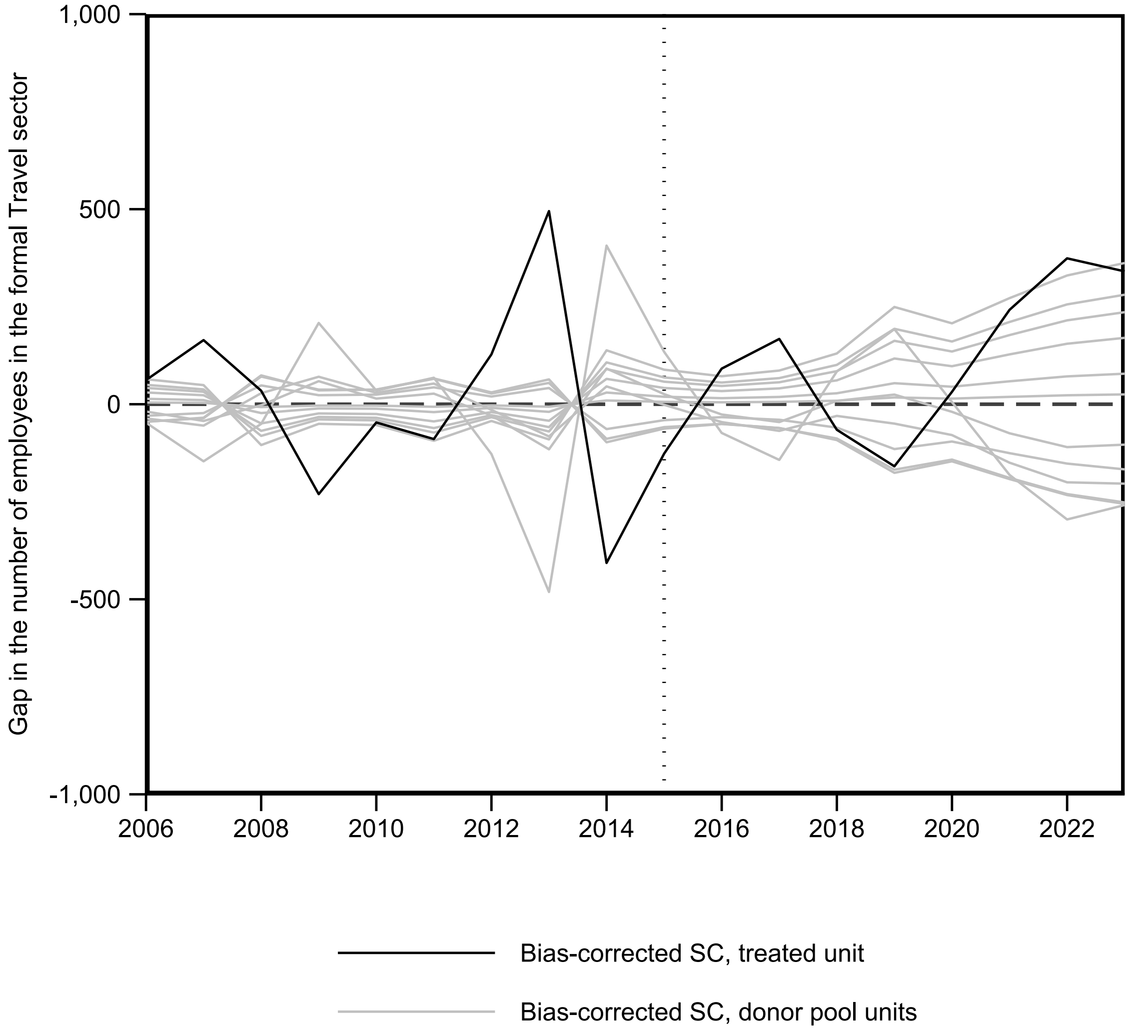
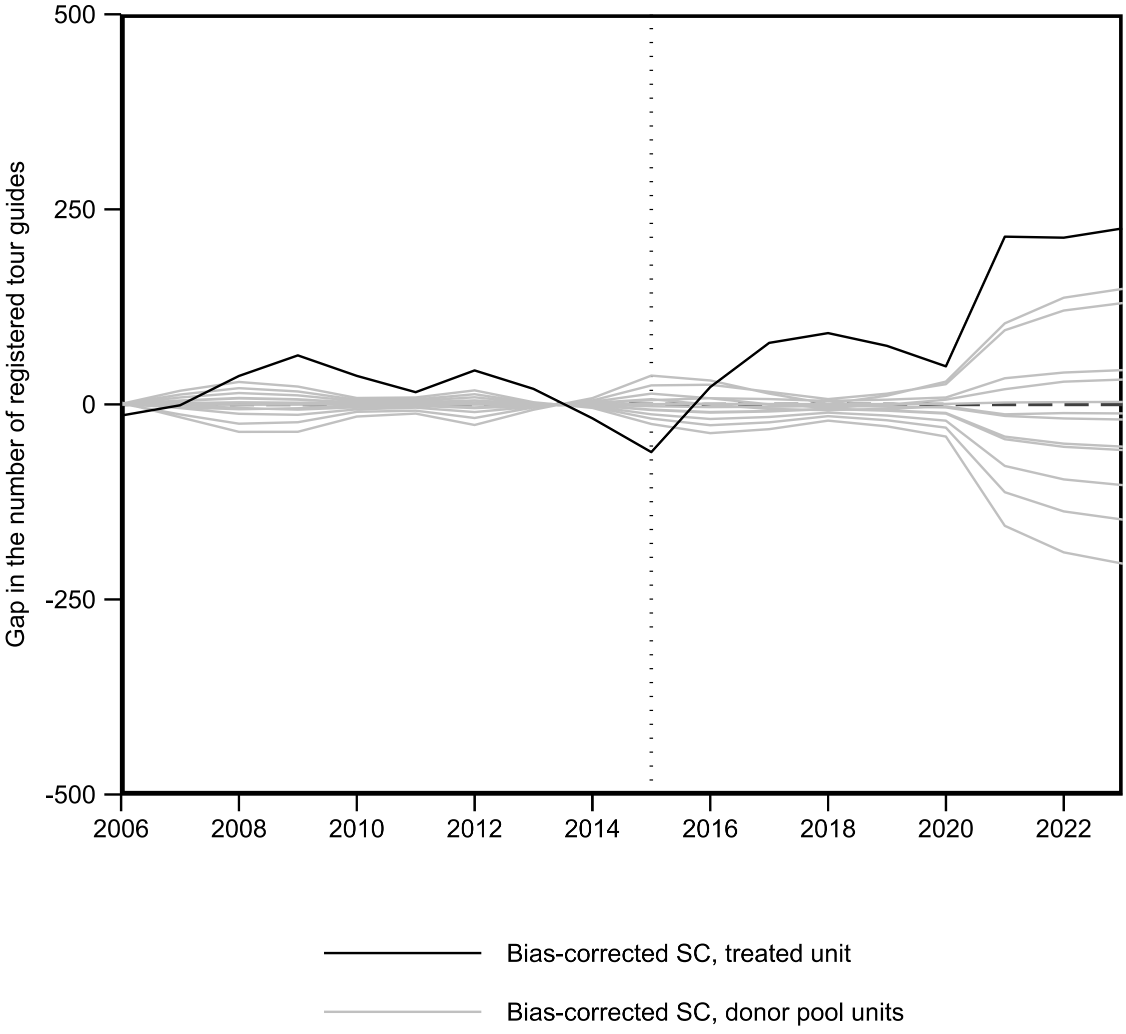


