The impacts of BRT on the spatial distribution of jobs in Curitiba, Brazil

Luiz Pedro C. S. Silva*

Abstract

Urban land use planning is a challenging task, especially in developing countries. Some cities manage land use with Transit Oriented Development, with the aim to coordinate urban growth with public transport. This paper evaluates the extent to which a new Bus Rapid Transit (BRT) infrastructure impacted the spatial distribution of jobs in the city of Curitiba, Brazil. We used data with geographic granular information to develop a novel quasi-experimental design that combines PSM, Diff-in-Diff and Double Diff-in-Diff models and evaluates the impacts of the new BRT infrastructure and zoning rule changes on the spatial distribution of jobs for different economic sectors. The results evidence spatial changes of service-related jobs toward the new BRT infrastructure. However, the initial positive impact in commerce-related jobs vanishes over time, suggesting that the significant delays in the execution of this infrastructure program has deteriorated the creation of jobs in the intervention area.

Keywords: Transit Infrastructure, Bus Rapid Transit, Spatial Distribution of Urban Employment, Curitiba.
JEL Classification: C54, J61, R42.

* PhD student at the Federal University of Juiz de Fora.

1. Introduction

The technological evolution process of the motorized transport that increased the speed of travel during the 20th century had consequences in the economic dynamics of cities and led them to do massive investments in transport infrastructure (Anas et al., 1998). These investments are justified by the knowledge that cities must provide benefits through density, which requires the existence of urban amenities through economic mechanisms like speedy transportation and consumption diversity (Glaeser et al., 2001). Thus, the pursuit of these objectives must include policies that allow for sustainable land use developments.

There is a long date concern among urban planners about the effects of public transport infrastructure on the land use (Knight and Trygg, 1977; Cervero, 1984). They advocate that the expansion of the rapid transit network could be an alternative to coordinate the urban expansion by a compact multi-centered spatial structure and avoid the disamenities of scattered spatial dispertion toward peripheries (Cervero and Landis, 1996). This gave raise to the Transit Oriented Development (TOD) concept, which aim to enhance the connection between nodes of rapid transit and places (eg: work, live, leasure and shopping), and then, materialize sustainable land use paterns in cities (Bertolini, 1999; Cervero and Kockelman, 1997; Kamruzzaman et al., 2014). The effectivess of TOD policies to foment land use development depends on their capacity of enhancing diversity and intensity of human activity on the surrounding areas of its transport nodes (Bertolini, 1999), accordingly to their infrastructure standards (Vale, et al., 2018; Kamruzzaman et al., 2014; Zemp et al., 2011). An alternative to strengthen the integration between public transport and land use is the Bus Rrapid Transit (BRT) system, that yields speed and comfort of travel with significative lower cost than light and heavy rail or metro (Cervero and Dai, 2014). The atractiveness of the BRT as a solution for public transportation challenges due to its low cost effectiveness resulted in the adoption of this rapid transit model by 166 cities worlwide.

The city of Curitiba in Brazil is a case of the urban expansion recognized as a well succeeded example for the use of BRT, by which its process led to an urban form with higher population density over the structural axes (which are served by BRT corridors). Besides that, the zoning of Curitiba adopt rules of mixed land use that follow a spatial hierarchy based on the BRT infrastructure and consolidates a TOD environment. In 2006, Curitiba launched the *Linha Verde* (*LV*) intervention, which is its most recent policy to foment a linear urban expansion. This urban intervention aims to enhance residential occupation and the intensity of commerce and service activities around the federal road BR-116, which used to be an area with low land use development due to its environmental characteristics. The main mechanisms to achieve the goals of the *LV* rely on the implementation of 22 km BRT exclusive bus corridors and new tube stations, which were 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 this city's total area, there are no empirical studies evaluating the effects of the *LV* on the spatial distribution of jobs, which is a key element on the land use development.

This study has the objective to evaluate the local impacts of the *LV* on the spatial distribution of jobs of the city of Curitiba. We used longitudinal data in high spatial resolution to make a novel quasi-experimental design that can be useful for other studies about urban interventions. It combines Propensity Score Matching, Diff-in-Diff, and Double Diff-in-Diff models with the aims to understand the short and long run local impacts of the *LV* on the jobs of different economic sectors. There is evidence of positive impacts of the BRT corridor's expansion on the job density of cities like Bogotá and Quito (Bocarejo et al., 2013; Rodriguez et al., 2016; Verge-Tovar and Rodriguez, 2022), Seoul (Cervero and Kang, 2011; Kang, 2010), and Los Angeles (Schuetz, 2015). However, the strategies of identification of such effects are based on arbitrary spatial areas or distances from the BRT infrastructure that make the results scuptible to omitted variable and selection bias, as well as violation of the stable unit treatment values assumption.

