

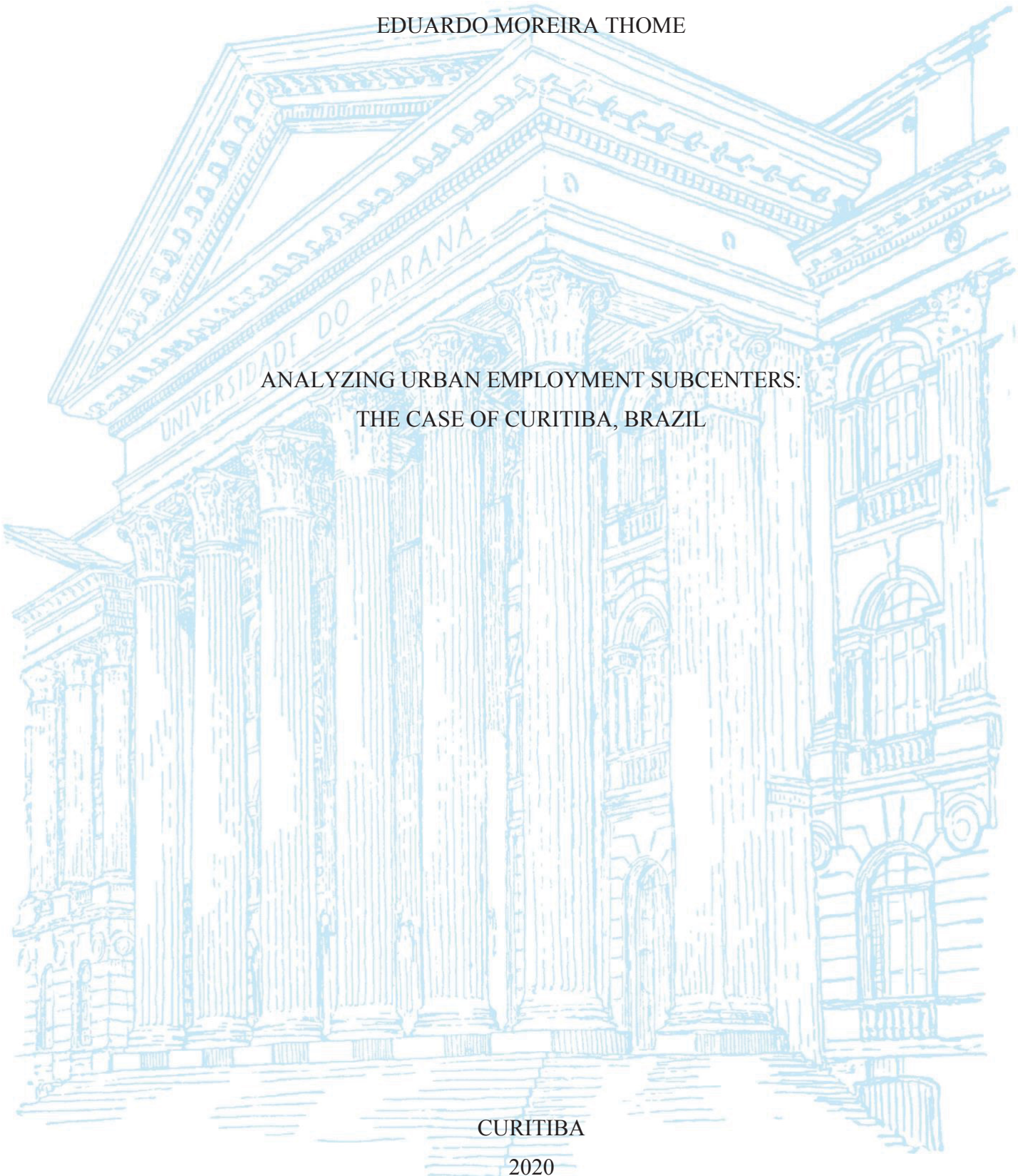
UNIVERSIDADE FEDERAL DO PARANÁ

EDUARDO MOREIRA THOME

ANALYZING URBAN EMPLOYMENT SUBCENTERS:
THE CASE OF CURITIBA, BRAZIL

CURITIBA

2020



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THE CASE OF CURITIBA, BRAZIL

Dissertação apresentada ao curso de Pós-Graduação em Desenvolvimento Econômico, Setor de Ciências Sociais Aplicadas, Universidade Federal do Paraná, como requisito parcial à obtenção do título de Mestre em Economia.