Figure 38 – Bias-corrected gaps in Recife Metropolitan Region and control units: Number of employees in the formal Travel sector



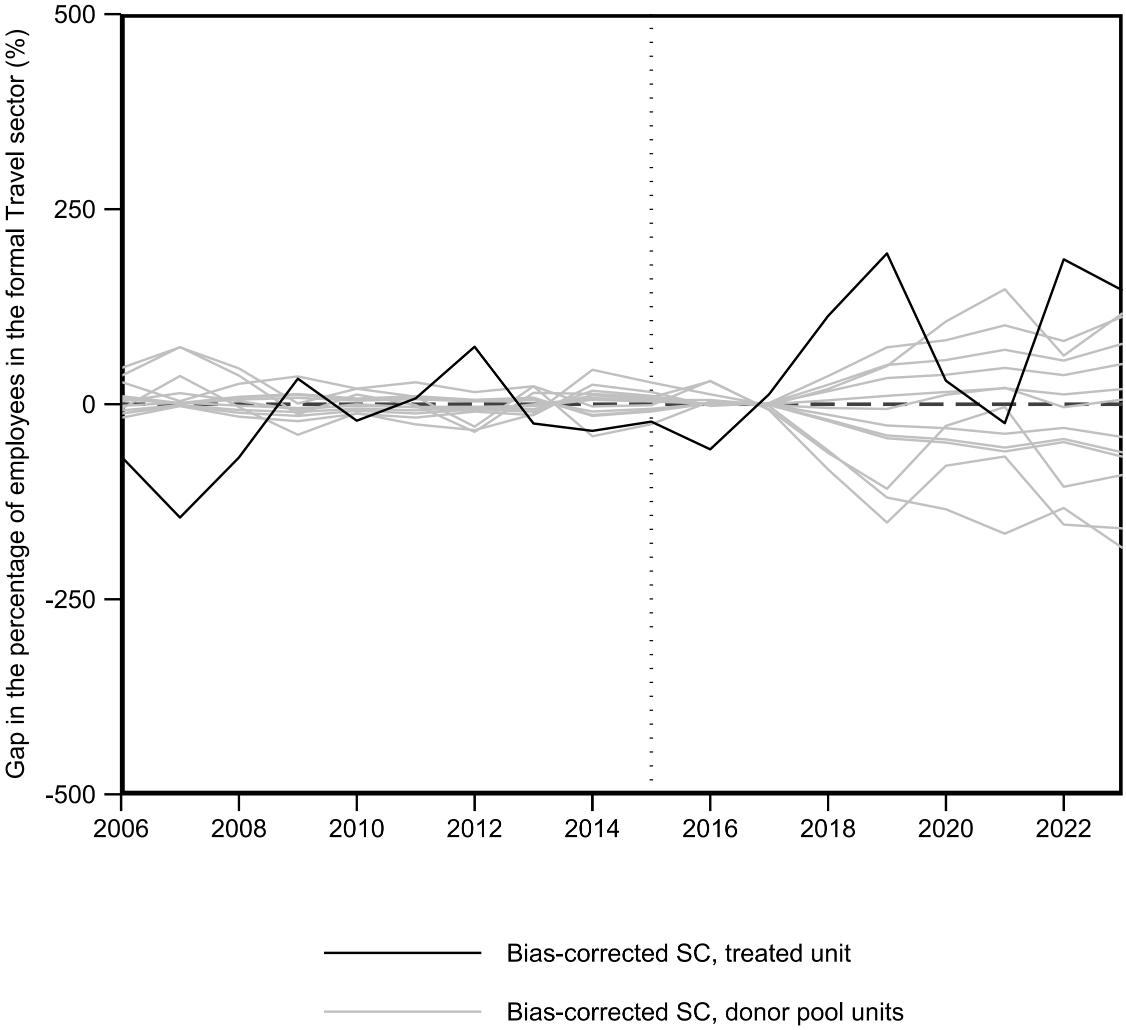
Analyzing the number of registered tour guides, a different result is observed. With bias correction, the hub effect on the number of guides was significant for certain years, specifically 2018 and 2019. The results can be verified in Figure 39 and Table 18 in Appendix D.