The novel research design used in this study contributes to the literature of impact evaluation of urban interventions with a more reliable approach: the spatial refinement of our longitudinal data allows us to use the geography of the zoning laws of the *LV* to assign the treatment and control groups. Moreover, the spatio-temporal differences in the execution of the *LV* intervention allows exploring the distinct effects of the *LV* (BRT infrastructure versus zoning law changes). Besides that, this paper brings the first evidence about the impacts of the *LV* on the employment spatial distribution of the city of Curitiba, which is pioneer on the use *TOD* policies by the implementatiton of the inovative BRT system in structural axes that guide its linear urban expansion process since the 1970s (IPPUC, 2019). This investigation dialogues with a growing body of literature about the impacts of the BRT system on the land use (Cervero and Kang, 2011; Schuetz, 2015; Tsivanidis, 2022; Verge-Tovar and Rodriguez, 2022), and by the lens of accessibility to job opportunities (Scholl et al., 2018; Venter, 2016), and jobs-housing ratio (World Bank, 2017), given that the spatial distribution of jobs is an input for the measures used in these approaches.

The remainder of this paper is organized as follows. The next section describes the *Linha Verde* intervention of Curitiba and is followed by a section presenting the data, then the next section details the identification strategy with the quasi-esperimental design, followed by results and discussion. The final remarks are highlighted in the last section.

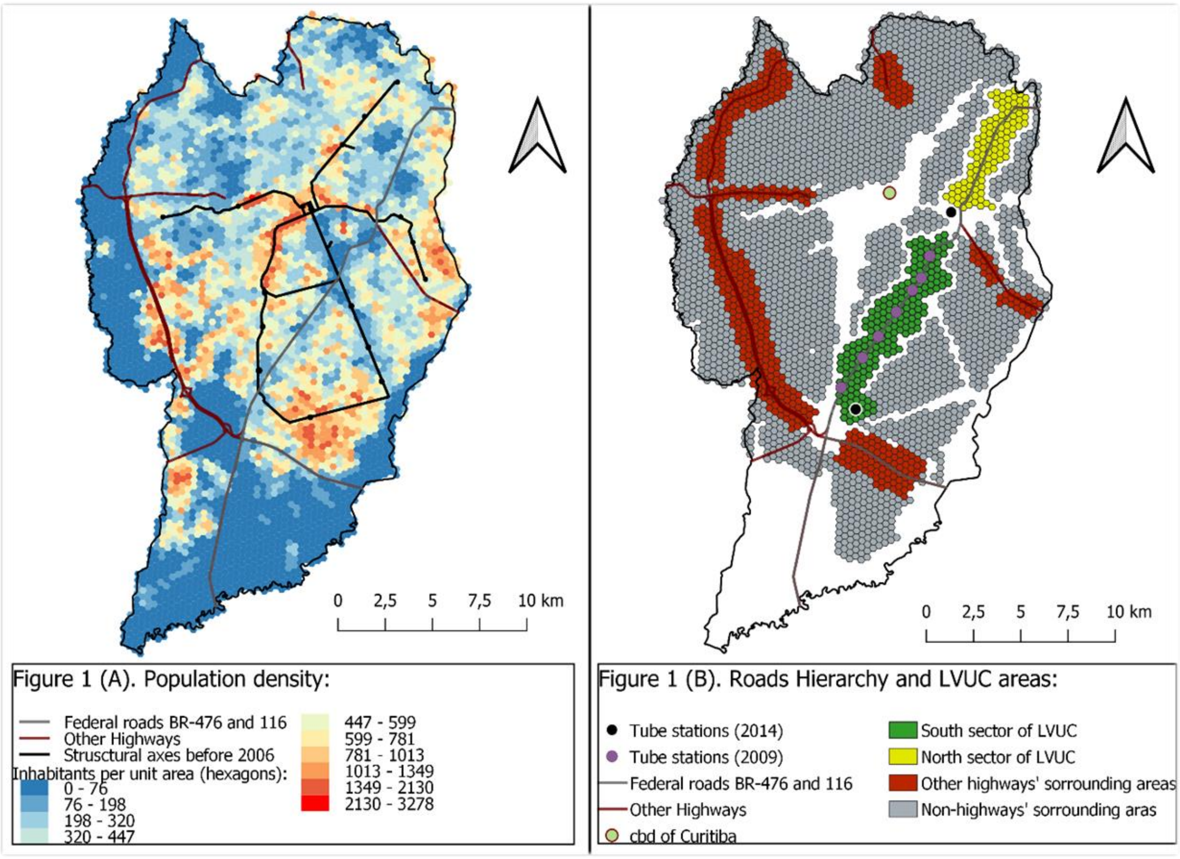
2. The Linha Verde Urban Consortium of Curitiba Intervention

Curitiba is a city located in the south region of Brazil with 1.9 million inhabitants that has a long relationship with TOD policies in its process of urban growth. Since the year of 1966, this city's urban plans have been guiding a linear urban expansion process based on structural axes[2], which induce the population density and economic activities to areas accordingly to local road and transit infrastructure (regular bus or bus rapid transit) standards (IPPUC, 2019). Nevertheless, in the 2000s, Curitiba still had areas with intense road infrastructure and underused land. The federal road BR-116, which was built in the 1990s decade, passes from the south to the northeast limits of the city, and had created 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, and had its land use more related to industrial activity. Figure 1 (A) shows that in the year of 2000 the population density was still bellow the desired in such areas, even after three municipal policies[3] that attempted to improve the conectivity to residential areas as well as the local accessibility for active and transit modes (Curitiba, 2012).

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

[2] 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.

