Green lights to land development? Short and long term effects of the Linha Verde Consortium in the Labor Market of Curitiba, Brazil[1]

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Abstract

This study evaluates the short and long terms local impacts of a land development policy on the spatial distribution of jobs in Curitiba, a large global South city. In the year of 2006, Curitiba launched the Linha Verde Urban Consortium, an urban intervention that aims to connect its bus rapid transit network to the southeast and northeast territories of this city, which combined with local changes in zoning restrictions, encourages more intense land use in these low population density areas. We used a rich set of data in fine spatial resolution on a longitudinal analysis to generate a unique quasi-experimental design for urban areas, with the aim to evaluate the impacts of transit infrastructure improvements and zoning rules changes on jobs of different economic sectors, using PSM and double difference-in-difference econometric models. The results suggest an overall positive impact for non-industrial jobs, with stronger effects in the long term, 10 years after transport infrastructure improvements. This analysis contributes to the understanding of the impacts of BRT infrastructure improvements in the spatial distribution of economic activities in the short and long term within urban areas with low population density.

Keywords: Impact Evaluation; Bus Rapid Transit; Urban Labor Market; Curitiba; quasi-experimental design.

Resumo

Este estudo faz uma avaliação de impacto de curto e longo prazo de uma política de desenvolvimento de uso do solo na distribuição espacial dos empregos na cidade de Curitiba, uma grande cidade localizada no Sul Global. No ano de 2006, Curitiba lançou o *Consórcio Urbano Linha Verde*, uma intervenção urbana que tem o objetivo de conectar o seu sistema de ônibus de transporte rápido (*BRT*) a territórios localizados nas regiões sudeste e nordeste da cidade, e que combinado com mudanças de restrições de zoneamento, estimula maior intensidade de uso do solo nessas regiões de baixa densidade populacional. Para isso, foi utilizado um rico conjunto de dados em resolução espacial fina em uma análise longitudinal, a fim de proporcionar um desenho quase-experimental único para análise de intervenções urbanas, que possibilita a avaliação do impacto das obras de infraestrutura de transporte público e mudanças de zoneamento nos empregos de diferentes setores econômicos, por meio do uso

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de modelos econométricos do Método de Escore de Propensão (PSM) e Duplas Differenças em Differenças. Os resultados sugerem impactos globais positivos nos empregos não industriais, com maiores efeitos no longo prazo, 10 anos após o início das entregas de infraestrutura de transporte. Esta análise contribui para a compreensão dos impactos da melhoria de infraestrutura de *BRT* na distribuição espacial das atividades econômicas no longo e curto prazo em áreas urbanas de baixa densidade populacional.

Palavras chave: Avaliação de impacto; Bus Rapid Transit; Mercado de trabalho urbano; Curitiba; Desenho quase-experimental.

JEL Classification: R14, J18, C21
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1 Introduction

The transport system exerts important influence on the location of economic activities of urban areas, by way of its potential strength to shape local demands and supplies for intra-urban travels. Many cities have made their urban consolidation based on *Transit Oriented Development* (*TOD*) policies, in the aim to promote sustainable paths of land use developments (Mulley and Nelson, 2021).

In Brazil, the city of Curitiba have been using *TOD* policies since the 1970 decade, by 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, with higher population density over the structural axes combined with mixed land use, which follows a hierarchy by road infrastructure.

This city had launched in the year of 2006 the Linha Verde Urban Consortium (*LVUC*), which is its most recent action to foment a linear urban expansion. This urban intervention aims to encourage higher human occupation and concentration of commerce and service activities around the federal road BR-116, which have strived to be a developable urban area due to its unfavourable environmental characteristics.

The main mechanisms to 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 encompass 11% of its total area, there are no studies that investigate the *LVUC* effects on its jobs spatial structure. The empirical analysis of *LVUC* economics effects rely on the Curitiba's real estate market, arguing in favour of increases in the level of prices of terrains close to the intervention area (Branco, 2016), which are common findings of *BRT* impacts in other urban areas (Cervero and Kang, 2011; Rodriguez and Targa, 2004; Zhang and Yen, 2020).