Figure 39 – Bias-corrected gaps in Recife Metropolitan Region and control units: Number of registered tour guides



Considering the result on real income in the formal Accommodation sector, no statistically significant effects were observed in any of the years analyzed, with the lowest p-value being 0.154 in 2016 and 2017. Results can be verified in Figure 40 and Table 19 in Appendix D.

Figure 40 – Bias-corrected gaps in Recife Metropolitan Region and control units: Real income in the formal Accommodation sector



In addition to the results at the metropolitan region level, results at the capital city level were also analyzed. Here, important differences were found. For the municipality of Recife, the increase in the percentage of employees in the formal Travel sector and in the number of registered tour guides, given the implementation of the airline hub, proved to be considerably significant in all years after the intervention, with a p-value of 0.077. Results related to the percentage of employees in the Travel sector can be verified in Figure 41 and Table 20. Meanwhile, the results for the number of tour guides are shown in Figure 42 and Table 21.

Figure 41 – Bias-corrected gaps in Recife and control units: Proportion of employees in the formal Travel sector (%)

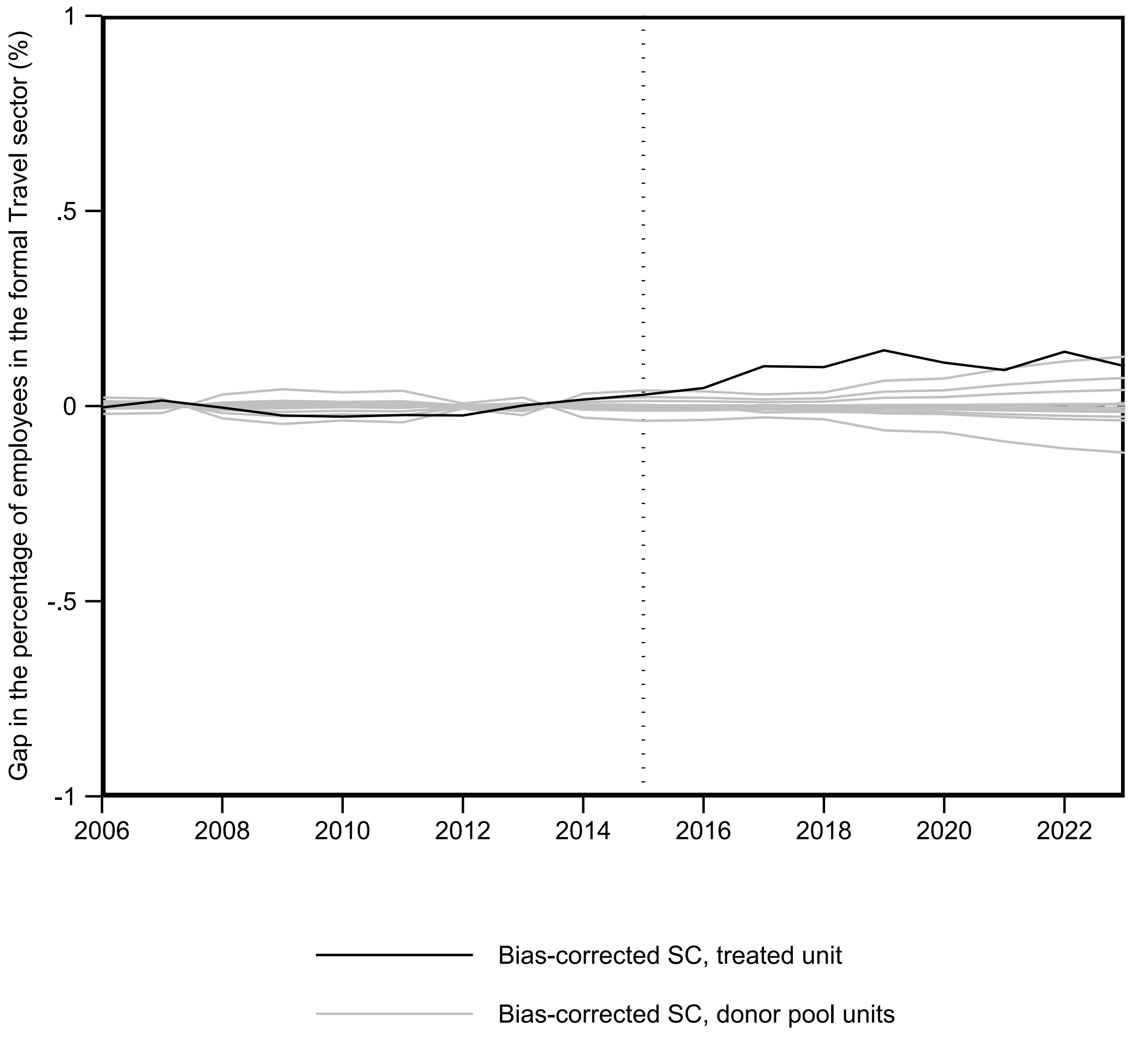
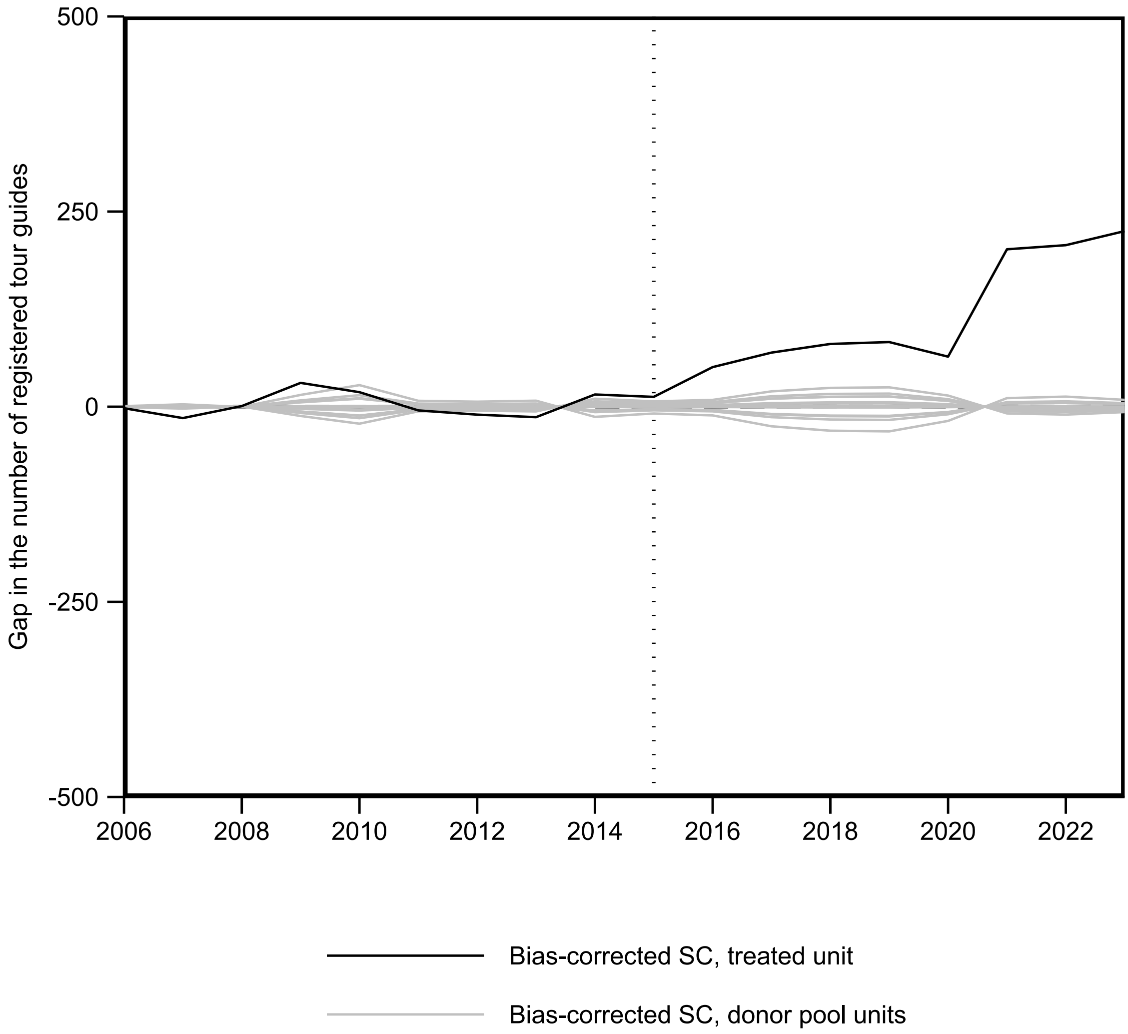
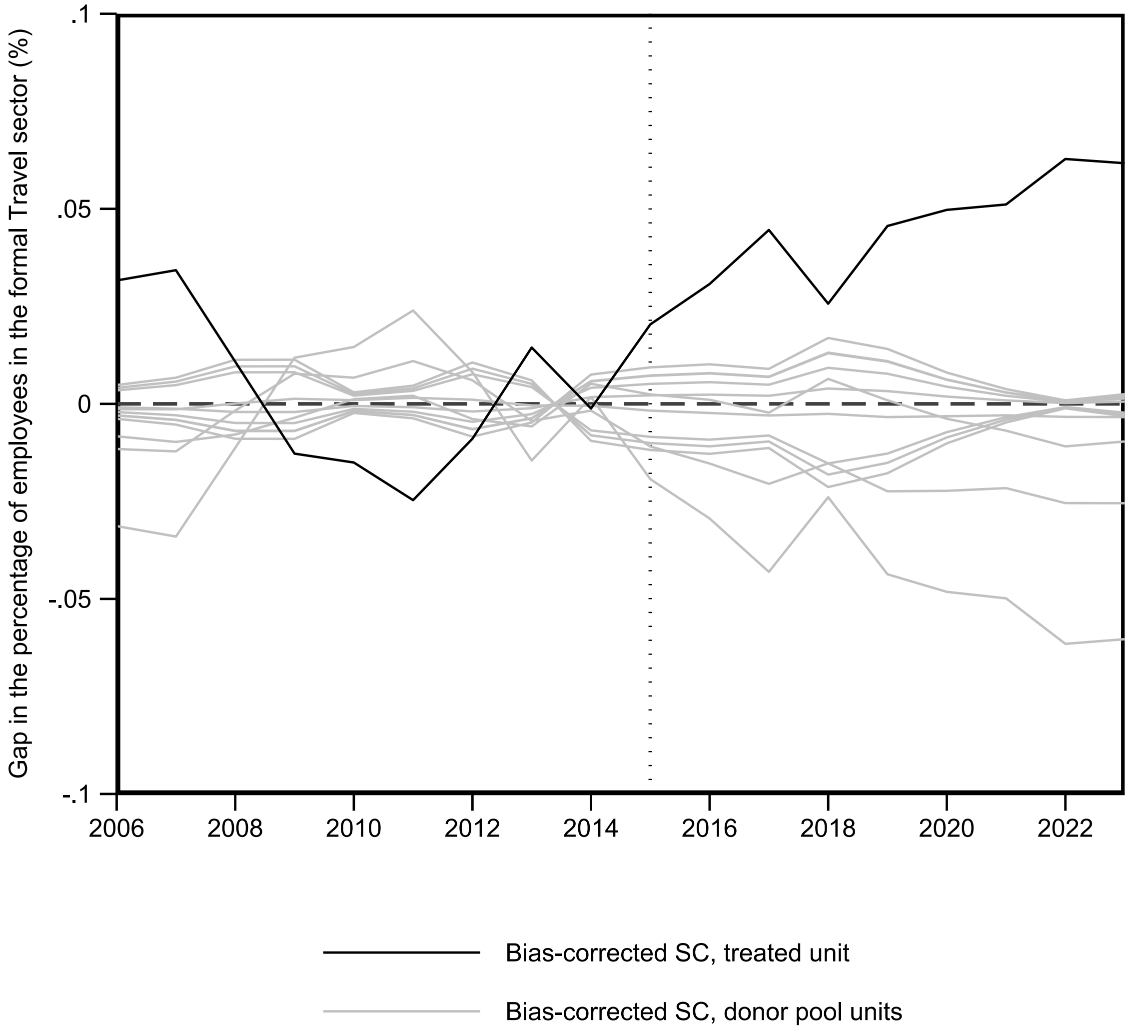