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



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 aims to foment land use development in most of the BR-116 road surrounding area embracing 22 neighborhoods. The *LVUC* transformed 22 km of the BR-116 road into a new structural axis, in addition to the construction of exclusive bus corridors and BRT tube stations. In accordance with the linear urban expansion pattern of Curitiba, this new improvement in transit infrastructure was followed by changes in zoning rules, wich allow for more intense and mixed land use with the aims to attract population, commerce, and service activities to the *LVUC* area (Curitiba, 2012).

The *LVUC* is delimited in two areas: the South sector and North sector. The public transport infrastructure improvements started partially in the former, by the year 2007, on a 9.4 km long BRT corridor that finished in the year 2009, with the conclusion of seven new tube stations, as shown in 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 expanded the allowance of land use for residential, commerce and service purposes. The same zoning rules became valid in the north sector in the year 2011 (Curitiba, 2012), and the zoning rules of the year 2000 remained in the remaining territory of the city of Curitiba[4].

In the year 2012, the South sector had a complementary expansion of transit infrastructure on a 1.7 km long BRT corridor with one new tube station for the Brazilian World cup. The launching of this transit infrastructure in 2014 was the end of the *LVUC* intervention in the south sector. Parallel to that, the transport infrastructure interventions in the north sector started in the year 2010. However, because of legal irregularities, this sector faced many interruptions during the process of its transit infrastructure construction, which resulted only in a 1.8 km long area of exclusive corridors and one new tube station by the year 2014. Although there is still an attempt to finish the transit infrastructure project in the whole north sector, until the year 2019, there were no further conclusions of BRT station tubes or exclusive bus corridors in the north sector (Curitiba, 2019). Therefore, in the year 2020, 14 years after the beginning of the LVUC intervention, there was a total finantial spent of R$ 486 million[5], in which only part of transport infrastructure was finished (South sector).

3. Data

The empirical analysis of this study projected the city of Curitiba in a hexagon grid with $0.11km^2$ area each. We aim to observe the spatio-temporal distribution of data within each hexagon with granulated information of resolution 9 in a spatial hierarchical index[6] H3. Thus, we followed three procedures to create the spatial structure of data. For the demographic, economic and infrastructural information, we adopted the same two-step spatial areal weighted interpolation of data developed by (Pereira et al., 2019). In the first step, it uses the *aerial* package in R to do an areal weighted interpolation from the original spatial structure of the data into the hexagon grid in H3 resolution 9. In the second step, the procedure uses information from the Brazilian census statistical grid of 2010, which has information of population in squared spatial units of 200 x 200 meter (IBGE, 2016) to realocate the socioeconomic data where there was population detected in 2010. This spatial data structure allows observation of information without assuming spatial evenness in the distribution of it, as well as avoiding bias of socioeconomic information in areas with no population, which brings more reliability for a spatial refined data analisys (Pereira et al., 2022).

[4] The remaining areas of the city maintained the 2000s zoning rules until the year of 2019. See Curitiba (2000) and Curitiba (2012) for more details of these zoning rules.
[5] https://www.plural.jor.br/noticias/vizinhanca/em-obras-ha-13-anos-linha-verde-sera-concluida-so-em-2022/.
[6] See: https://eng.uber.com/h3/ for more details.

The population data is from the Global Human Settlement Layer (*GHSL*), provided by the European Union (Florczyk et al., 2019), for the years 2000 and 2015. This information structures into squared grids of 350 m^2, which is its finest spatial resolution. Figure 1(A) shows this data for the year 2000. The information about income is from the Brazilian Censuses of 2000 and 2010, which are available in census tracts that have between 200 to 300 households each. The Information on urban night light intensity (luminosity) is from satellite images of the National Oceanic and Atmospheric Administration (*NOAA*), of each 30-arc-second-square (which consists of a 0.86km^2 area) of Curitiba. We followed Gaduh et al. (2022) and computed the six-year period means of the luminosity of 2001-2006 with the aim to observe local urban activity intensities. We also observed the influence of the rules of the zoning laws valid for the period 2000-2019 through the building height allowed [7] and the number of different land activities allowed in that territory (Curitiba, 2000). In this zoning spatial data, we did a one-step areal weighted spatial interpolation, in which a zoning shapefile was used to determine the spatial proportion of each zoning geometry that intersects the hexagon grid.

The outcome variables were structured in microdata of latitude and longitude (points). We used information from the Relação Anual de Informação 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 and match with each 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 related activities[8] (transport and communication, clinical and hospitals, education, financial institutions, food, repair, accommodation) within formal jobs[9].

4. Empirical Strategy

4.1. The quasi-experimental design for the LVUC intervention

This study developed a quasi-experimental design to identify the causal effects of the LVUC in the spatial distribution of employment in Curitiba. The mechanisms to be evaluated are the zoning rule changes and the BRT new corridor’s expansion. Our fine spatial data was used in

[7] This variable was inverted: (1/the maximum height). In this sense, we consider zero as no height restriction.
[8] Following the national classification of economic activities (CNAE) from IBGE.
[9] 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.

a quasi-experimental design that focuses on two specific areas of the city of Curitiba as being treated by the LVUC intervention, which are the hexagons shown in Figure (1.B), located on the South sector and on the North sector. Because the LVUC intervention includes changes in the permissiveness of land use by increasing the maximum build height and the variety of economic activities, the geography of its sectors became a reliable assignment to define the treated areas. An important fact about LVUC is that it had different time of implementation of its BRT infrastructure, in which only the South sector had concluded this infrastructure by the year 2019. Thus, we assigned the North sector as only being treated by more permissive zoning rules, while the South sector had this benefit in addition to 9.4 km of new BRT corridors.

