The roads for land development: Assessing the effects of the Linha Verde Consortium on the spatial distribution of employment in Curitiba, Brazil[1]

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Abstract

In the year 2006, Curitiba launched the Linha Verde Urban Consortium, an urban intervention based on mixed land use rules that aim to promote linear urban development in the North-South axis. This policy defined a specific zoning area combined with infrastructure investments in a new bus rapid transit network to increase population density across the North-South axis. This paper aims to evaluate the local impact of this land development policy on the spatial distribution of employment in the short and long run. We used a granulated dataset with detailed spatial resolution, and econometric techniques with a quasi-experimental design to evaluate the impacts of transport infrastructure improvements and zoning rule changes on the spatial distribution of jobs for different economic sectors. The results show a positive impact on the overall employment of activities in the area benefited by transport infrastructure investments. Additionally, relevant differences were observed in the dynamic employment of the commerce sector, with a higher impact in the long-run.

Keywords: Impact Evaluation, Urban Transport Infrastructure, Spatial Distribution of Urban Employment.

Resumo

No ano de 2006, Curitiba lançou o Consórcio Urbano Linha Verde, uma intervenção urbana baseada em regras de uso misto do solo que visam promover desenvolvimento urbano de forma linear no eixo Norte-Sul. Esta política define uma área de zoneamento específica, e combinada com investimentos em uma rede de infraestrutura de transporte BRT, busca aumentar a densidade populacional ao longo do eixo Norte-Sul. O presente estudo tem o objetivo de avaliar os impactos dessa política de desenvolvimento de solo na distribuição espacial do emprego no curto e no longo prazo. Foi utilizada uma base de dados granulada em alta resolução espacial e métodos econométricos em um desenho quase-experimental, para avaliar os impactos das melhorias de infraestrutura de transporte e das mudanças de zoneamento na distribuição espacial dos empregos para diferentes setores econômicos. Os resultados mostram impactos positivos nos empregos totais das atividades localizadas na área beneficiada pelos investimentos de infraestrutura de transporte. Além disso, foram observadas diferenças relevantes na dinâmica dos empregos do setor do comércio, sendo maiores no longo prazo.

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JEL Classification: R14, J18, C21

1 Introduction

The transport system is determinant for the location of economic activities in urban areas through its potential strength to shape local demands and supplies for intraurban travel. Many cities have made their urban consolidation based on *Transit Oriented Development* (*TOD*) policies, with the aim to promote sustainable paths of land use development (Mulley and Nelson, 2021). In Brazil, the city of Curitiba has been using *TOD* policies since the 70s, through the implementation of its Bus Rapid Transit (BRT) system in structural axes that guided a linear urban expansion process (IPPUC, 2019). This urban consolidation pattern relates to the urban form of Curitiba, which combines higher population density over the structural axes and mixed land use rules, following a spatial hierarchy based on the road infrastructure.

In the year of 2006, Curitiba launched the *Linha Verde Urban Consortium* (*LVUC*), which is its most recent policy action to foment a linear urban expansion. This urban intervention aims to encourage higher residential occupation and more intensity of commerce and service activities around the federal road BR-116, which has been an area with low development due to its environmental characteristics. The main mechanisms to achieve the goals of the *LVUC* rely on the implementation of 22 km BRT exclusive bus corridors and new tube stations, combined with urbanization improvements and zoning rules that allow for more intense and mixed land use (Curitiba, 2012).

Nevertheless, despite the territorial extension of this urban intervention in Curitiba encompassing 11% of its total area, there are no empirical studies evaluating the effects of the *LVUC* on the spatial distribution of jobs. The hypothesis of the capacity of transportation system to change land use relates to a massive theoretical discussion about the endogenous forces that drive urban consolidation: the inter-relationship of whether in urban areas jobs follow people or the opposite (Carlino and Mills, 1987; Deitz, 1998). In intra-urban spatial level, there is growing interest to understand the impacts of BRT infrastructure on the land use of cities worldwide (Bocarejo et al., 2013; Rodriguez et al., 2016; Stokenberga, 2014; Cervero and Kang, 2011; Verge-Tovar and Rodriguez, 2022). However, the causal identification of BRT local effects remains a challenge, either due to delays in the implementation of these transport infrastructures or because of selection bias and endogeneity in econometric models. Longitudinal data in fine spatial resolution is a scarce and powerful resource to deal with these issues and build a quasi-experimental design that properly treats endogeneity in the policy effects estimates.

The aim of this study is to evaluate whether the *LVUC* intervention has been effective in modifying the spatial structure of jobs in the city of Curitiba, by affecting the employment density in the *LVUC* area of influence. This analysis also investigates the sectoral heterogeneity of the employment change related to *LVUC* and considers two different points in time (5 and 10 years) in the impact evaluation to explore short and long run effects. We used very granulated spatial data to observe the distribution of demographic, economic, and urban amenities within Curitiba in a longitudinal analysis, with the aim to observe the spatial dynamics of jobs. We combined Propensity Score Matching (PSM) and Triple-in-diff (Double Differences-in-Differences) models to build a quasi-experimental design, which allows identifying the marginal effects of *LCUV* transport infrastructure on the spatial distribution of jobs in different economic activities after this urban intervention.

Our findings show evidence supporting the positive influence of the BRT infrastructure investments and zoning rules promoted by the *LCUV* on the spatial distribution of employment in Curitiba. We argue these effects also provide evidence that *LCUV* has been effective in promoting the development of economic activities to supply demand in this local consumer market. Our robustness check analysis supports the overall impact of *LCUV* on the spatial distribution of jobs. This paper organizes into the following sections: a literature review, a description of the *Linha Verde Urban Consortium*, a data and empirical strategy section, and the results section. Beside this introduction, the last section presents the final remarks.

2 Literature Review

The car-oriented cities emerged from the late 19th century in a pattern of urban consolidation toward economies of scale through transport infrastructure, which exerted a strong influence on the dynamics of the spatial distribution of urban activities (Anas et al., 1998). The spatial concentration or dispersion of firms is related to the potential economic gains based on access to transport infrastructure, labor, and consumer markets (Fujita and Ogawa, 1982; Fujita and Ogawa, 1996). Thus, the spatial concentration of such economic externalities, defined as the agglomeration effects, is an endogenous mechanism for the location of firms and households in urban locations (Rossi-Hansberg, 2004).

Furthermore, there is a potential inter-relationship between firms and households in the allocation of economic activities in urban areas (Carlino and Mills, 1987). Deitz (1998) suggests that great access to customers, a related group of workers, and transport infrastructure[4], encourage firms to outbid others, whereas the population is attracted to urban areas with a high supply of compatible jobs, the level of transport infrastructure, and neighbourhood quality. The lagged local population is also a determinant of the self-selection of firms and residences in urban areas (Carlino and Mills, 1987; Deitz, 1998).

Empirical evidence has shown different directions of causality to the eggs or chicken dilemma: "*do jobs follow people or people follow jobs?*". The potential of duality or the direction of causality also relates to the demographic, economic context and spatial resolution of the area studied (Hoogstra et al., 2005; Tervo, 2016), as well as the groups of people or jobs analyzed (Tervo, 2016; Deitz, 1998, Arauzo-Carod, 2007). The empirical literature has found stronger causality relationships between jobs following people (Hoogstra et al., 2005; Deitz, 1998; Arauzo-Carod, 2007).

Within the hypothesis that local population influence jobs location over urban areas, one should consider the role of zoning restrictions. Because individuals' consumption of the household good is constrained by the price mechanism (Alonso, 1964), the relationship of zoning restrictions with the supply of households play an important role in local household

[4] That allow for lower commuting times to their workers.

demands, and therefore, in the spatial population distribution (Vermeulen, 2009; Glaeser et al., 2005).