Figure 42 – Bias-corrected gaps in Recife and control units: Number of registered tour guides



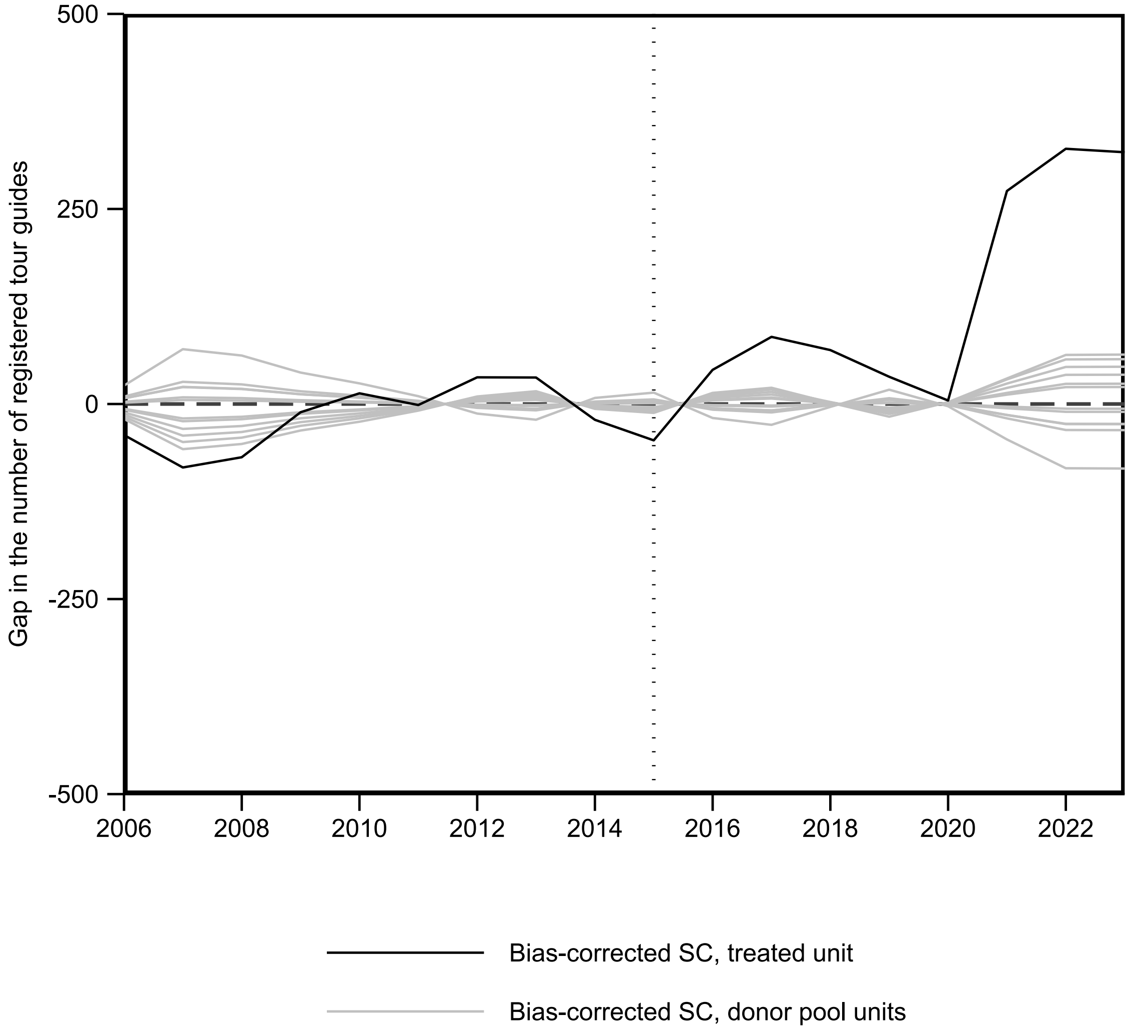
Regarding the federative unit, the increase in the percentage of employees in the formal Travel sector lost even more significance after bias correction, reaching a minimum p-value of 0.231. More information can be found in Table 22 and Figure 43.