From the goals of the *LVUC* of attracting population and firms for more intense land use, remains a massive theoretical discussion about the endogenous forces that drive urban consolidation: the inter-relationship of wether in urban areas jobs follow people or the opposite (Carlino and Mills, 1987; Deitz, 1998).

Although this question depends on the context of analysis, it converges to strong influences of local lagged population and jobs, level of transport infrastructure, of income, and the occupational dimension of economic activities (Deitz, 1998; Hoogstra, 2005; Tervo, 2016). The zoning rules are also an exogenous force on the inter-relationship between the distribution of job and population (Vermeulen, 2009; Hsieh and Moretti, 2019), and its interaction with transport infrastructure can promote sustainable land use development (Lee and Bencekri, 2021).

Therefore, the objective of this study is to evaluate the efficacy and effectiveness of the *LVUC* in modifying the spatial structure of jobs in the city of Curitiba, for commerce and service activities, in the short and long terms.

We used fine spatial data to observe the distribution of demographic, economic, and urban amenities in Curitiba in a longitudinal analysis, in the aim to observe the spatial dynamics of its labor market. We combined *Propensity Score Matching* (*PSM*) and *Triple-in-diff* (*Double Differences-in-Differences*) models to build a quasi-experimental design, with the objective of observe the marginal effects of *LCUV* transport infrastructure in the spatial distribution of jobs in different economic activities sectors, for 5 and 10 years after such urban intervention.

Our results suggest positive influence of the combination of *BRT* infrastructure and zoning rules change in the spatial jobs distribution of Curitiba. We argue that such urban intervention attracted residents to this new structural axis, and then, economic activities to supply new demands in those local consumer markets. We ran a robustness check analysis that supports the overall impacts on spatial jobs distribution.

This paper has the following division: a literature review, a section describing the *Linha Verde Urban Consortium*, followed by another that details the methodology of this analysis, and then, the results. Beside this, a section of final remarks, that finishes this paper.

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 strong influence on the dynamics of spatial distribution of urban activities (Anas et al., 1998). The spatial concentration or dispersion of firms related to the potential economic gains based on the access to transport infrastructure, labor and consumer markets (Fujita and Ogawa, 1982; Fujita and Ogawa, 1996), and the spatial concentration of such economic externalities, defined as the agglomeration effects, became a mechanism of self-selection of firms and households on 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, to related group of workers, and to transport infrastructure[4], encourage firms to outbid others, whereas population is attracted to urban areas with high supply of compactible jobs, the level of transport infrastructure, and neighbourhood quality. The lagged local population is also a determinant for self-selection of firms and residences over urban areas (Carlino and Mills, 1987; Deitz, 1998).

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

Empirical evidences have 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 groups of people or jobs analysed (Tervo, 2016; Deitz, 1998, Arauzo-Carod, 2007). However, the empirical literature have found stronger causality relationships of 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 in initial stages of this relationship. Because individuals' consumption of household 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 demands, and therefore, in the spatial population distribution (Vermeulen, 2009; Glaeser et al., 2005).

The aim of zoning restrictions is to avoid negative externalities inherent to the urban consolidation processes, such as high level of pollution and noise, on the overloading of transport network (congestion), of land use, among others. In a counterpoint, these restrictions face trade-offs related to some collateral effects.

These collateral effects of zoning restrictions can be seen in the spectrum of maximizing the aggregate prices of land markets, through the allocation of land use between commercial and residential purposes (Duranton and Puga, 2015; Rossi-Hansberg, 2004). Another spectrum is the collateral effect in labor market size and productivity growth, because of household supply restrictions (Hsieh and Moretti, 2019).

There are also effects of urban sprawl related to restriction of lot size, maximum height, and building taxes (Joshi and Kono, 2009; Vermeulen and Rouwendal, 2014). Zoning restrictions can also interfere in the intra-urban commuting conditions, through taxations of trips within specific zones (Tang, 2021; Tikoudis et al., 2018).

Given 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 supply of public transport infrastructure to promote centralised decentralisation of economic activities. Key factors for the success of *TOD* policies are to promote simultaneously more usage of public transport and increase the local population and land use densities, in the aim to equalize local demand and supply for trips and economic activities, which allow for a sustainable land use[5] (Vale, 2021).