Zoning restrictions aim to avoid negative externalities inherent to the urban expansion processes, but there are trade-offs related to economic collateral effects. There is a challenge to maximize the aggregate prices of land markets through the allocation of land use between commercial and residential purposes (Duranton and Puga, 2015; Rossi-Hansberg, 2004). Household supply restrictions also influence in the labor market size and productivity growth (Hsieh and Moretti, 2019), and restriction of lot size, maximum height, and building taxes can cause urban sprawl (Joshi and Kono, 2009; Vermeulen and Rouwendal, 2014). Zoning restrictions can also interfere in the intra-urban commuting conditions (Tang, 2021; Tikoudis et al., 2018).

In the challenge of optimizing the land use in urban areas, policymakers developed the *Transit Oriented Development* (*TOD*) concept, which combines land use mixed rules with the supply of public transport infrastructure to promote centralized decentralisation of economic activities. Key factors for the success of *TOD* policies are to promote more usage of public transport and increase the local population and land use densities with the aim to equalize local demand and supply for trips and economic activities, which allow for sustainable land use[5] (Vale, 2021). The incentives for more jobs close to public transport stations and land use diversity are among the important instruments of *TOD* policies, which are mechanisms to diminish the potential demand for commuting trips to distant areas of the city (Kamruzzaman, 2014). Thus, *TOD* policies that foment public transport improvements are supposed to exert influence on the urban structure, with spatial dispersion of economic activities in multicentric areas composed of compact structures (Lee and Bencekri, 2021; Thomson, 1977).

In the sense of using the transport system to boost the local demand for trips, evidences from many cities over the world suggest that the Bus Rapid Transit (BRT) is a cost-effective alternative (Cervero and Kang, 2011; Stokenberga, 2014; Deng and Nelson, 2010). It relates to efficient implementations of BRT systems at most, i.e., exclusive bus lanes, fast boarding platforms and good active accessibility to BRT stations, that bring more comfort to the users and speed of commutation. This encourages the shift from private vehicles to public transport modal with lower monetary costs than rail systems (Levinson et al., 2003; Bruun, 2005).

However, there is still a lack of understanding about the range of effects of BRT interventions in urban areas. Although there is some convergence in favor of increases in household prices (Cervero and Kang, 2011; Branco, 2016; Rodriguez and Targa, 2004; Deng and Nelson 2010), this is not the case for the impacts on the local land use, which have scarcity in empirical evidences. Among the few studies dedicated to the understanding of BRT impacts on land use changes, Kang (2010), and Cervero and Kang (2011) identified more intensive service and commercial land use close to areas of Seoul's BRT expansion after 2 and 3 years, respectively. In the city of Colombia, Bocarejo et al. (2012) had not found any impact in the city of Bogotá after 3 years of its BRT infrastructure expansion. However, Rodriguez et al.

[5] The types of TOD policies could vary even within a city. They essentially focus on giving a function to each city sub area, in the aims to guarantee the success of the whole system, given the available urban economic resources. See Mulley and Nelson (2021) for more information about *TOD* policies.

(2013) have found effects of land use changes for commercial purposes in areas close to BRT stations 5 years after its implementation in Bogotá.

These evidences suggest that the potential impacts of BRT on land use depend on the magnitude of the intervention and local characteristics, such as demographic and economic (Stokenberga, 2014). It is also very important to consider the time after the infrastructure implementation (Cervero and Kang, 2011). The hypothesis out by this discussion is whether the local areas of the BRT infrastructure improvements in Curitiba became more attractive to jobs in the commercial and service sectors, due to more attractiveness of population in such areas and higher connectivity with the rapid transit system.

3 The Linha Verde Urban Consortium of Curitiba Intervention

Curitiba is a city with 1.9 million inhabitants located in the south region of Brazil, which has a long relationship with *TOD* policies in its urban consolidation process. Since the year of 1966, this city's urban plans guide linear urban expansion based on structural axes[6], which aim to induce the population density and economic activities to areas that are compatible with local road and transport infrastructure supply (IPPUC, 2019).

Nevertheless, in the 2000s, this city still had areas with intense road infrastructure and underused land. This was the case of the federal road BR-116, which since 1990 decade pass from the south to the northeast limits of the city, and has caused negative externalities to its surrounding areas, due to intense traffic of vehicles. This local environment resulted in low population density in the surrounding areas of BR-116 (See Figure 1.A), with its land use related to industries at most, even after three municipal policies[7] that attempted to improve spatial integration to residential areas and local accessibility[8] for active and transit modes (Curitiba, 2012).

In 2006, the city of Curitiba launched the Linha Verde Urban Consortium (*LVUC*), which aims to foment land development in most of the BR-116 road surrounding area. The *LVUC* transformed 22 km of the BR-116 road into a new structural axis, followed by the construction of exclusive bus corridors and BRT tube stations. In accordance with the linear urban expansion pattern of Curitiba, this new local range of transport infrastructure combined with changes in the zoning rules allow for more intense and mixed land use, which aims to attract population, commerce, and service to the *LVUC* area (Curitiba, 2012).

The *LVUC* divides into two areas, the sectors south and north. The transport infrastructure improvements started partially in the former, by the year 2007, in a 9.4 km long project that finished in the year 2009 with seven new tube stations (See Figure 1.B). The south sector had changes in its zoning rules by the year 2008, where its new floor area ratio and maximum height allowed for more intense land use for residential, commerce and service purposes. The same zoning rules became valid to the north sector in the year 2011 (Curitiba, 2012), and the zoning rules of the year 2000 remained in the rest of Curitiba[9].

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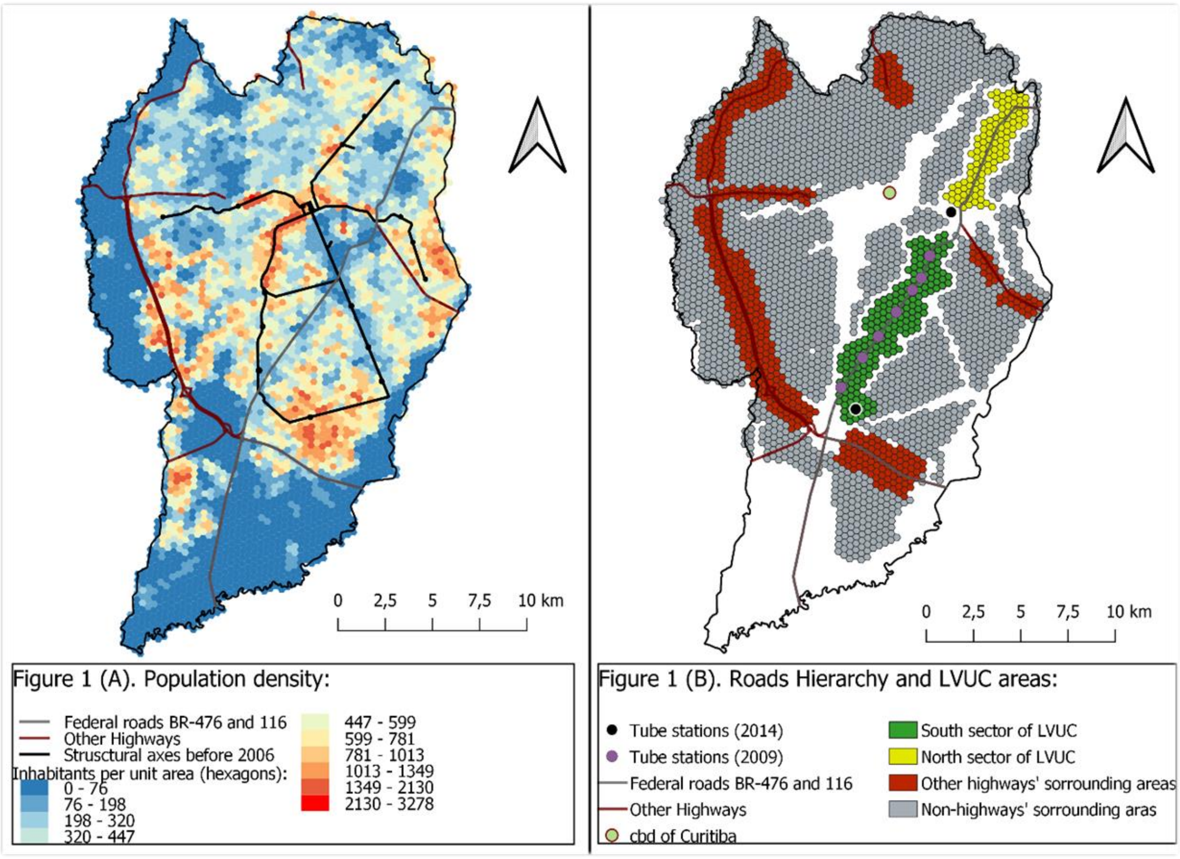
[6] Which followed a tripod concept that combines the transport infrastructure, road axes and land use rules to optimize land development in a sustainable manner. See Curitiba (2011) for more details.