Figure 43 – Bias-corrected gaps in Pernambuco and control units: Proportion of employees in the formal Travel sector (%)



On the other hand, when analyzing the number of registered tour guides, the results remain significant, with a p-value of 0.077. The results for this variable are shown in Figure 44 and Table 23 in Appendix D.

Figure 44 – Bias-corrected gaps in Pernambuco and control units: Number of registered tour guides



8 CONCLUSION

This study aimed to assess the economic impacts of implementing airline hubs in specific regions, focusing on the case of Azul Linhas Aéreas' hub, established in the city of Recife in 2016. The analysis considered both general and sectoral effects on employment and income.

This company's base of operations enabled greater connectivity among cities in Brazil's Northeast by increasing the number of flights. Despite the evident expansion in the supply of this service, there has been no prior evaluation of the economic impact of this regional hub in the literature. Based on the available information, this study appears to be the first to analyze the economic effects of airport hubs in a developing country such as Brazil.

Using the synthetic control method, significant results were found regarding employment in the tourism sector, specifically in the Travel Agencies and Tour Operators sector at both the metropolitan region and the capital city levels, as well as in the number of registered tour guides in both the capital and the federative unit. However, after bias-correction estimators were applied, the results proved to be especially significant at the capital city level. That is, the increases in the share of formal employees in the Travel sector and in the number of registered tour guides were both positive and significant in Recife, where the hub was implemented.

These findings align with the theories proposed by Rodrigue (2024) and Appold and Kasarda (2013), who argue that the economic impact of air transport is most strongly pronounced near airport hubs, influencing entire sectors within a given region. Although no significant effects on income and employment in other sectors were found after bias correction, the observed impact on the tourism and Travel sector is particularly relevant for the local economy, as it boosts formal employment within this segment of the service sector.

Several reasons may explain these results. First, it is important to recognize that this is a regional hub, with limited scale and impact compared to larger connection centers. Moreover, the concentration of effects in the capital city likely stems from its geographic centrality around the airport, making the impact more pronounced in this area. Additionally, demand for tourism services tends to be higher in the capital, where most tourists choose to stay. Regarding sector-specific effects, one hypothesis is that, despite the increase in passenger numbers in Recife, the Accommodation and Food Service sectors already had sufficient capacity and infrastructure to meet additional demand without requiring new hires. This dynamic differed in the Travel Agencies and Tour Operators sector, which needed to fill new job openings to accommodate the increased demand for these services.

In conclusion, although the hub's implementation did not generate significant effects on the economy as a whole, it had positive and meaningful impacts on local tourism, particularly within the formal Travel Agencies, Tour Operators, and Booking Services sector, as well as on the number of registered tour guides in the city. Given the characteristics of the Recife airport hub, the results suggest that interventions of this nature can serve as important instruments for job creation in urban areas of the country.

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APPENDIX A – AIRLINE DATA BY YEAR

Table 11 – Airline market share by year

Year	Main Companies (%)	Others (%)
2006	62.06	37.94
2007	64.97	35.03
2008	65.83	34.17
2009	69.59	30.41
2010	68.82	31.18
2011	67.65	32.35
2012	67.65	32.35
2013	73.89	26.11
2014	83.84	16.16
2015	82.93	17.07
2016	82.06	17.94
2017	81.58	18.42
2018	80.63	19.37
2019	88.13	11.87
2020	87.46	12.54
2021	88.93	11.07
2022	89.10	10.90
2023	88.90	11.10

APPENDIX B – PREDICTORS AND WEIGHTS IN RECIFE

Table 12 – Predictors of tour guides in Recife

	Treated	Synthetic	Sample Mean
Formal Employees CLT (%)	74.02	69.91	69.81
High School Completed (%)	43.17	43.09	43.31
Bachelor's Degree Completed (%)	20.55	23.73	23.13
Total Number of Flights	56,537	49,005	36,478
Total Number of Guides	180	180	144
Brown-Skinned Workers (%)	52	34	46
Black-Skinned Workers (%)	06	08	09
Real Monthly Salary (R$)	3,997.90	3,953.37	3,571.59
Unemployment Rate (%)	08	08	08
Population Aged 25 to 54 (%)	45	45	46