The promotion of 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 in the urban structure, with spatial dispersion of economic activities in multicentric areas, composed by compact structures (Lee and Bencekri, 2021; Thomson, 1977).

[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.

In the sense of using the transport system to boost the local demand trips, evidences of 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 the public transport modal with lower monetary cost than rails systems (Levinson et al., 2003; Bruun, 2005).

However, there is still lack of understanding about the range of effects of BRT interventions in urban areas. Although there is some convergence in favour 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 in the local land use, which still have very scarce 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. (2013) found effects of land use changings for commercial purposes in areas close to *BRT* stations 5 years after its implementations in Bogotá.

These evidences suggest that the potential impacts of *BRT* in the land use depend on the size 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). Therefore, the hypothesis carried by this discussion is wether 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, as well as higher connectivity with the transport system.

3 The Linha Verde Urban Consortium of Curitiba Intervention

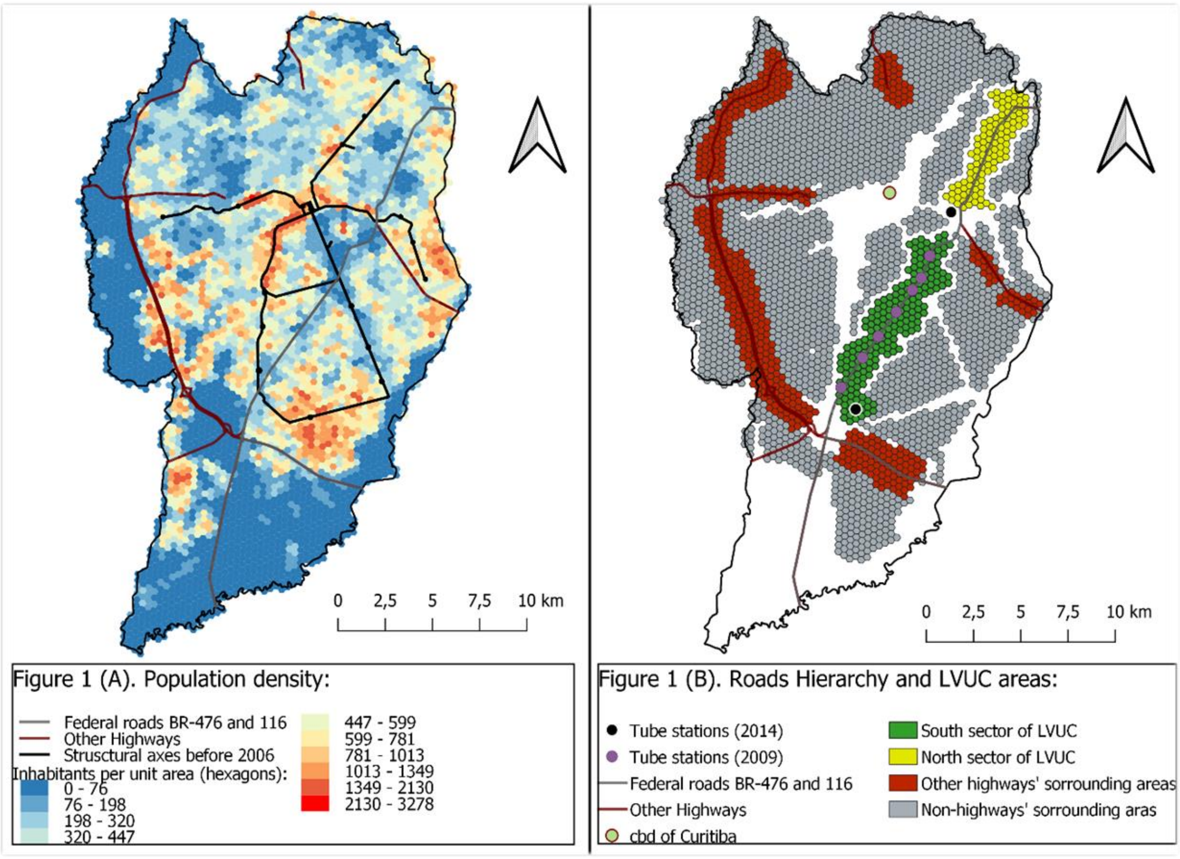
Curitiba is a city with 1.9 million inhabitants located in the south region of Brazil, which has a long relationship with *TOD* policies on its urban consolidation process. Since the year of 1966, this city's urban plans guide linear urban expansion based on structural axes[6], which aim to induce the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