[7] The intervention programs "BR-Vida", "BR-Cidade", "Sistema de Alta Complexidade (STAC)".

[8] Conceptualized as the easy to reaching places, given the transport network conditions.

[9] The remaining areas of the city kept with the 2000's zoning rules until the year of 2019. See Curitiba (2000) and Curitiba (2012) for more details of these zoning rules.

Figures 1(A) and 1(B) – Population distribution, transport infrastructure, and zoning areas of *LVUC* in the city of Curitiba.



Source: Own Elaboration, from GHSL 2000 population data and IPPUC road infrastructure data.
Note: Spatial unit areas are homogeneous hexagons of 0.11 km^2

In 2012, the south sector started transport infrastructure improvements in a 1.7 km long exclusive bus corridor with one new tube station for the Brazilian World cup. The launching of this transport infrastructure in 2014 completed the *LVUC* intervention in the south sector. Parallel to that, the transport infrastructure interventions in the north sector started in the year of 2010. However, because of legal irregularities, this sector faced many interruptions in its structure construction, which resulted only in a 1.8 km long area of exclusive corridors and one new tube station by the year 2015. There is still attempt to finish the transport infrastructure implementation in the whole north sector. However, in the year of 2019, there were no further inaugurations of BRT station tubes or exclusive bus corridors in the north sector (Curitiba, 2019).

4 Data

This empirical analysis used hexagons as spatial units with 0.11 km^2 area each, which follow a spatial hierarchical index[10] H3 in resolution 9, the same adopted by Pereira et al. (2022). We transformed the city of Curitiba into a hexagon grid with the aim to observe the spatial distribution of human activity within each hexagon over periods in fine resolution, without

[10] See: https://eng.uber.com/h3/ for more details.

assuming spatial evenness distribution of our data. Our strategy consisted of the spatial areal weighted interpolation of demographic, economic, and structural characteristics.

The population data is from the Global Human Settlement Layer (*GHSL*) for the years 2000 and 2015, comprised of squared grids of 350 m^2, which is its finest spatial resolution. This data is produced by the European Union (Florczyk et al., 2019). We used the *areal* R package to interpolate the *GHSL* grids with our hexagonal spatial units weighted by area. Each hexagon contains the sum of the population of the *GHSL* grids that are located on it. Figure 1 shows these data for the year 2000.

The Information on urban luminosity is from the National Oceanic and Atmospheric Administration (*NOAA*). We computed the six-year period means of the luminosity of 2001-2006 and applied weighted areal interpolation of *NOAA* spatial distribution in the hexagons grid, with the aim to observe local urban infrastructure. We also observed the influence of the rules of the zoning law for the period 2000-2019 through the building height allowed [11] and the number of different land activities allowed in that territory (Curitiba, 2000). For this task, we did the areal weighted spatial interpolation of zoning shapefiles to catch the spatial proportion of each zoning geometry in the hexagon grids.

We used income from the Brazilian Census of 2000 and 2010 in a two-step weighted areal interpolation procedure[12]. It consists of an application of areal spatial interpolation of the income census tract on the *GHSL* grids for both the 2000 and 2010 censuses. This strategy distributes income only in urban areas where the *GHSL* detected human activity, which avoids biased spatial distributions. In the second step to determine the income spatial distribution, we did an areal weighted interpolation of the *GHSL* spatial income in the hexagonal grids.

For the outcome variables, we used the Razão Anual de Identificação Social (*RAIS*) database, of the Brazilian ministry of labour, which has information about the address, number of employees, economic sector of activity, among other characteristics of Brazilian formal firms. We obtained the geographic coordinates of firms and jobs in the city of Curitiba from Google Maps APIs through the *geocode* package in *R*, to find the spatial location of each firm within the appropriate hexagon. This fine geocoded jobs database did not include industrial and government-related jobs. It consists of commerce (retail, wholesale trade, real estate companies) and service activities[13] (transport and communication, clinical and hospitals, education, financial institutions, food, repair, accommodation) within formal jobs[14].

5 Empirical Strategy

In the aim to evaluate the local impacts of the integration of the BRT infrastructure and zoning rule changes on the spatial distribution of non-industrial jobs in Curitiba, we adopted a quasi-experimental design for triple-difference econometric models. Because we want to observe causal inference of the *LVC* intervention after treatment (transport infrastructure), we must have the appropriate counterfactual group for the comparison of the outcomes. Otherwise, we

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[11] This variable was inverted: (1/the maximum height). In this sense, we consider zero as no height restriction.

[12] There are no population grids for the census tracts of the 2000 Brazilian Census. IBGE only created the methodology that allows for fine spatial resolution in the 2010 Brazilian census.

[13] Following the national classification of economic activities from IBGE.

[14] Which are the Jobs regulated under the Brazilian labour legislation, when employers and employees formalize such relationship by signing a document so-called *carteira de trabalho* in portuguese.

might have selection bias on the models, which leads to under or over estimates of the causal impact of the intervention on the treated group (Angrist and Pischke, 2008).

We built the control groups by observing a set of local attributes to measure similarities of them with the treatment group hexagons in the year 2006 using a Propensity Score Matching (*PSM*) method. The estimated scores of a *PSM* aim to make the treatment assignment strongly ignorable based on a set of sample information, by balancing for unbiased means between control and treatment group samples, which leads to proper estimates of the average treatment effects (Rosenbaun and Rubin, 1983). We pre-selected such hexagons of Curitiba by excluding the ones that already had exclusive bus lanes or BRT tube stations to avoid selection bias on the counterfactual candidates. Figure 1.B illustrates the groups' spatial distribution of the candidates of our quasi-experimental design.

The propensity score was estimated by a logit model with the nearest neighbour method with a ratio 5. The probability that the hexagon is in the *LVUC* South Sector zoning is explained by: population density in 2000, mean household income in 2000, linear distance from the hexagon centroid to a BRT station in 2006, linear distance from the hexagon centroid to the CBD of Curitiba, mean luminosity during the 2001-2006 period, the quantity of different land use activities allowed in the hexagon, and the maximum high allowed for buildings from the zoning rules.