The selection bias is a concern in causal identification of average treatment effects, since the intervention area is not randomly determined (Angrist and Pischke, 2010; Baum-snow and Ferreira, 2015). Thus, we used a Propensity Score Matching (PSM) model to control for observable urban characteristics that relate to the likelihood of receiving the *LVUC* intervention. The objective of this model is to make the treatment assignment strongly ignorable based on sample information, by balancing for unbiased means between control and treatment group samples (Rosenbaun and Rubin, 1983). We did the PSM on the hexagons of Curitiba that neither had BRT corridors until 2006, nor belonged to the *LVUC* area, in the aims to avoid selection bias on the counterfactual candidates. Therefore, our candidates for counterfactuals are the grey and red hexagons shown in Figure 1.B, while the green hexagons are the treatment group.

The propensity score was estimated using a logit model with the nearest neighbour method with a ratio 5. The probability for the hexagon being treated by the LVUC is explained by the logs of: population density in the year 2000, mean household income in the year 2000, linear distance from the hexagon centroid to a BRT station in the year 2006, linear distance from the hexagon centroid to the CBD of Curitiba, mean luminosity during the 2001-2006 years period, the quantity of different land use activities allowed in the hexagon, and the maximum height allowed for buildings accordingly to the zoning rules. Table 1 summarizes the t-means test that compares the means of treatment group with the counterfactual group formed by the PSM models, and shows strong balance between the variable means of such groups.

Table 1 – Descriptive statistics after Propensity Score Matching estimates.

		LVUC (South Sector)		PSM Counterfactuals (Highways + remaining streets)
Variable	**N**	**Mean (Sd)**	**N**	**Mean (Sd)**
Log income	108	2.79 (3.19)	373	3.09 (2.14)
Log population	108	7.49 (0.48)	373	7.43 (0.73)
Log linear dist to a BRT station	108	5.57 (0.52)	373	5.65 (0.86)
Log quantity of land uses	108	-5.46 (1.10)	373	-5.51 (1.31)
Log allowed Height	108	1.91 (0.24)	373	1.93 (0.34)
Log linear dist to CBD	108	8.61 (0.26)	373	8.65 (0.54)
Log luminosity	108	-2.58 (0.22)	373	-2.56 (0.33)

Source: Own elaboration, from the study database.
Notes: 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. *** / ** / ***** denotes significant at the 10% / 5% / 1%, respectively. Counterfactual group was formed based on nearest neighbour propensity score matching model.

We tested the parallel trends between the hexagons located in the counterfactual group built by the PSM model and those located on the *LVUC* sectors, which are the treated groups. Figure 2 shows that before the year 2009, both the hexagons in the counterfactual and the treated groups have had similar trends on the quantity of non-industrial jobs. It suggests that the set of variables used in the PSM model controls for relevant characterstics to make these groups similar, and that any shock on unobservable characteristics that would change the trajectory of the outcomes (jobs) is commonly observed through this set of variables (Angrist and Pischke, 2010). Another concern about causal identification of average treatment effects in urban interventions is the likelihood of spillover effects to areas that were not targeted by the policy design, what may violate the Stable Unit Treatment Value Assimption (SUTVA) in the analysis (Baum-snow and Ferreira, 2015). However, Curitiba has a long time tradition of discipline of land use with its zoning rules (Cervero, 1998; Deng and Nelson, 2010). Thus, we assume that the institutional strengh behind the spatial delimitation through the zoning rules assures that the hexagon's land uses are constrained by the zoning rules of Curitiba (Curitiba, 2012).