Nevertheless, in the beginning of the 2000 years, this city still had areas with intense road infrastructure and underused land. This was the case of the federal road BR-116, that since the 1990 decade pass from the south to the northeast limits of the city, and have caused negative externalities to their surround areas due to intense traffic of vehicles.

This local environment resulted in low population density in the surround areas of BR-116 (See Figure 1.A), with its land use related to industries at most, even after three municipal

[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.

policies[7] that attempted to improve spatial integration to residential areas and local accessibility[8] to active and transit modes (Curitiba, 2012).



Figures 1.A and 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 2006, the city of Curitiba launched the Linha Verde Urban Consortium (*LVUC*), which aim to foment land development in most of the BR-116 road surrounding area. The *LVUC* transformed 22 km of the BR-116 road in a new structural axis, followed by the construction of exclusive bus corridors and BRT tube stations. In accordance to 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 aim to attract population, commerce and service to the *LVUC* area (Curitiba, 2012).

The *LVUC* contains two spatial areas, the sectors south and north. The transport infrastructure improvements started partially in the former, by year of 2007, in a 9.4 km long project that finished in the year of 2009 with seven new tube stations (See Figure 1.B).

The south sector had changes in its zoning rules in the year of 2008, where its new floor area ratio and maximum height allowed for more intense land use for residential, commerce

[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.

and service purposes. The same zoning rules became valid to the north sector in the year of 2011 (Curitiba, 2012). In the rest of Curitiba, the zoning rules of the year of 2000 remained[9].

In 2012, the south sector kept transport infrastructures improvements in a 1.7 km long exclusive bus corridor area with one new tube station, for the Brazilian World cup. The launching of this transport infrastructure completed the *LVUC* intervention in the south sector, in the year of 2014.

Parallel to that, the transport infrastructure interventions in the north sector started in the year of 2010. However, due to legal irregularities, this sector faced many interruptions in its constructions, which resulted only in a 1.8 km long area of exclusive corridors and one new tube station in the year of 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 hexagon grids as the homogeneous spatial units with a 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 aim to observe the spatial distribution of human activity within each hexagon over periods in fine resolution without assuming spatial evenness distribution of our data. Therefore, our strategy consisted in spatial areal weighted interpolation of demographic, economic and structural characteristics.

The population data came from the Global Human Settlement Layer (*GHSL*) for the years of 2000 and 2015, comprised in squared grids of 350 m^2, which is its finest spatial resolution. We used the *areal* R package to interpolate the *GHSL* grids with our hexagonal spatial units weighted by area. Thus, each hexagon contains the sum of the population of the *GHSL* grids that are spatially located on it. The results for the year of 2000 are ilustrated in figure 1.

The Information of urban luminosity came from the National Oceanic and Atmospheric Administration (*NOAA*). We computed the six-year period means of luminosity of 2001-2006, and applied weighted areal interpolation of *NOAA* spatial distribution with the hexagons. This data aims to observe local urban infrastructure.

We also observed the influence of the rules of the zoning law for the period 2000-2019 through the allowed building height[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 relation of each zoning geometry with the hexagon grids.

We used income from the Brazilian Census of 2000 and 2010 in a two-step weighted areal interpolation procedure[12]. We applied areal spatial interpolations of the income census tract on the *GHSL* grids for both 2000 and 2010 census. This strategy distributes income only

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

in urban areas where the *GHSL* detected human activity, which avoids biased spatial distributions. The second step for the income spatial distribution was the 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 address, number of employees economic sector of activity, among other characteristics of Brazilian formal firms. We obtained the geographic coordinates of firms and jobs of 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 excluded 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

The aim of this empirical analysis is to evaluate local impacts of the integration to the *BRT* infrastructure and zoning rule changes on the spatial distribution of non-industrial jobs of Curitiba. For this, 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 outcomes comparison. Otherwise, we 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).