Table 1 summarizes the balance of means of the three groups formed for our empirical analysis. According to the t-test, we reject the alternative hypotheses of different means in most of the variables used in the *PSM* model in the north sector and all of the variables in the remaining areas. Figures A1 and A2 in Annex A illustrate the balance of means of our analysis. Therefore, the *PSM* results in Table 1 suggest a balance of means, which reduces selection bias for the counterfactual groups. Another important assumption for this kind of strategy for a causal inference analysis is the parallel trends between the compared groups.

Figures B1 and B2 provide a visual check for the parallel trends of the *LVUC* South Sector, and the counterfactual groups (Other Roads, Streets and avenues surrounding areas and North Sector) obtained from the *PSM* results. According to Figures B1 and B2 in annex B, the three groups had very similar trends in the outcomes (jobs) in the early years before the delivery of the transport infrastructure (2009). This allows us to assume an appropriate comparison of the outcomes among the different groups, as the intervention is an important different aspect of the trajectory of the groups. Figure B1 also shows the importance of economic sector-based analysis, as we can see different pre-intervention trajectories between commerce and service sectors, which leads us to hypothesize different average effects of the *LVUC* intervention on treated after treatment.

Table 1 – Summary for the *PSM* results.

	Treatment	Counterfactuals

	LV South group		LV North group		LV Roads and remaining areas' group	
Variable	**N**	**Mean (Sd)**	**N**	**Mean (Sd)**	**N**	**Mean (Sd)**
Log income	157	3.77 (2.45)	38	2.68 (1.81)***	526	3.69 (2.93)
Log population	157	5.67 (7.59)	38	5.50 (5.54)	526	5.64 (0.98)
Log linear dist to station	157	6.66 (6.90)	38	7.21 (6.88)***	526	6.67 (1.30)
Log quantity of land uses	157	-5.90 (1.00)	38	-5.79 (1.14)	526	-5.88 (1.46)
Log allowed Height	157	2.01 (1.44)	38	1.98 (2.13)	526	2.01 (0.22)
Log linear dist to CBD	157	8.79 (3.42)	38	8.56 (2.53)***	526	8.76 (0.44)
Log luminosity	157	-2.72 (1.49)	38	-2.70 (1.20)	526	-2.72 (0.12)

Source: Own elaboration, from the study database.

Note: The p-value column summarises the results of a t.test means between the controls and treatment group in the table, under the null hypothesis of different means.

As discussed in section 3, the *LVUC* treatment areas had different times of implementation in the BRT infrastructure. However, both the North and South Sectors had changes on zoning rules that encourage more intensive land use by the year 2009 (Curitiba, 2012). Therefore, the *LVUC* intervention area has heterogeneous treatment effects, and a typical difference in difference model will face estimation bias for the outcomes. In the aim to properly isolate the transport infrastructure treatment effect, we used triple-difference (TD) models, which calculate the double differences of means among groups of interest (Ravaillon et al., 2005; Berck and Vilas-Boas, 2015; Ölden and Moen, 2020).

Equation (1) represents the mathematical scheme of our TD models, following the similar intuition of Heilmayr et al. (2020) to isolate heterogeneous policy effects. In the case of this application for the Curitiba urban area, this aims to estimate the double difference in difference of outcome means between the North sector, South sector, roads surrounding areas, and the control group:

$$\beta_6 = \{[(Avg_{South,post} - Avg_{South,pre}) - (Avg_{North,post} - Avg_{North,pre})] - [(Avg_{Road,post} - Avg_{Road,pre}) - (Avg_{Contr,post} - Avg_{Contr,pre})]\} \quad (1)$$

where the first part of this equation represents a Difference in Difference for the north and south sectors, and the second part represents the Difference in Difference between the roads surrounding areas and the control group. As this intervention aims to intensify the land use in the *LVUC* area, we have a significant number of zeros in the outcome variables (10.7% and 10.5% of the sample for commerce and services), which are non-negative and discrete. Therefore, we used poisson panel models to avoid estimation bias. The econometric reduced form of our poisson TD fixed effects models follows:

$$Jobs_{ist} = \beta_0 + \beta_1 Road + \beta_2 ZonLV + \beta_3 ZonLV.South + \beta_4.Road.D_{t=1} + \beta_5 ZonLV.D_{t=1} + \beta_6 ZonLV.South.D_{t=1} + \beta_7 D_{t=1} + \beta_8 X + \varphi + \varepsilon_i \quad (2)$$

where *Jobs* are the outcomes of interest: total number of jobs in the hexagon *i*, which belong to the economic sector *s*, in the period *t*. *Road* is a dummy for the hexagons located in a road surrounding area, *ZonLV* is a dummy for hexagons located in the *LVUC* zoning area, *ZonLV.South* is a dummy for the hexagons located in the South Sector of the *LVUC*. The dummy for samples in the second period is represented by $D_{t=1}$, so the interaction *ZonLV.South.*$D_{t=1}$ indicates the hexagons in the South Sector in the second period. The *X* vector for control variables contains the logs of population and income, φ is a fixed effect within group coefficient and ε is an error term. Therefore, β_6 is the coefficient that shows the effects of the *LVUC* intervention within the dimension of its transport infrastructure (tube stations and exclusive bus lanes), combined with zoning rules changes.

Our econometric models adopted two comparison periods (*t=1*), the years 2014 and 2019, with 2006 as the baseline period (*t=0*). Thus, given that the inaugurations of these interventions started in the year of 2009, we are evaluating the short and long-term (5 and 10 years, respectively) effects of the BRT infrastructure on the jobs spatial distribution. We carry the hypothesis that these econometric models identify the local effects of the intervention in the jobs spatial distribution, given population, income, and local fixed effects. The *LVUC* local effects are more likely to be observed in the long term.

6 Results

6.1 Impacts of the LVUC on the spatial distribution of jobs in Curitiba

This section starts exploring the results of the overall impacts on jobs, by observing the aggregate quantity of this outcome in the short and long terms. Table 2 reports estimates of these poisson triple-difference fixed effects models (PTDFE) with and without the matched sample, with the aim to compare the results of both strategies of identification. As discussed in section 5, the coefficient *ZonLV.South.Post* identifies the effects of the BRT new infrastructure on the spatial distribution of jobs. According to table 2, there was positive local impact on the overall spatial distribution of jobs, in either 5 or 10 years after the delivery of the new transport infrastructure.

Table 2 – PTDFE models for estimates of overall impacts on jobs.

Model	(1)	(2)	(3)	(4)
Year of comparison	2014	2019	2014	2019
Variable	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**
ZonLV.South.Post	0.1757***	0.3289***	0.2279***	0.3842***
Propensity Weighted	NO	NO	YES	YES
Log-Likelihood	-1,121,945	-1,117,478	-395,233	-359,445

Source: Own elaboration, from the study database.
Note: Signif. codes: p-value < 0.01 '***'; p-value < 0.05 '**'; p-value < 0.1'*'. Additional controls on these models are dummies for roads hexagons, *LVUC* zoning area, South sectors, roads hexagons in the second period, South sectors in the second period, and *LVUC* zoning area in the second period, log of income and log of population.

Models 1 and 2 in table 2 were estimated using unbalanced data for comparison with the treatment group, as can be seen in Annex A. Although they suggest a positive impact of the intervention on jobs, the magnitude of such coefficients is biased. Because models 3 and 4 were estimated using a balanced sample, as described in table 1 and Annex A, these are our favorite estimative for the overall impacts of the intervention on the outcomes. Note that the log-likelihood strongly converges toward zero when using balanced data, which suggests better goodness of fit for the models 3 and 4.