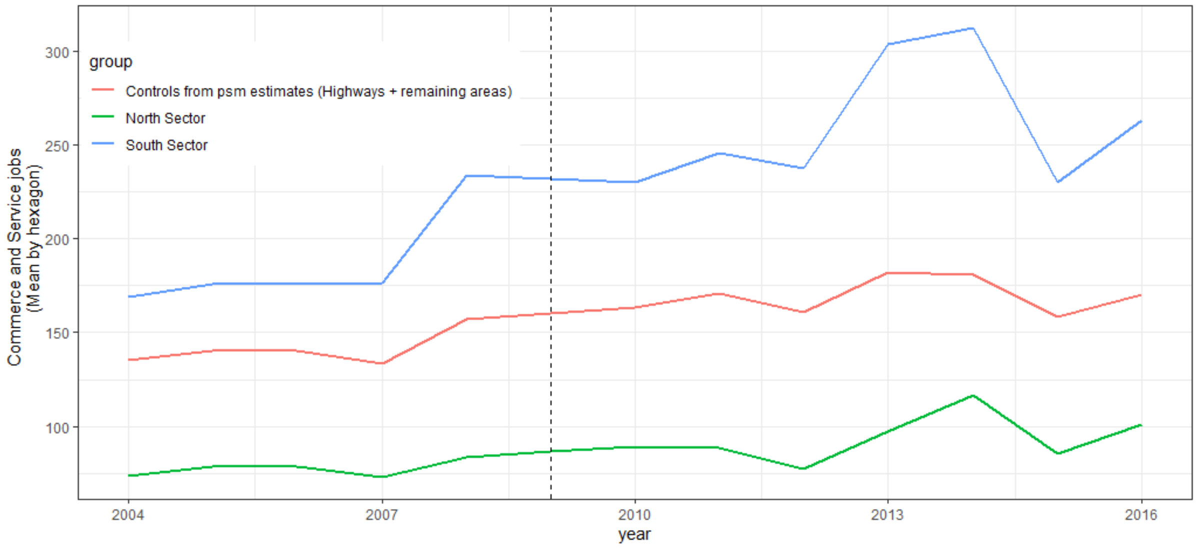


Figure 2 – Parallel trends for the treatment and counterfactual groups.
Source: Author's own elaboration.

4.2. The causal identification econometric models

For the causal identification, we used econometric models with Differences-in-Differences (DID) and Double Diff-in-Differences (TD) methods to estimate the impacts of the *LVUC* in the spatial density of jobs. Our DID models are mathematically represented in equation (4.1).

$$ATE = (Avg_{tread,post} - Avg_{tread,pre}) - (Avg_{Control,post} - Avg_{Control,pre}) \qquad (4.1)$$

Following the Differences-in-Differences method, the Average Treatment Effect (ATE) is composed by the difference in the averages of the outcomes within the treated group post and pre intervention, minus the average diffferences in the outcome within the control group post and pre intervention. Because we deal with a significant amount of zero values on the sample (11%) due to our spatial unit size of 0.11km^2 and the characteristics of the land use that motivated the *LVUC* intervention, we used poisson econometric models with the reduced form:

$$Jobs_{ist} = \beta_0 + \beta_1 LVSouth + \beta_2 Post + \beta_3(LVSouth.Post) + \beta_8 X_{it} + \varphi_i + \gamma_t + \varepsilon_i \qquad (4.2)$$

where *Jobs* is the average quantity of jobs in the period *t* on the hexagon *i*, at the sector *s* (commerce or services). *LVUCSouth* is a dummy variable for the hexagons in the South Sector of *LVUC*, and *Post* indicates the post intervention period, averaged between (2006-2008 against 2010-2012) for the sort run, and (2002-2008 against 2010-2016) for the long run. *X* is a vector of time-varying covariates, composed by the hexagon's population density and mean income, φ is a within group fixed effect, and γ is a time-fixed effect. Therefore, the iteraction dummy $LVUCSouth.Post$ results in the β_3 coefficient, which represents the ATE on the jobs' density. However, as previously discussed, there was heterogeneous treatment between the South and North sectors due to delays in the conclusion of the BRT infrastructure. Thus, we doubled the differences within each group (LVUC and Controls) to estimate the relative average treatment effects (RATE) due to the BRT infrastructure on the jobs' density through Double Diff-in-Differences models. This method estimates the net outcome gains by differentiating the groups based on the exposition to the intervention (Berck and Vilas-Boas, 2015; Heilmayr et al., 2020; Ravaillion, 2005). The Double Diff-in-Differences models are mathematicaly represented in equation (4.3).

$$RATE = \{[(Avg_{South,post} - Avg_{South,pre}) - (Avg_{North,post} - Avg_{North,pre})] - [(Avg_{Highw,post} - Avg_{Highw,pre}) - (Avg_{Nohighw,post} - Avg_{Nohighw,pre})]\} \quad (4.3)$$

The *RATE* estimator makes clean estimatives of the effects of the BRT infrastructure on the jobs' density. It compares the intertemporal differences between the hexagons of the South sector, of the North sector, of those surrounding the urban highways of Curitiba, and those Non-surrounding highways, which follow the geography shown in Figure (1.B). The reduced form for the poisson the Double Diff-in-Difference models follows:

$$Jobs_{ist} = \beta_0 + \beta_1 Highway + \beta_2 LVNorth + \beta_3 LVSouth + \beta_4 Post + + \beta_5 Highway * Post + \beta_6 LVNorth * Post + \beta_7 LVSouth * Post + \beta_8 X_{it} + \varphi_i + \gamma_t + \varepsilon_i$$
(4.4)

where *Highway* is a dummy indicating that the hexagon *i* sorrounds a federal or state highway that crosses the territory of Curitiba, and *LVs* North and South are dummies for the hexagons within the the two sectors of the *LVUC* intervention. In this model, β_7 is a coeficient that compares the relative change in the outcomes with each group in equation (4.3) due to the average treatment effects of BRT. We assume that by estimating such geographically disaggregated effects, the RATE observes the net jobs' density gains due to BRT infrastructure.

5. Results

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

This subsection presents the analyses for the impacts of the *LVUC* on the overall (service and commerce related) formal jobs in the short and long run, through the periods of 3 and 7 years after the BRT intervention, respectively. Table 2 shows that although the results show positive impacts of the intervention in the South Sector hexagons in the short run, these hexagons' relative economic advantages seem to have had decreased in the long run.