For this, we built the control groups observing a set of local attributes to measure similarities of areas throughout the city of Curitiba with the treatment group areas in the year of 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 properly estimates of the average treatment effects (Rosenbaun and Rubin, 1983).

We pre-selected such areas of Curitiba by excluding the ones that already had exclusive bus lanes or *BRT* tube stations, avoiding selection bias to the counterfactual candidates. Figure 1.B illustrates the groups' spatial distribution of our quasi-experimental design.

The *PSM* followed was estimated by a logit model. The probability of the hexagon being 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.

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

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

We used the nearest neighbour method with ratio 5. 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. Figure A in the annex illustrates the balance of means of our analysis.

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.

Therefore, the *PSM* results in Table 1 suggest balance of means, which consists in an appropriate counterfactual group for the *LVUC* hexagons. From these results, another important assumption for a causal inference analysis is the parallel trends between the compared groups. Figure 2 provides 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.

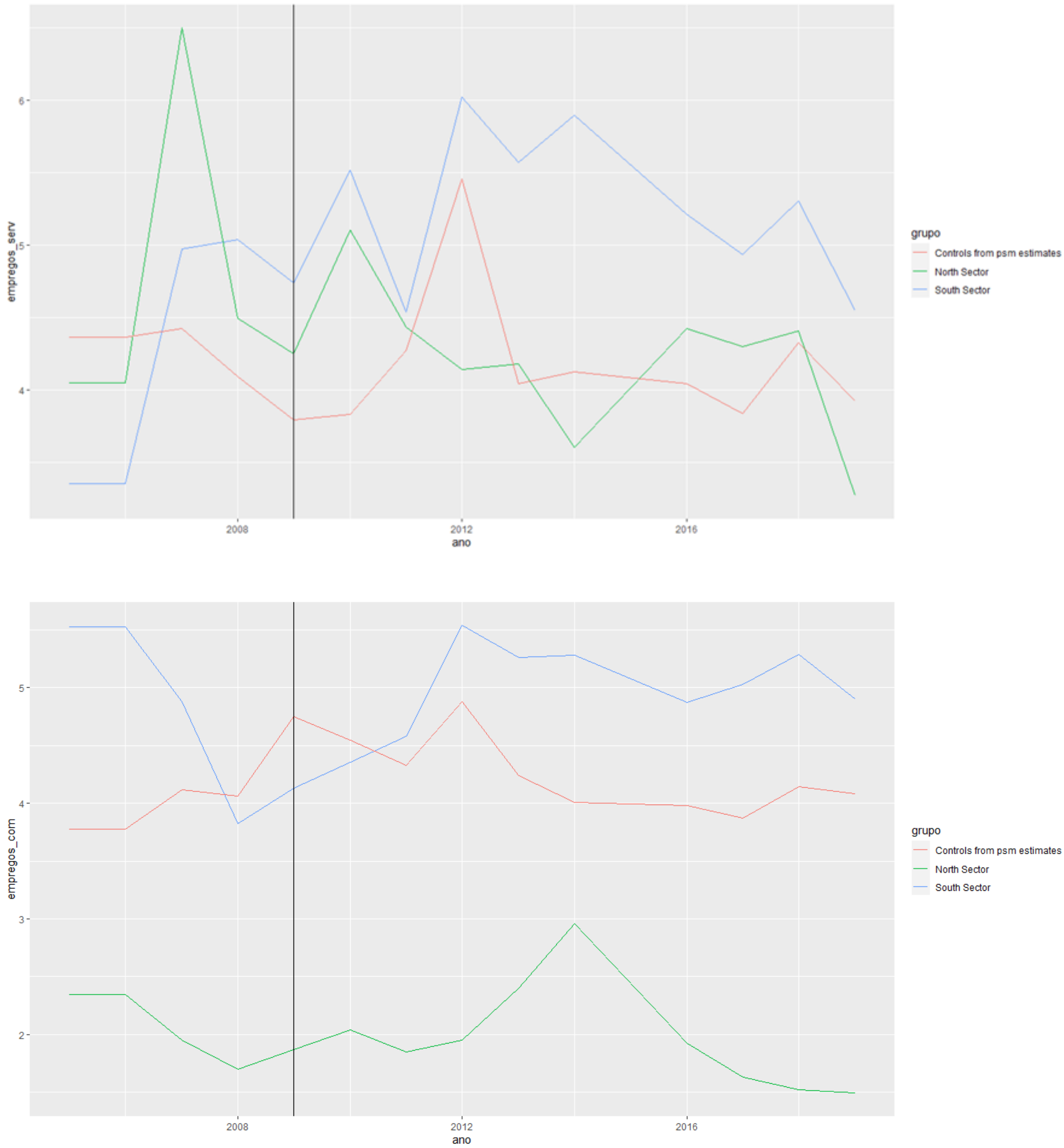


Figure 2 – Parallel trends of services and commerce jobs, respectively, for each group.
Source: Own elaboration, from the study database.

According to figure 2, the three groups had very similar trends on 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 on the trajectory of the groups. Figure 2 also shows the importance of an 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.

As discussed in section 3, the *LVUC* treatment areas had different time of implementation in the *BRT* infrastructure. However, both North and South Sectors had changes on zoning rules that encourage more intensive land use by the year of 2009 (Curitiba, 2012).

Therefore, the *LVUC* intervention area has heterogeneous treatment effects, so a typical difference in difference model will face estimation bias for the outcomes. In the aims to isolate the transport infrastructure treatment effect, we used triple-difference (DDD) models, which calculate the double differences of means among groups of interest (Berck and Vilas-Boas, 2015; Olden and Moen, 2020).

The equation (1) represents the mathematic scheme of our DDD models, which aims to estimate the double difference in difference of outcome means between 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 variable (10.7% and 10.5% of the sample), which is strictly positive and discrete. Therefore, we used poisson panel models to avoid estimation bias.