Both unbalanced and balanced samples' models suggest the same direction for all of the coefficients, which supports the robustness of positive impact results. But the analysis' refinement for the PTDFE, which uses *PSM* matched sample, suggest that by treating selection bias, we under estimated the transport infrastructure impacts in the short and long-terms. Given the specification of our matched PTDFE models, the results are interpreted as the marginal percentage change of the outcome with a unit change in the explanatory variable. Therefore, model 3 suggests that in 2014 the transport infrastructure caused an average increase of 22.7% in the formal jobs, when compared with counterfactual groups.

The long-term effects in formal jobs are estimated by model 4, which suggests an average increase of 38.4% in formal jobs for the south sector, compared to the control groups. This result observes how transport infrastructure affected the spatial dynamics of formal jobs in Curitiba. In a context of a severe national economic crisis that started in 2015, where employment structure faced notable changes in Brazil, the model 4 results indicate that transport infrastructure improvements increased the local potential attraction of jobs. The combination of Zoning rule changes with transport infrastructure is pointed as the economic mechanism that encouraged higher local non-industrial employment density, given the spatial data structure of this study.

Another economic mechanism that explains the local attraction of firms relates to population increase. If we assume that jobs actually follow people, this might be the case in the south sector areas, as detected in the model of Annex C, which observes a higher density of apartments when comparing the years 2000 and 2010. Therefore, we infer that a higher local potential consumer market emerged in such hexagons, given the incentives through the zoning rules changes and multimodal accessibility improvements. Indeed, the hedonic analysis of Branco (2016) suggests that the local residential market responded to the *LVUC* interventions with increases in prices, which indicates more local attractiveness for residential purposes.

A further understanding of the *LVUC*'s positive impacts is possible by decomposing the analysis by economic sector. Thus, table 3 shows the results for the matched sample in commerce and service activities. Models (5) and (6) suggest that services' activities had local average increases for the south sector of 48.4 and 44%, in 5 and 10 years after the delivery of BRT transport infrastructure, respectively. This economic sector encompasses very dynamic activities (mentioned in section 4), which have been a long trend of absorbing labor in the recent employment structural change in Brazil (Silva et al., 2006).

The jobs from the commerce economic activities had a significantly lower response related to the transport infrastructure in 2014, although positive at 7.8%, compared to the counterfactual groups. However, these economic activities had a much higher increase of attractiveness to the south sector areas in the long term, at 33.8% percentage points, while there was a tiny decrease of 4.47% in percentage effects for the service activities for the south sector.

The outcomes trajectories of Figure B2 (Annex B) show that the number of formal jobs in service activities had lower stability on the south sector hexagons after the delivery of transport infrastructure than did the commerce activities. It is possible to see a steeper declination of service jobs in the south sector for service activities after 2015, the first year of the Brazilian huge economic crisis, where the commerce activities had a faster and stronger recovery in such hexagons than in the remaining ones.

Table 3 – Matched PTDFE models for impacts on jobs by sector

Sector	Other Services		Commerce	
Model	(5)	(6)	(7)	(8)
Year of comparison	2014	2019	2014	2019
Variable	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**
ZonLV.South.Post	0.4848***	0.4401***	0.0785***	0.4164***
Matched Sample	YES	YES	YES	YES
Log-Likelihood	-306,090	-289,544	-189,468	-163,272
Number of obs	7,390	1,652	7,390	1,652

Source: Own elaboration, from the study database.
Note: Signif. codes: p-value < 0.01 '***'; p-value < 0.05 '**'; p-value < 0.1'*'. Additional controls on these models are dummies for roads hexagons, *LVUC* zoning area, South sectors, roads hexagons in the second period, South sectors in the second period, and *LVUC* zoning area in the second period, log of income and log of population.

The results of the *LVUC* are positive for the success of this intervention, as it suggests higher density and diversity of land use related to the combination of zoning rule changes and transport infrastructure improvements. The efficacy in attracting economic activities (here observed by the number of jobs) is a very important mechanism to the sustainability of the transport system, as it foments local demands for trips by public transport, increases taxes revenues, income, and local positive externalities for the residences, and unburden the transport municipal system (Vale, 2021).

6.2 Robustness Check

We also tested the robustness of the results of our models through a placebo test analysis. The intuition behind such a strategy is to evaluate whether the observed effects of the intervention would also be detected without the treatment. Therefore, this placebo test analysis aims to observe the triple-differences between all groups before the beginning of construction of the BRT south sector infrastructure. In this sense, we used the year 2002 as a baseline and 2006 as a comparison year[15]. Within such model design, any effect observed in the overall jobs spatial distribution cannot be attributed to the transport infrastructure intervention, as we assume no significant structural change in the treatment area, which would be a placebo effect. The results of the placebo test models are shown in table 4.

When we use the unmatched sample for such analysis in the model (9), we observe a negative small impact on the overall number of non-industrial jobs with a 10% significance level. However, as discussed above, our unmatched samples have selection bias, which leads to potential under or over estimates of average treatment effects. Thus, we consider the results of model (10), which has *PSM* matched sample and deals with selection bias.

Table 4 – Models for estimates of overall impacts on jobs for placebo tests

Model	(9)	(10)

[15] The year 2002 is the earliest available data from RAIS with address information. Because of that, we had to make 4 years comparison in this placebo analysis.

Years of comparison	2002-2006	2002-2006
Variable	**Coefficient**	**Coefficient**
ZonLV.South.Post	-0.0194*	0.0112
Propensity Weighted	NO	YES
Log-Likelihood	-910,221	-275,772
Number of obs	7,390	1,652

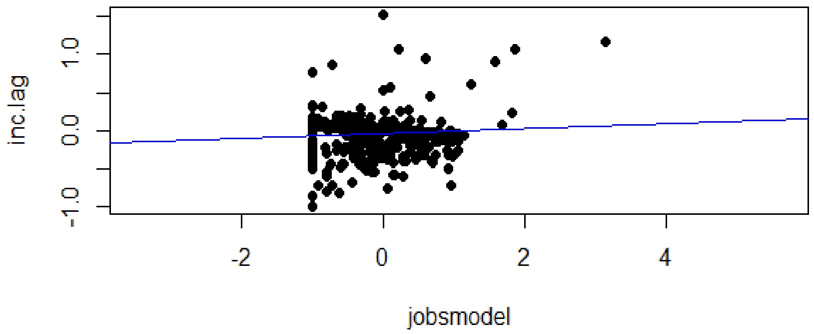
Source: Own elaboration, from the study database.

Note: Signif. codes: p-value < 0.01 '***'; p-value < 0.05 '**'; p-value < 0.1'*'. Additional controls on these models are dummies for roads hexagons, *LVUC* zoning area, South sectors, roads hexagons in the second period, South sectors in the second period, and *LVUC* zoning area in the second period, log of income and log of population.

Model (10) suggests no statistical significance of the coefficient that observes the effects of this transport infrastructure intervention after treatment, which in this placebo test analysis, is the year 2006. Note that once again the log-likelihood is higher in the matched model than in model (9), indicating better goodness of fit in the former model. Therefore, these results bring support to stronger evidence that models (1-8) actually observe economic effects related to the intervention, as our identification strategy in equation (2) identifies changes in the relationship of the control variables with the outcomes only after the post-treatment period.