Table 2 – Results of diff-in-diff regressions for the overall jobs.

Coefficient	Short Run (1)	Long Run (2)	Short Run (3)	Long Run (4)	Short Run (5)	Long Run (6)	Short Run (7)	Long Run (8)
LVUCSouth*Post	0.090***	0.078***						
	(0.0082)	(0.0088)						
LVUCNorth*Post			-0.04***	-0.049***				
			(0.0100)	(0.0107)				
LVUC*Post					0.076***	0.059***		
					(0.0093)	(0.0100)		
Highways*Post							-0.063***	0.103***
							(0.0276)	(0.0310)
N (hexagons)	**1,242**	**1,248**	**1,242**	**1,242**	**1,242**	**1,248**	**1,242**	**1,248**

Notes: Signifcance codes: p-value < 0.01 '***'; p-value < 0.05 '**'; p-value < 0.1'*'. Standard deviation in parenthesis. Each model have the additional dummies of the differences-in-differences, and control variables of log of income, log of population, intra-group fixed effects, and time-fixed effects. The regressions for the Curitiba city exclude hexagons located in the old trinary axises, as shown in Figure 1(B).

The models in table 2 show that the hexagons located in the South Sector had positive impacts with magnitudes of 9% and 7.8% in the short run and long run, respectively. These results in the long run suggest for stagnation in the economic atractiveness of the North Sector due to the delays in the conclusion of the BRT infrastructure. Despite this lack of gains in attractiveness for economic activity in North Sector for the long run, the DID model for the whole *LVUC* area shows that its aggregated performance led to gains in jobs' density of 7.6% and 5.9% in the short and long run, respectively. However, these gains in the *LVUC* structural axis were larger than the gains in the surrounding highways areas only in the short run, which relates to the increases of jobs' density in the South Sector. Therefore, we infer that there would have been significative positive impacts in the jobs' density if the Linha Verde structural axis had not only changed its zoning rules, but also finished the construction of BRT infrastructure. Although the results show that the *LVUC* had weak positive impacts in the sort run and null impacts in the long run on the overall jobs, it may be the case that there are different patterns if the analysis considers each economic sector separately. Therefore, we made a further analysis that investigates the *LVUC* impacts by economic sectors.

5.2 Impacts of the LVUC on the jobs of commerce economic sectors

Now we show analyses of the impacts in the job density by economic sector. Table 3 has the results of the analysis for the commerce-related jobs, which includes jobs in retail, wholesale trade, and real estate companies. The Diff-in-Diff models in Table 3 are consistent in showing that although the South Sector had small positive impacts in the jobs' density in the short run, it also showed negative results in the long run. They also suggest that the North Sector had small decreases in the jobs' density in the comparison with the surrounding highways' hexagons for the short run, however, converted in positive impacts in the long run. This combination of results for the South and North sectors in the comparison between the *LVUC* axis and the surrounding highways' hexagons resulted in positive effects of 3.2% of the urban intervention in commerce-related jobs in the short run and null effects effects in the long run.

Table 3 – Results of diff-in-diff regressions for the commerce-related jobs.

Coefficient	Short Run (1)	Long Run (2)	Short Run (3)	Long Run (4)	Short Run (5)	Long Run (6)	Short Run (7)	Long Run (8)
LVUCSouth*Post	0.038***	-0.104***						
	(0.0116)	(0.0125)						
LVUCNorth*Post			-0.017	0.180***				
			(0.0142)	(0.0159)				
LVUC*Post					0.032**	0.0108		
					(0.0130)	(0.0141)		
Highways*Post							0.003	0.479***
							(0.0472)	(0.0581)
N (hexagons)	**1,242**	**1,248**	**1,242**	**1,242**	**1,242**	**1,248**	**1,242**	**1,248**

Notes: Signifcance codes: p-value < 0.01 '***'; p-value < 0.05 '**'; p-value < 0.1'*'. Standard deviation in parenthesis. Each model have the additional dummies of the differences-in-differences, and control variables of log of income, log of population, intra-group fixed effects, and time-fixed effects. The regressions exclude hexagons located in the old trinary axises, as shown in Figure 1(B).

The low capacity of the urban intervention on fomenting local atraction of commerce-related activities has multiple sources. Besides the significative delays in finishing the construction of the BRT infrastructure, one must take into consideration the local income growth over periods, which is very explanative about the atractivity for commerce and service activities, as detected by (Kang, 2019). Our data from the Brazilian censuses of 2000 and 2010 show that while the income growth in a 10 year period within the *LVUC* area was of 10.71%, in the Highways' surrounding hexagons it was of 23.18%, which overpassed the mean income of the *LVUC* in 2010. The population growths of these areas did not had significative differences over the period 2000-2010. Thus, it is likely that commerce activities in Curitiba are more sensitive to income and other factors than to BRT infrastructure. However, further conclusions about these specific causes are out of the scope of this study.