From this statement, the econometric reduced form of our poisson DDD 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*. $D_{t=1}$ is a dummy for samples in the second period, so 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 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*), as the years of 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 short and long term (5 and 10 years, respectively) effects of the *BRT* infrastructure in the jobs spatial distribution. We carry the hypothesys that observes the impact of the intervention in the jobs distribution, given population and income spatial distribution, as well as 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 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 DDD fixed effects models with and without the matched sample, in the aims 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 in the spatial distribution of jobs. According to table 2, there was positive local impact in the overall spatial distribution of jobs, in either 5 or 10 years after the delivery of the new transport infrastructure.

The 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. Therefore, although they suggest positive impact of the intervention on jobs, the magnitude of such coefficients are biased. Because the models 3 and 4 were estimated using a balanced sample, as described in table 1 and annex A, these are our favourite 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.

Table 2 – Poisson DDD fixed effect 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***
ZonLV.Post	-0.0008	-0.3950***	-0.7675***	-1.086***
Roads.Post	0.1610***	0.1693***	0.8749***	0.7392***
ZonLV.South	0.2289***	0.2294***	0.2053***	0.2290***
ZonLV	1.6133***	1.6128***	2.2853***	2.2490***
Roads	-0.5084***	-0.5101***	-1.2044***	-1.190***
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 log of income and log of population.

Both unbalanced and balanced samples' models suggest the same direction for all of the coefficients, which supports robustness of positive impact results. But the analysis' refinement for the poisson DDD fixed effects, that 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 poisson DDD fixed effects 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 average increase of 22.79% in the formal jobs, when compared with counterfactual groups.

The long term effects in formal jobs is estimated by model 4, which suggests average increases of 38.42% 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 notably changes in Brazil, the model 4 results indicate that transport infrastructure improvements increased the local potential attraction to 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 helps to explain 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 B, whose observes a higher density of apartments when comparing the years of 2000 and 2010. Therefore, we infer that a higher local potential consumer market emerged in such areas, given the incentives through the zoning rules changes and multimodal accessibility improvements. Indeed, the analysis of (Branco, 2016) suggests that the local residential market responded to the *LVUC* interventions with increases of prices, which indicates more local attractiveness for residential purposes.