One could argue for the presence of spatial dependence in the estimates of our econometric models. One reason for that would be due to the presence of spillover effects of the policy, which would bring estimation bias (Delgado and Florax, 2015). Therefore, we also tested the presence of spatial dependence following (Anselin, 1988) methodology, by observing the Moran's I for the residuals of the cross-sectionals overall jobs model. Figure 2 shows the reasonably random relationship between the spatial lagged outcome based on a queen matrix and the cross-sectional residuals for the overall jobs estimated by a poisson model. The Morans'I test value was 0.0331, which suggests no spatial correlation for our estimates.

Figure 2 - Spatial lagged outcome versus residuals from cross-sectional poisson model.



7 Final Remarks

The impact analysis of this study aims to assess the local impact of the *Linha Verde Urban Consortium* on the spatial distribution of jobs in Curitiba. We carry the hypothesis that if the urban intervention attracted the population through its positive externalities, it also attracted more economic activities, which we observe through the local quantity of formal jobs. The other mechanisms of this policy for more intense land use in economic activities are the BRT transport infrastructure and zoning rules changes, which became more permissive in land use.

Our findings show positive effects of the BRT transport infrastructure 5 and 10 years after the implementation of these transit stations. These results are valid for formal jobs in commerce and service activities, where the former had small positive effects in 5 years, and significant increases in 10 years. The positive effects in the jobs of other service activities remained reasonably stable in the long term. Therefore, we argue the *Linha Verde Urban Consortium* intervention has been effective in reshaping the urban development of Curitiba, by stimulating the formation of a new area of local labor and consumption markets.

We also used a robustness check through placebo tests on our quasi-experimental design, by using the same analysis in periods before the beginning of the *Linha Verde Urban Consortium* implementation. The results of these placebo tests suggest robustness for our matched triple-difference models. We also test one of the mechanisms for the *LVUC* effects by estimating the differences for the treated hexagons within the dimension of residential land use over a ten years period, which suggests more verticalization in the South sector.

The limitations of this study rely on the external validity of the results, which are limited to urban areas with similar urban aspects to Curitiba. However, we believe our research design contributes to a high internal valid analysis, given the granulated spatial resolution of our data. Further research could investigate the economic gains of BRT transport infrastructures in Curitiba, such as income, commuting time and accessibility, as well as the application and development of this quasi-experimental design for assessing the effects of urban interventions in other urban areas.

References

Anselin, L. (1988). Spatial econometrics: methods and models. Kluwer, Dordrecht.

Anas, A.; Arnott, R.; Small, K. (1998). Urban spatial structure. Journal of Economic Literature v. 36(3), pp. 1426–1464.

Angrist, J. D.; Pishcke, J. Mostly harmless econometrics. Princeton university press, 2009.

Branco, J. A influência do sistema BRT no preço dos imóveis em Curitiba: uma análise com modelos de preços hedônicos. 2016. (Dissertation thesis for Master degree in Economic Development) Universidade Federal do Paraná. <Available in: < https://www.prppg.ufpr.br/siga/visitante/trabalhoConclusaoWS?idpessoal=28030&idprograma=40001016024P0&anobase=2016&idtc=13 >.

Berck, P.; Villas-Boas, B, S. (2015). A note on the triple difference in economic models. Applied Economic letters. v. 23(4), pp.239-242. doi:10.1080/13504851.2015.1068912.

Bocarejo, P, J.; Portilha, I.; Pérez, A, M. (2013). Impact of Transmilenio on density, land use, and land value in Bogotá. Research in Transportation Economics. v. 40, pp-78-86.

Bruun, E. (2005). Bus Rapid Transit and Light Rail: Comparing Operating Costs with a Parametric Cost Model. Journal of the Transportation Research Board, n. 1927, pp. 11–21.

Carlino, A, G.; Mills, S, E. (1987). THE DETERMINANTS OF COUNTY GROWTH. Journal of Regional Science, V. 27(1), pp. 39-54.

Cervero, R.; Kang, D, C. (2011). Bus rapid transit impacts on land uses and land values in Seoul, Korea. Transport Policy, v.18, pp-102-116.

CURITIBA. Para entender o histórico da Linha Verde. (2019). Available in: << https://webcache.googleusercontent.com/search?q=cache:jTbWe3bLg8kJ:https://www.curitiba.pr.gov.br/noticias/para-entender-o-historico-da-linha-verde/51996+&cd=2&hl=pt-BR&ct=clnk&gl=br>> . Accessed in august of 2020.

CURITIBA. Prospecto de Registro da Operação Urbana Consolidada Linha Verde 2012.

Deitz, R. (1997). A Joint Model of Residential and Employment Location in Urban Areas. Journal of Urban Economics. v. 44, pp-197-215.

Delgado, S. M.; Florax, R. J. G. M. (2015). Difference-in-Differences Techniques for Spatial Data: Local Autocorrelation and Spatial Interaction. Netherlands: Tinbergen Institute Discussion Paper, n. 091/VII.

Deng, T.; Nelson, D, J. (2010). Recent Developments in Bus Rapid Transit: A Review of the Literature. Transport Reviews. v. 31, pp. 69-96. 10.1080/01441647.2010.492455.

Duranton, G.; Puga, D. (2015). Urban Land Use. (Chapter 8) In: Handbook of Regional and Urban Economics. North-Holland, 5th Edition.

Florczyk, A. J.; Corbane, C.; Ehrlich, D.; Freire, S.; Kemper, T.; Maffenini, L.; Melchiorri, M.; Pesaresi, M.; Politis, P.; Schiavina, M.; Sabo, F.; Zanchetta, L. (2019). GHSL Data Package 2019 (Publications Office of the European Union EUR 29788 EN). https://doi.org/10.2760/290498.

Fujita, M.; Ogawa, H. (1982). Multiple equilibria and structural transition of nonmonocentric urban configurations. Regional Science and Urban Economics, v. 12(2), pp.161-196.

Fujita, M.; Thisse, F.J. (1996).Economics of Agglomeration. Journal of the Japanese International Economies, v.10, pp.339-378.

Glaeser, E.; Gyuorko, J.; Saks, E, R. (2005). Why have Housing Prices Gone up? AEA PAPERS AND PROCEEDINGS. v. 95(2), pp. 329-333.

Heilmayr, R.; Rausch, L, L.; Munger, J.; Gibbs, K, G. (2020). Brasil's Amazon Soy Moratorium reduced deforestation. Nature food. v. 1, pp. 801-810. https://doi.org/10.1038/s43016-020-00194-5.

Hoogstra, G; Van Dijk, J; Florax, R, J, G, M. (2005). Do jobs follow people or people follow jobs? A metaanalysis of Carlino-Mills studies. 45th Congress of the European Regional Science Association. http://hdl.handle.net/10419/117811.

Hsieh, C.; Moretti, E. (2019). Housing Constraints and Spatial Misallocation. (2019). American Economic Journal: Macroeconomics. v. 11(2), pp.1-39. https://doi.org/10.1257/mac.20170388.

Instituo De Pesquisa e Planejamento Urbano De Curitiba – IPPUC- (2019). Ampliação da capacidade e velocidade da linha direta inter 2. Available in: < http://www.ippuc.org.br/visualizar.php?doc=https://admsite2013.ippuc.org.br/arquivos/documentos/D327/D327_036_BR.pdf >. Accessed in January 2022.

Joshi, K, K.; Kono, T. (2009). Optimization of floor area ratio in a growing city. Regional Science and Urban Economics. v. 39. pp. 502-511.

Kamruzzaman, Md.; Baker, D.; Washington, S.; Turrel, G. (2014). Advance transit oriented development typology: case study in Brisbane, Australia. Journal of Transport Geography. v. 34, pp. 54-70.