Orientador: Prof. Dr. Alexandre Alves Porsse

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Curitiba, 28 de Fevereiro de 2020.

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Para Ana Maria e Cylon, eternamente em meu coração.

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*“Le dije a mi coraje
Antes que te de calambre
Cocíname las ganas que
Mis sueños tienen hambre”
Calle 13*

*“¿Te das Cuenta, Benjamín? El tipo puede cambiar
de todo: de cara, de casa, de familia, de novia, de
religión, de Dios. Pero hay una cosa que no puede
cambiar, Benjamín. No puede cambiar de pasión.”
El Secreto de sus Ojos*

RESUMO

Diversos estudos foram desenvolvidos para avaliar a presença de subcentros de emprego analisando a sua distribuição espacial no espaço urbano. Em sua maioria eles analisam países desenvolvidos e poucos estudos exploraram as cidades dos países em desenvolvimento, particularmente a América Latina. Além disso, a relação entre políticas de planejamento urbano e sua influência na formação de subcentros pouco foi analisada em trabalhos empíricos. Nesse sentido, a atenção se volta para a cidade de Curitiba (Brasil). Desde a década de 1970, Curitiba adotou uma política de planejamento urbano orientada pelo transporte urbano que incentivou o desenvolvimento de subcentros. O núcleo dessa política é o sistema BRT (*Bus Rapid Transit*) que combinado com as políticas de uso da terra que foram estabelecidas nas últimas décadas compõem as principais forças que influenciam a distribuição de pessoas e atividades econômicas na cidade. Este trabalho tem como objetivo avaliar a presença de subcentros de emprego em Curitiba e como eles se relacionam com o BRT. Para identificar os subcentros de emprego e avaliar se o CBD permanece como o principal atrator de emprego na cidade utilizamos a abordagem semi-paramétrica desenvolvida por McMillen (2001). A base de dados contém informações sobre o emprego formal no nível da empresa fornecido pela RAIS no ano de 2010, contendo 50.553 empresas e 658.061 empregados na cidade. Esses dados foram georreferenciados em células de um quilômetro quadrado sobre a cidade. Os resultados mostram que Curitiba possui uma estrutura policêntrica composta por onze subcentros de emprego. A distribuição espacial desses subcentros é altamente correlacionada à rede BRT, evidenciando o papel da política de planejamento urbano na formação de subcentros de emprego. Além disso, a análise gravitacional sugere que o CBD não é mais o principal local na atração de emprego, uma vez que a maior parte da variabilidade da distribuição espacial da densidade do emprego é explicada pelos SBDs. Assim, os resultados do presente trabalho para a cidade de Curitiba evidenciam que uma política de planejamento urbano orientada pelo transporte de longo prazo é muito eficaz para promover a estrutura urbana policêntrica, sendo uma estratégia que contribui para contrabalançar as forças do mercado que favoreceriam a estrutura urbana monocêntrica.

PALAVRAS CHAVE: Regressão semi-paramétrica, Densidade do emprego urbano, Subcentros, Policentrismo.

ABSTRACT

Several studies have shown a trend away from monocentric city proposed by the Alonso-Mills-Muth model through the spatial analysis of employment distribution in the urban space. Most of these studies are concerned to cities in developed countries and few have explored the polycentric urban structure of cities in developing countries, particularly to Latin America. Further, the use of urban planning policies and their influence in promoting subcenters has been left aside in empirical work. In that sense, the city of Curitiba (Brazil) emerges as focal point in this analysis. Since the 1970's Curitiba adopted a Transit-Oriented Development (TOD) oriented urban planning policy searching to promote polycentricity. The core of this policy is the Bus Rapid Transit (BRT) system in combination with mixed land-use patterns and are the main force influencing the distribution of people and economic activities across the city. Therefore, this paper aims to assess the presence of employment subcenters in Curitiba and how it relates to the BRT system. In order to identify the employment subcenters and to assess whether the CBD remains as the main employment attractor in a polycentric city we use the semi-parametric approach developed by McMillen (2001). The employment database contains data on formal employment at the firm level provided by the Ministry of Employment for the year of 2010. These data were geo-referenced in grid cells of one square kilometer over the city. The results show that Curitiba has a polycentric structure with nine employment subcenters. The spatial distribution of these subcenters has a strong relationship to the BRT network, evidencing the role of TOD urban planning policy in shaping the polycentric structure. Further, the gravitational analysis suggests the CBD is no longer the main employment attractor since most of the variability of the spatial distribution of employment density is explained by the SBDs. Thus, our findings for Curitiba shows that a long-term TOD policy is very effective for promoting polycentric urban structure, being a strategy that contributes to counterbalance the market forces that would favor the monocentric urban structure.