A further understanding of the *LVUC* 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.

As shown in table 3, models (5) and (6) suggest that services' activities had local average increases for the south sector of 48 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 of Brazil (Silva et al., 2006).

Table 3 – Matched Poisson DDD fixed effect models for impacts on jobs by sector

Sector	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***
ZonLV.Post	-2.0049***	-2.1587***	0.4935***	0.2275***
Roads.Post	2.0057***	1.9380***	-0.3013***	-0.6945***
ZonLV.South	0.0348***	0.0772***	0.2402***	0.2394***
ZonLV	2.2243***	2.2125***	1.7352***	1.711***
Roads	-1.1672***	-1.1961***	-0.8482***	-0.8195**
Log-Likelihood	-306,090	-289,544	-189,468	-163,272

Source: Own elaboration, from the study database.

Notes: Signif. codes: p-value < 0.01 '***'; p-value < 0.05 '**'; p-value < 0.1'*'. Additional controls on these models are log of income and log of population.

The jobs from the commerce economic activities had a significant lower response related to the transport infrastructure in 2014, although positive in 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, in 33.8% percentage points, while there was a tiny decrease of 4.47% in service activities related jobs for the south sector. This difference of trajectories of the *LVUC* transport infrastructure effects might relate to the necessity of higher investments in fixed capital than in service activities.

The outcomes trajectories of figure 3 show that the amount 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 faster (2016) and stronger recover in such hexagons than in the remaining ones.

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 amount 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, local positive externalities for the residences, and unburden the transport municipal system.

6.2 Robustness Check

We also tested the robustness of the results of our models through a placebo test analysis. The intuition behind such 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 double-differences in differences between all groups before the beginning of construction of the *BRT* south sector infrastructure. In this sense, we used the year of 2002 as baseline and 2006 as comparison year[15].

Within such model design, any effect observed in the overall jobs spatial distribution can't 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.

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

Model	(9)	(10)
Year of comparison	2006	2006
Variable	Coefficient	Coefficient
ZonLV.South.Post	-0.0194*	0.0112
ZonLV.Post	-0.3128***	-0.7134***
Roads.Post	0.3175***	0.4909***
ZonLV.South	0.2053***	0.1553***
ZonLV	1.9366***	3.0413***
Roads	-0.7768***	-1.6846***
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 log of income and log of population.

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

When we use the unmatched sample for such analysis in 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.

From this, 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 of 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 evidences 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 real post treatment period.

7 Final Remarks

The evaluation analysis of this study aims to measure the existence of local impact of the *Linha Verde Urban Consortium* on the spatial jobs distribution. We bring the hypothesis that if the urban intervention attracted population through its positive externalities, it also attracted more economic activities, which we observe through the local quantity of 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 results found positive effects of the *BRT* transport infrastructure in 5 and 10 year after the delivering of such infrastructure. 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 service jobs remained reasonably stable in the long term. Therefore, we found efficacy and effectiveness of this urban intervention in the objective of diversifying local land use with non-industrial activities.

We also used 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.

The limitations of this study rely on the external validity of the results, which are limited to urban areas with similar urban aspects of Curitiba. However, our research design contributes with a high internal valid analysis, given the fine spatial resolution of our data. Further researches 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 our quasi-experimental design for urban interventions in other urban areas.