Lee, S.; Bencekri, M. Urban Form and public transport design. (2021). Chapter 17. In: Mulley, C.; Nelson, D, J. (2021). Urban Form and Accessibility: Social, Economic, and Environmental Impacts. Elsevier.

Levinson, S, H.; Zimmerma, S.; Clinger, J.; Rutherford, S.; Smith, L, R.; Cracknell, J.; Soberman, R. (2003). Bus Rapid Transit: Volume 1: Case Studies in Bus Rapis Transit. Federal transit Administration. Report 90. http://www.national-academies.org/trb/bookstore.

Mills, E. S. (1967). An aggregate model of resource allocation in a metropolitan area. American Economic Review. v. 57, pp. 197–210.

Pereira, H, M, R.; Herszenhut, D; Braga, K, V, C.; Bazzo, P, J.; Oliveira, A, L, J.; Parga, P, J.; Saraiva, M.; Silva, P, L.; Tomasiello, B, D; Warwar, L. (2022). Distribuição Espacial de Características Sociodemográficas e Localização de Empregos e Serviços Públicos das Vinte Maiores Cidades do Brasil. Instituto de Pesquisa Econômica e Aplicada (Ipea). Texto para Discussão, n. 2772.

Ravallion, M.; Galasso, E.; Lazo, T.; Philipp, E. (2005). What can Ex-Participants Reveal about a Program's Impact?. The Journal of Human Resources. v. 40(1), pp. 209-229.

Rodriguez, D.; Targa, F. (2013). Value of accessibility to Bogotá's bus rapid transit system. Transport Reviews: A Transnational Transdisciplinary Journal. v. 24(5), pp. 587-610. doi: 10.1080/0144164042000195081.

Rosenbaum, R, P.; Rubin, B, D. (1983). The Central Role of the Propensity Score in Observational Studies for Causal effects. Biometrika, v. 70 (1), pp. 41-55.

Rossi-Hansberg, E. (2004). Optimal land use and zoning. Review of Economic Dynamics. v.7, pp. 69-106.

Stokenberga, A. (2014). Does Bus Rapid Transit Influence Urban Land Development and Property Values: A Review of the Literature. Transport Reviews. v. 34(3), pp. 276–296. http://dx.doi.org/10.1080/01441647.2014.902404.

Tang, K, C. (2021). The cost of traffic: Evidence from the London Congestion Charge. Journal of Urban Economics, v. 121.

Tervo, H. (2016). Do People Follow Jobs or Do Jobs Follow People? The Case of Finland in an International Context. The Journal of Regional Analysis & Policy. v. 46(1), pp. 95-109.

Thomson, J. M. (1978). Great cities and their traffic. Penguin Books.

Tikoudis, I.; Verhoef, J.; Ommeren, V, N, J. (2018). Second-best urban tolls in a monocentric city with hosing market regulations. Transportation Research part B. v. 117, pp. 342-359.

Vergel-Tovar, E, C.; Rodriguez, A, D. (2022). Bus rapid transit impacts on land uses and development over time in Bogotá and Quito. The Journal of Transport and Land Use. v. 15(1), pp. 425-462.

Vale, S, D. (2021). Active accessibility and transit-oriented development: Connecting two sides of the same coin. (Chapter 8) In: Mulley, C.; Nelson, D, J. (2021). Urban Form and Accessibility: Social, Economic, and Environmental Impacts. Elsevier.

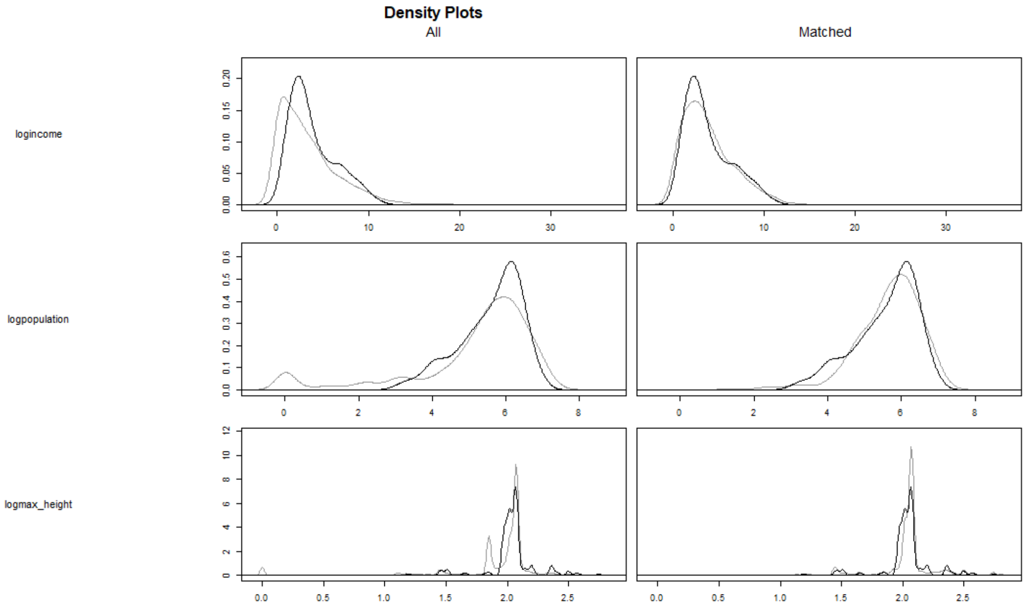
Vermeulen, W.; Ommeren, V, J. (2009). Does land use planning shape regional economies? A simultaneous analysis of housing supply, internal migration and local employment growth in Netherlands. Journal of Housing Economics. v.18, pp-294-310.

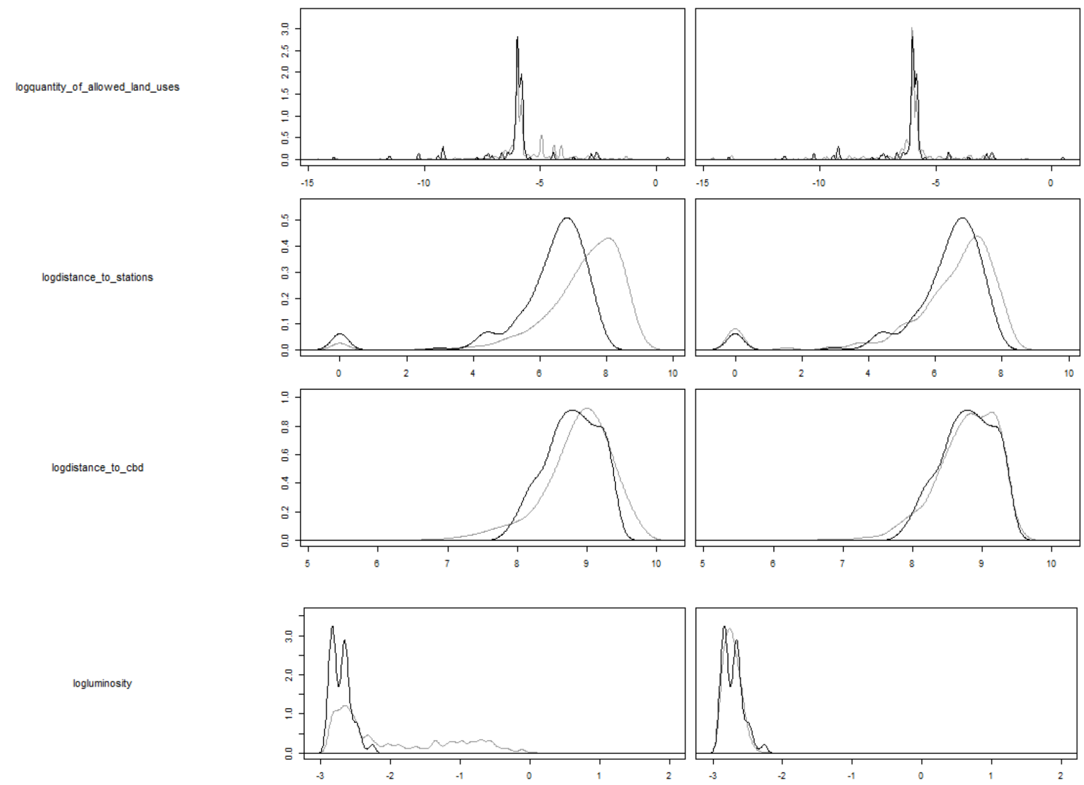
Vermeulen, W.; Rouwendal, J. (2014). On the Value of Foregone open space in sprawling cities. Journal of Regional Science. v. 54, pp.61-69.