Table 13 – Municipality weights in the Synthetic Recife: total of tour guides

Weight	Municipality
0.00	Belém (PA)
0.16	São Luís (MA)
0.18	Teresina (PI)
0.00	Fortaleza (CE)
0.01	Natal (RN)
0.00	Aracaju (SE)
0.00	Salvador (BA)
0.39	Vitória (ES)
0.00	Curitiba (PR)
0.19	Florianópolis (SC)
0.00	Porto Alegre (RS)
0.07	Goiânia (GO)

APPENDIX C – PREDICTORS AND WEIGHTS IN PERNAMBUCO

Table 14 – Predictors of tour guides in Pernambuco

	Treated	Synthetic	Sample Mean
Formal Employees CLT (%)	74.67	74.51	73.61
High School Completed (%)	42.58	42.62	43.05
Bachelor's Degree Completed (%)	16.33	15.32	15.81
Total Number of Flights	62,865	52,216	47,313
Total Number of Guides	289	289	314
Brown-Skinned Workers (%)	62	56	52
Black-Skinned Workers (%)	05	07	07
Real Monthly Salary (R$)	2,410.18	2,404.66	2,374.13
Unemployment Rate (%)	09	07	07
Population Aged 25 to 54 (%)	42	42	43

Table 15 – State weights in the Synthetic Pernambuco: total of tour guides

Weight	State
0.00	Pará
0.20	Maranhão
0.32	Piauí
0.00	Ceará
0.00	Rio Grande do Norte
0.31	Sergipe
0.03	Bahia
0.00	Espírito Santo
0.00	Paraná
0.11	Santa Catarina
0.00	Rio Grande do Sul
0.01	Goiás

APPENDIX D – BIAS-CORRECTED P-VALUES

Table 16 – Classic and bias-corrected gaps and p-values by year between Recife Metropolitan Region and its synthetic version: Number of paid passengers

Year	Gap	Gap Bias-Corrected	P-value	P-value Bias-Corrected
2006	199608.2	91751.85	.	.
2007	89351.99	85590.91	.	.
2008	320366	309441.3	.	.
2009	252753.7	35951.14	.	.
2010	190244.4	-250781.5	.	.
2011	-134048.3	-399848	.	.
2012	-138731.5	-105490.5	.	.
2013	216778.2	443509.8	.	.
2014	17567.27	-135028.4	.	.
2015	118934.1	196858	.	.
2016	709559.5	762443.6	.0769231	.1538462
2017	1401712	1304801	.0769231	.1538462
2018	1834776	1945039	.0769231	.1538462
2019	2109844	2263976	.0769231	.1538462
2020	1818295	2178646	.0769231	.1538462
2021	3364003	4079834	.0769231	.1538462
2022	3127914	3593796	.0769231	.1538462
2023	3047945	4020056	.0769231	.1538462

Table 17 – Classic and bias-corrected gaps and p-values by year between Recife Metropolitan Region and its synthetic version: Percentage of employees in the formal Travel sector (%)

Year	Gap	Gap Bias-Corrected	P-value	P-value Bias-Corrected
2006	0.0524081	0.0975513	.	.
2007	0.0467212	0.1058341	.	.
2008	0.0142763	0.0436014	.	.
2009	-0.0072655	-0.0186233	.	.
2010	0.0050758	-0.0082727	.	.
2011	-0.0163574	-0.0247708	.	.
2012	-0.0016448	-0.0030391	.	.
2013	0.0242216	0.0574426	.	.
2014	-0.0039361	-0.0345656	.	.
2015	0.0231216	0.0049329	.	.
2016	0.0437296	0.0280122	0.1538462	0.9230769
2017	0.0777684	0.0409125	0.0769231	0.9230769
2018	0.0651761	0.0268122	0.0769231	0.9230769
2019	0.0684374	0.0268019	0.1538462	0.9230769
2020	0.0576183	0.0374852	0.1538462	0.9230769
2021	0.0690647	0.0575929	0.1538462	0.9230769
2022	0.0876388	0.0768831	0.1538462	0.9230769
2023	0.0802827	0.0621822	0.1538462	0.9230769

Table 18 – Classic and bias-corrected gaps and p-values by year between Recife Metropolitan Region and its synthetic version: Number of registered tour guides

Year	Gap	Gap Bias-Corrected	P-value	P-value Bias-Corrected
2006	-20.575	-14.34396	.	.
2007	-3.478	-1.145558	.	.
2008	21.108	36.43071	.	.
2009	48.731	62.82161	.	.
2010	42.562	36.59036	.	.
2011	24.966	15.63401	.	.
2012	50.71	43.56142	.	.
2013	19.92	19.86572	.	.
2014	-12.036	-17.88687	.	.
2015	-55.977	-61.17426	.	.
2016	7.346	22.19288	.9230769	.9230769
2017	61.909	78.85281	.6153846	.6923077
2018	94.245	91.37046	1.4615385	.0769231
2019	94.79	75.00879	.5384616	.0769231
2020	83.39	48.75571	.5384616	.6923077
2021	238.334	215.006	.2307692	.6923077
2022	263.639	213.6664	.1538462	.7692308
2023	301.578	225.6185	.1538462	.7692308

Table 19 – Classic and bias-corrected gaps and p-values by year between Recife Metropolitan Region and its synthetic version: Real income in the formal Accommodation sector