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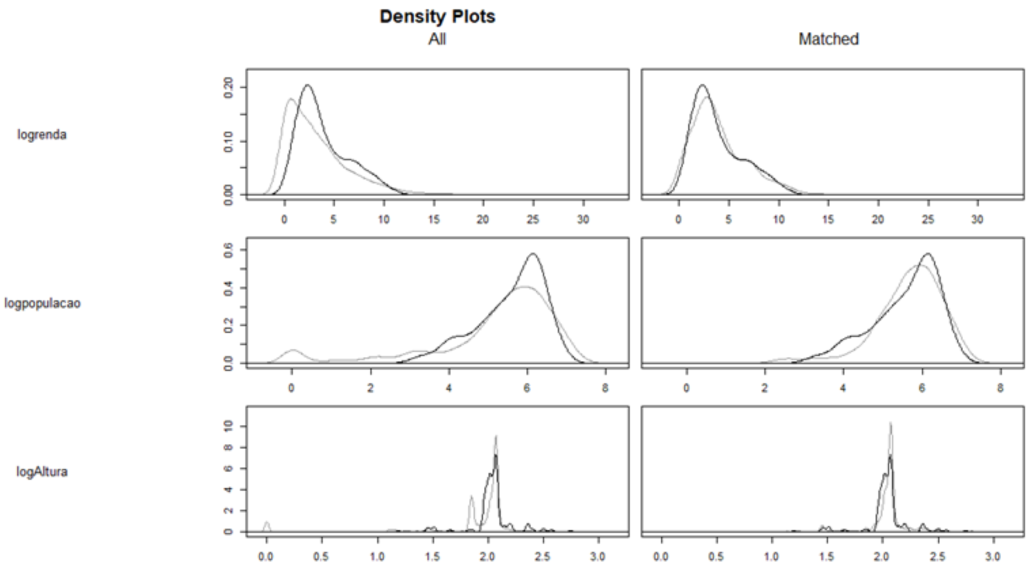
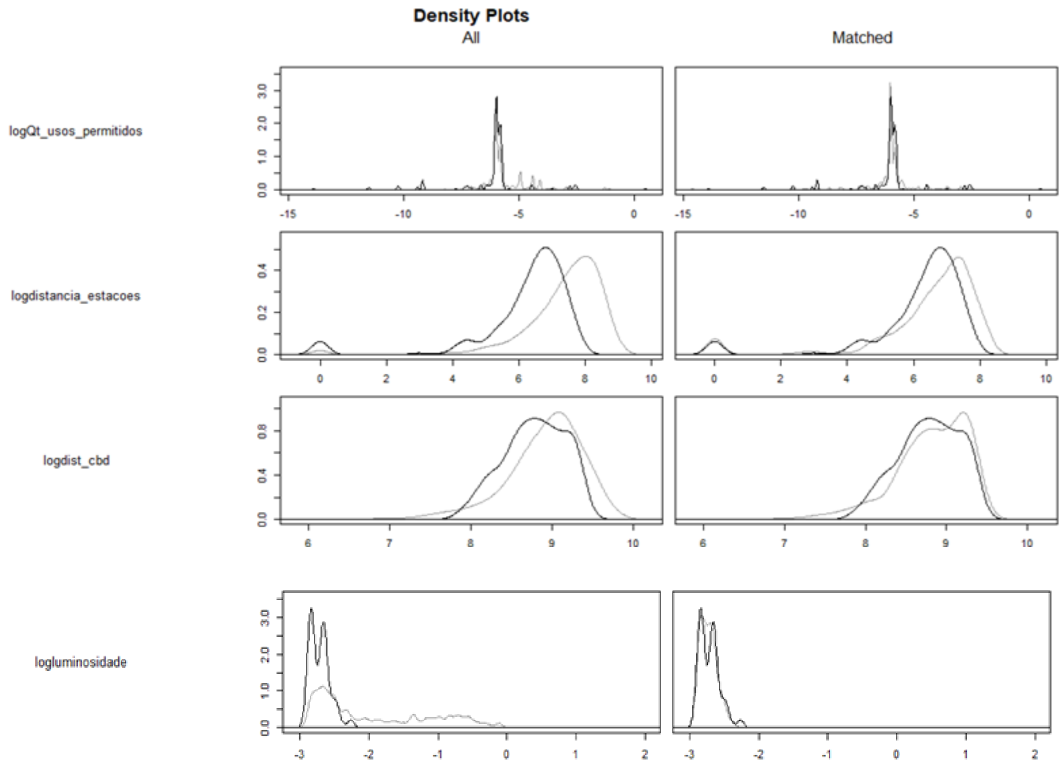
Annex A

Figure 3 - PSM Density plots for unbalanced and balanced samples.





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

Annex B

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	0.2519***
ZonLV.Post	-0.2278***
Roads.Post	0.0619
ZonLV.South	0.0051
ZonLV	0.0381
Roads	-0.0484
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.