Besides that, Curitiba (2012) describes that previous to the intervention period, the South Sector had significative presence of storage and industrial sheds, corresponding to 53% of the total of its land area, while this percentage was 11% for the North Sector. This land use pattern may be harmful for the local development of retail sales activities, as they are impeditive to a contiguous land development, and reduce the incentives of investiments in these activities nearby such areas (Schuetz, 2015). There is also evidence that the South Sector had significant increases in the land value due to the *LVUC* intervention (Branco, 2016; Gavriloff and Fraga, 2014). This local effect in the real estate market can stagnate investments in business that require large areas to operate, as does most of retail sales (eg: malls, supermarkets).

5.3 Impacts of the LVUC on the jobs of service economic sectors

Here we discuss the results of the regression models for the impacts of jobs' density on the service-related jobs, which embrace jobs located in offices of credit, capitalization, secure, and educational institutions, as well as restaurants, bars, accomodations, and medical services. The DID models in table 4 show that for this economic agregated sector, the South Sector had very consistent positive impacts on the jobs' density, which roughly doubled in percentage points from the short to the long run analyzes.

Table 4 – Results of Diff-in-Diff regressions for the service-related jobs.

Coefficient	Short Run (1)	Long Run (2)	Short Run (3)	Long Run (4)	Short Run (5)	Long Run (6)	Short Run (7)	Long Run (8)
LVUCSouth*Post	0.115***	0.249***						
	(0.0120)	(0.0127)						
LVUCNorth*Post			-0.056***	-0.234***				
			(0.0143)	(0.0148)				
LVUC*Post					0.991***	0.100***		
					(0.0136)	(0.0145)		
Highways*Post							-0.107***	-0.0353
							(0.0347)	(0.0375)
N (hexagons)	**1,242**	**1,248**	**1,242**	**1,242**	**1,242**	**1,248**	**1,242**	**1,248**

Notes: Signifcance codes: p-value < 0.01 '***'; p-value < 0.05 '**'; p-value < 0.1'*'. Standard deviation in parenthesis. Each model have the additional dummies of the differences-in-differences, and control variables of log of income, log of population, intra-group fixed effects, and time-fixed effects. The regressions hexagons located in the old trinary axises, as shown in Figure 1(B).

There is also consistency about the increasing negative impacts in the jobs' density for the North Sector over time, as well as the positive impacts in the *LVUC* axis. We interpret that the local atraction of service-related jobs within the South Sector was high enough to assure positive impacts within the *LVUC* area, even with the negative results for the North Sector. Thus, the DID analyzes evidence that in an opposite trend from the commerce-related jobs, the service-related jobs moved from the highways' surrounding hexagons toward the *LVUC* hexagons. The positive impacts of the LVUC intervention in the service-related jobs' density in the South Sector relates to the potential benefits promoted by the new BRT ifrastructure. This conclusion is reforced by the contrast within the *LVUC* axis between the South and North Sectors, given that the last had only changes in the zoning rules.

These results converge with what was found by Nelson et al. (2013), which evidence that the positive impacts of the BRT infrastructure in service-related activities were stronger than in commerce- related activities, such as retail sales. However, one must consider the built environments within the LVUC intervention. According to Curitiba (2012), while before the intervention period the North Sector was prodominant in horizontal buildings (houses), the South Sector had more vertical buildings (apartments). The director planning of Curitiba has incentives for the use of active facades in the built environment within the structural axises, which enhance the increase of mixed land use between residences in condos and service stores nearby BRT infrastructure. This built environment is more favourable to service-related activities, given that they require smaller areas than commerce-related activities.

Although we have detected a good performance of the South Sector in atracting service-related jobs, this economic sector tends to be less intensive in the total number of employees. In our database, there was a total of 1.29 milion service-related, and 1.51 milion commerce-jobs in the sample for the total period. However, one should consider that service-related activities are local positive externalities, as they provide local consumer amenities, which are relevant incentives to promote density in urban areas (Glaeser et al., 2001). Consumer diversity is also an incentive for the location of people toward the economic activities nearby rapid transit stations. Accordingly to TOD concepts, this incentive is a mechanism to increase ridership in Public Transport and materialize a sustainable land use (Bertolini, 1999; Kamruzzaman et al., 2014). Therefore, we conclude that the jobs atracted by the BRT infrastructure implemented in the *LVUC* intervention succeeded in improving the local range of amenities for households nearby.

The transport infrastructure amenities also impacted the geography of the labour market, but with positive effects restricted to very specific economic activities. We infer from the results that the failure in the execution of the *LVUC* intervention in the North Sector regarding the BRT infrastructure stagned the local relative atraction of economic activities, and therefore, the potential impacts on the jobs' density.

5.4 Double diff-in-diff results

Finally, the models in Table 5 show the results of the Double Diff-in-Differences models, in which the coefficients are interpretable as the percentage net difference in the outcome between each group. Consistent with the DID models, the Double Diff-in-Differences models show relative gains in the commerce-related jobs' density for both the short and long run periods in the South sector. However, although the South Sector was the only group that had statistic significance in the relative gains of commerce-related jobs' density for the short run, it is noticeable that these relative economic advantages had vanished in the long run. Following the mathematics of these models in equation (4.3), the relative increases in the attractiveness of the hexagons located in the highways' surrounding areas are part of the explanation for the stagnation in the relative gains of the South Sector, which overcame the relative gains of the Linha Verde South.