Year	Gap	Gap Bias-Corrected	P-value	P-value Bias-Corrected
2006	-17.69409	-66.85635	.	.
2007	-72.00367	-145.2325	.	.
2008	-41.69557	-68.28334	.	.
2009	0.553605	32.72686	.	.
2010	26.00786	-21.11286	.	.
2011	-11.87739	7.463151	.	.
2012	-11.97404	73.65754	.	.
2013	40.12143	-24.6777	.	.
2014	3.410383	-34.12759	.	.
2015	-21.43794	-22.31553	.	.
2016	-0.3927739	-57.8031	1	0.1538462
2017	11.19572	12.89396	0.9230769	0.1538462
2018	25.39014	113.0833	0.8461539	0.7692308
2019	-100.5465	193.2746	0.5384616	0.7692308
2020	13.79396	30.14174	0.6153846	0.9230769
2021	-5.564514	-24.28938	0.6153846	1
2022	18.55434	185.7182	0.9230769	0.9230769
2023	100.3697	145.844	0.6153846	0.9230769

Table 20 – Classic and bias-corrected gaps and p-values by year between Recife and its synthetic version: Percentage of employees in the formal Travel sector (%)

Year	Gap	Gap Bias-Corrected	P-value	P-value Bias-Corrected
2006	0.0203727	-0.0035566	.	.
2007	0.0104387	0.014254	.	.
2008	-0.0199514	-0.0040868	.	.
2009	-0.0339374	-0.0241998	.	.
2010	-0.0097421	-0.0271087	.	.
2011	-0.0222573	-0.0230179	.	.
2012	-0.0078671	-0.0240505	.	.
2013	0.00268	0.001564	.	.
2014	0.0069637	0.0165603	.	.
2015	0.0321089	0.0289442	.	.
2016	0.0524173	0.0461424	0.0769231	0.0769231
2017	0.0879498	0.1020281	0.0769231	0.0769231
2018	0.0719256	0.0997531	0.0769231	0.0769231
2019	0.0804832	0.1429131	0.0769231	0.0769231
2020	0.0595873	0.1112063	0.0769231	0.0769231
2021	0.0634912	0.0923558	0.0769231	0.0769231
2022	0.111502	0.1392481	0.0769231	0.0769231
2023	0.0945983	0.1021798	0.0769231	0.0769231

Table 21 – Classic and bias-corrected gaps and p-values by year between Recife and its synthetic version: Number of registered tour guides

Year	Gap	Gap Bias-Corrected	P-value	P-value Bias-Corrected
2006	-10.849	-1.913102	.	.
2007	-18.915	-14.55887	.	.
2008	-1.424	0.8008215	.	.
2009	25.579	30.49819	.	.
2010	20.808	18.5864	.	.
2011	7.689	-4.723412	.	.
2012	7.683	-10.15526	.	.
2013	-2.405	-13.38773	.	.
2014	-1.716	15.64966	.	.
2015	-19.555	12.61674	.	.
2016	13.532	50.71028	0.4615385	0.0769231
2017	22.332	69.31232	0.5384616	0.0769231
2018	28.882	80.40397	0.4615385	0.0769231
2019	26.551	82.83703	0.6923077	0.0769231
2020	21.198	64.14569	0.8461539	0.0769231
2021	147.475	201.6844	0.1538462	0.0769231
2022	146.278	206.9735	0.1538462	0.0769231
2023	150.122	224.9722	0.1538462	0.0769231

Table 22 – Classic and bias-corrected gaps and p-values by year between Pernambuco and its synthetic version: Percentage of employees in the formal Travel sector (%)

Year	Gap	Gap Bias-Corrected	P-value	P-value Bias-Corrected
2006	0.0038184	0.0316402	.	.
2007	0.0054969	0.034273	.	.
2008	0.0079942	0.0108216	.	.
2009	-0.0037749	-0.0127529	.	.
2010	0.0012366	-0.015036	.	.
2011	-0.0022339	-0.024683	.	.
2012	0.0012013	-0.0089429	.	.
2013	0.0077809	0.0144388	.	.
2014	-0.0027345	-0.0011818	.	.
2015	0.0149982	0.0203689	.	.
2016	0.0220833	0.030722	0.0769231	0.2307692
2017	0.039795	0.0445853	0.0769231	0.2307692
2018	0.0274731	0.0256775	0.0769231	0.8461539
2019	0.0346622	0.0456001	0.0769231	0.8461539
2020	0.0348675	0.0497322	0.0769231	0.2307692
2021	0.0356312	0.0511104	0.0769231	0.2307692
2022	0.0391416	0.0627725	0.0769231	0.2307692
2023	0.0375925	0.0616874	0.0769231	0.2307692

Table 23 – Classic and bias-corrected gaps and p-values by year between Pernambuco and its synthetic version: Number of registered tour guides

Year	Gap	Gap Bias-Corrected	P-value	P-value Bias-Corrected
2006	-45.0000	-39.7347	.	.
2007	-70.2480	-81.3575	.	.
2008	-43.5250	-68.2219	.	.
2009	-4.5100	-10.5699	.	.
2010	-4.1940	13.7275	.	.
2011	-13.8800	-1.3130	.	.
2012	43.2370	34.1785	.	.
2013	29.8560	33.9538	.	.
2014	-14.9980	-20.2333	.	.
2015	-50.2650	-46.5861	.	.
2016	42.2450	43.8012	0.5385	0.0769
2017	102.7150	86.0739	0.3077	0.0769
2018	116.4660	69.0924	0.3846	0.0769
2019	100.0310	34.9050	0.3846	0.0769
2020	94.3750	4.5063	0.3077	0.0769
2021	317.3790	273.0747	0.1538	0.0769
2022	397.7210	327.1679	0.1538	0.0769
2023	435.1570	322.6801	0.1538	0.0769