Zhang, M.; Yen, T.H, B. (2020). The impact of Bus Rapid Transit (BRT) on land and property values: A meta analysis. Land Use Policy. v. 96.

Annex A

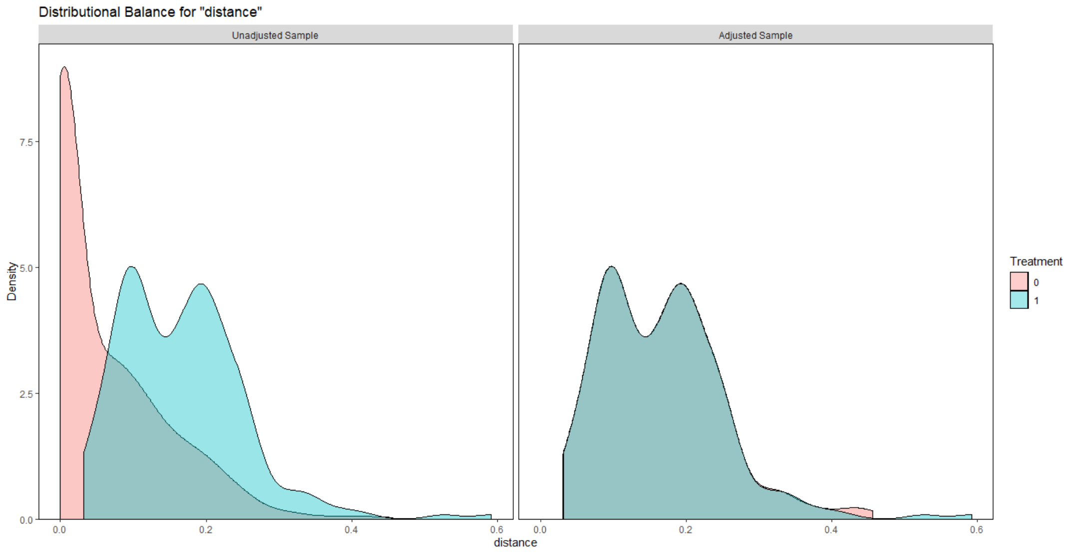
Figure A1 - PSM Density plots for unbalanced and balanced samples.





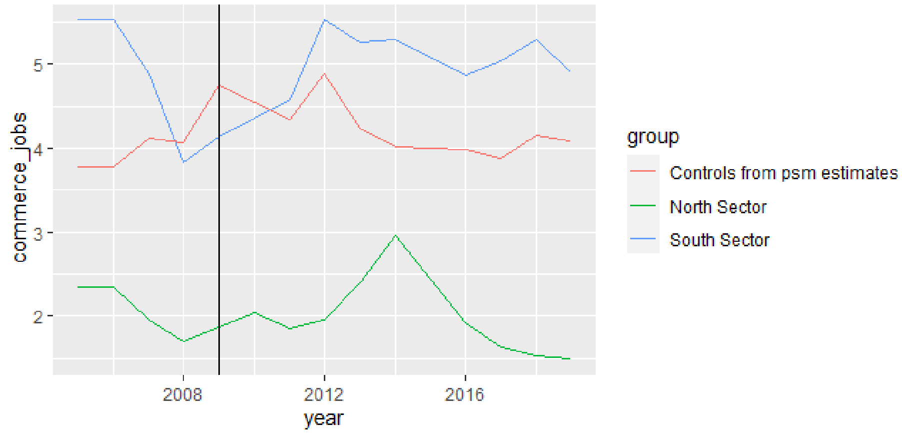
Source: Own elaboration, from the database of the study.

Figure A2 - PSM Density plots of distance for unbalanced and balanced samples.



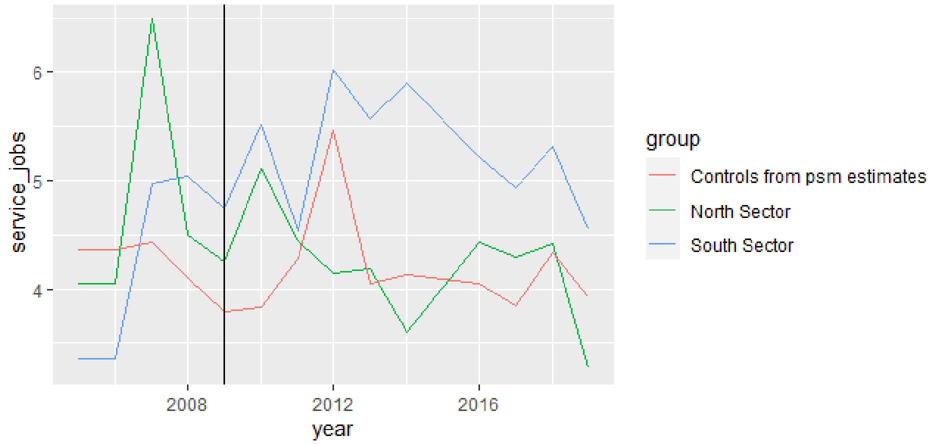
Annex B – Parallel time trends graphics.

Figure B1 – Time trend graphic for commerce jobs



Note: The outcomes are the mean quantity of commerce jobs for each hexagons per year.

Figure B2 – Time trend graphic for service jobs



Note: The outcomes are the mean quantity of service jobs for each hexagons per year.

Annex C

We run a triple difference model to test effects of the *LVUC* on the population density. This linear model has the percentage of apartments within the total of residences (houses + apartments) in each hexagon for the years 2000 – 2010. The samples (hexagons) are the same of the matched DDD poisson fixed effects models for the jobs effects' investigation, also using the matched counterfactuals. Table 5 show the results of such model.

Table 5 - matched DDD FE model for the proportion of apartments within residences.

Variable	**Coefficient**
ZonLV.South.Post	0.251^{***}
ZonLV.Post	-0.227^{***}
Roads.Post	0.061
ZonLV.South	0.005
ZonLV	0.038
Roads	-0.048
Propensity Weighted	YES
R^2	0.28

Number of obs	1,628

Source: Own elaboration, from the study database.

Note: Signif. codes: p-value < 0.01 '***'; p-value < 0.05 '**'; p-value < 0.1'*'. This linear model has additional controls: log of income, of population and of number of firms.

The results suggest that the percentage of apartments increased in the south sector 1 year after the delivering of the transport infrastructure and zoning rules changes, where the proportion of apartments in such hexagons increased by 25%, when we compare to the other areas of the city of Curitiba.