Table 5 – Results of double diff-in-diff regressions

	Commerce-related jobs		Service-related jobs		Overall jobs	
Coefficient	Short Run (1)	Long Run (2)	Short Run (3)	Long Run (4)	Short Run (7)	Long Run (8)
LVUCSouth*Post	0.044***	-0.0132	0.125***	0.203***	0.099***	0.094***
	(0.0117)	(0.0151)	(0.0150)	(0.0160)	(0.0105)	(0.0082)
LVUCNorth*Post	0.117	0.177***	0.125	-0.098***	0.020	0.175
	(0.0141)	(0.0190)	(0.0151)	(0.0185)	(0.0122)	(0.0131)
Highways*Post	0.033	0.498***	-0.038	-0.039	-0.002	0.160***
	(0.0484)	(0.0592)	(0.0363)	(0.0391)	(0.0286)	(0.0320)
N (hexagons)	**1,242**	**1,248**	**1,242**	**1,248**	**1,242**	**1,248**

Notes: Signifcance codes: p-value < 0.01 '***'; p-value < 0.05 '**'; p-value < 0.1'*'. Standard deviation in parenthesis. Each model have the additional dummies of the Double Diff-in-Differences models, and control variables of log of income, log of population, intra-group fixed effects, and time-fixed effects. The regressions exclude hexagons located in the old trinary axises, as shown in Figure 1(B).

Regarding the service-related jobs, also consistent with the diff-in-diff models, the relative average treatment effects on the Double Diff-in-Diff models show that the South Sector was the only that had positive relative impacts in the short and long runs, of 12.5% and 20%, respectively. They also evidence that there were relative negative impacts in the North Sector in the long run, and null relative impacts in the Highways' surrounding hexagons in both periods, which reinforce the positive effects more restricted to the serve-related jobs.

Although the south sector show positive impacts in the short and long run for the overall jobs in the Double diff-in-diff models, they were smaller than the positive impacts on the highways of the city. Therefore, these models suggest that the south sector didn't had net positive effects for the overall jobs. We argue that these dynamics of the spatial movement of the overall non-industrial jobs throughough the city of Curitiba, which resulted in the vanishing of the relative advantages for the Linha Verde structural axis, has multiple sources. The most remarkable relates to the execution of the LVUC intervention. It seems that the act of changing the zoning rules to being more permissive about the density of residential use, as well as commerce and services activities, wasn't enough to maintain increasing agglomeration forces of overall non-industrial jobs. Part of this related to the negative externalities that arose from the long time that the North Sector had been turned into a construction environment.

This context of bad execution of infraestructure building has the potential effect of creating an uncertain business environment (Sousa e Pompermayer, 2016), which made many of the planned externalities of the *LVUC* to be not materialized, both in the North and South Sectors. Since the LVUC axis is an interconnected transport network, the deviations caused by the BRT infrastructure construction in the North Sector influences negatively on the traffic flow of the South Sector. Another source for the losses in the relative advantages for the *LVUC* intervention area may relate to its push-pull effect according to each economic sector, since we detected large differences in the results according to the type of economic activity.

6. Final Remarks

The city of Curitiba is well referenced for the adoption of TOD policies through the implementation of a BRT system on planning its land use and urban growth. This study evaluates the Linha Verde Urban Consortium, the most recent action of the city of Curitiba to promote land use development through its BRT infrastructure that was launched in the year 2006. For the task of assessing the *LVUC* impacts on the land use through the geography of jobs, we developed a novel quasi-experimental design. We use a longitudinal data with spatial refinement that allows the adoption of the intervention design (the *LVUC* zoning) to assign the intended to treated areas, instead of using arbitrary spatial measures. We deal with selection bias with a PSM model, make a variety of Diff-in-Diff analyzes to investigate the range of spatio-temporal local impacts, and then observe the heterogeneous treatment effects using Double Diff-in-Diff models.

Our models evidence that within the geography of the *LVUC* intervention, the BRT infrastructure had positive impacts at some jobs' densities, with exception of the long run for the commerce-related jobs. The new BRT infrastructure had only persistent positive impacts in the service-related jobs' density, with negative impacts in commerce-related jobs in the long run. This combination of results vanished the long run relative positive impacts of the *LVUC* intervention for the overall jobs' density. We argue that fails in the execution of the *LVUC* project that relate to the construction of BRT stations and exclusive bus corridors stagned the creation of local amenities planned by the intervention. However, the positive effects that were detected on the hexagons that received BRT infrastructure and had changes in the zoning rules suggest that the intervention created positive amenities, mostly due to the increase of potential local consumption of service activities.

This study contributes to a more reliable identification strategy of causal impacts of urban interventions, which allows a robust identification of the *LVUC* impacts with significative geographic, temporal, and economic sectorial disaggregation. The limitations of this study rely on the period of analysis, wich do not observe the conclusion of the intervention that have been taking 17 years long. According to the literature of Public Transportation infrastructure, the wider impacts of such interventions are better detected in long periods after its construction. However, the results are conclusive about the impacts of such failures of implementation on the lack of creation of local amenities. Further studies could investigate long run impacts of the *LVUC* intervention in the jobs' densities after it be concluded, as well as other outcomes, such as real estate market, population, and accessibility.

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