KEY WORDS: Semi-parametric regression, Urban Employment Density, Subcenters, Polycentrism.

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1 INTRODUCTION

The first models of economic urban theory developed by Alonso (1964), Mills (1967) and Muth (1969) hypothesized a concentric city that concentrated employment in the Central Business District (CBD). The theoretical foundations of the AMM model were the basis of several studies in urban economics, but in recent years the urban spatial structure of large cities has seen a trend away from the monocentric model. The spatial analysis of employment location and land use patterns in large cities has shown evidence that urban structure is better characterized by polycentricity than monocentricity. Thus, employment tends to be relocated and concentrated in different centers besides the CBD, raising the importance of the so-called Secondary Business Districts (SBD).

Polycentricity has been empirically verified in several studies in major North American cities (Giuliano and Small, 1991; McMillen, 2001; Yang *et al.*, 2019) and across Europe (Veneri, 2013; Krehl, 2016; Mulicek and Maly, 2019). Other studies have explored the urban configuration in developing countries, predominantly on Chinese municipalities (Yue *et al.*, 2010; Lv *et al.*, 2017; Xie *et al.*, 2019). Nevertheless, little has been explored in Latin America (Fernandez-Maldonado *et al.*, 2014; Campos and Chagas, 2017; Belmiro, Rodrigues and Silveira-Neto, 2016). Mostly of these studies are mainly concerned in analyzing the distribution of employment across the urban space and identify employment subcenters. However, urban planning policies can play an important role in promoting employment polycentricity, an aspect which has not been well explored in the literature.

In that sense, the city of Curitiba (Brazil) emerges as focal point in this analysis. The city has taken strong and consistent measures to promote subcenters and employment decentralization from the CBD based on Transit Oriented Development (TOD) policies. Curitiba was the first city in Brazil and the second in the World to adopt the Bus Rapid Transit (BRT) system combined with mixed land-use patterns as a strategy of urban development. Since the middle of the 70's this policy has been put in practice, reshaping the city's landscape and given to Curitiba a differentiated status among other Brazilian capital cities in terms of mobility infrastructure and urban efficiency.

Also, within the country's economy, Curitiba plays an important role. The city is ranked as the fifth municipality that most contributes to the country's GDP with 1.40% overall¹. Further, in 2010 Curitiba had an HDI of 0.823 and was ranked as the 10th highest among all

¹ According to IBGE (from Portuguese, *Instituto Brasileiro de Geografia e Estatística*) the first four municipalities are: São Paulo (10.85%), Rio de Janeiro (5.85%), Brasília (3.60%) and Belo Horizonte (1.46%) (IBGE, 2015).

Brazilian municipalities and 4th considering only the state capitals². Also, in the same year, Curitiba had 1.917.185 million residents and was ranked as the eighth largest city in the country.

The historical context of urban policies and economic development put Curitiba as an interesting space for investigating the spatial pattern of urban employment. This research has four main objectives. The first objective is to assess whether the city of Curitiba has employment subcenters. The second objective is to identify some socioeconomic characteristics of each subcenter and the third to evaluate the gravity effect of CBD and SBDs in attracting employment. The fourth objective is to investigate the correlation between the TOD policies through the BRT network and the spatial distribution of employment across the city.

The main empirical strategy adopted in this study for achieving the first and second objectives is based on the methodological approaches developed by McMillen (2001) and Krehl (2016). However, there are other methodological strategies for identifying employment subcenters and the literature has not yet settled over which method is the most suited for estimating subcenters. Thus, we conduct a sensitivity analysis comparing the results with those obtained by using the approach proposed by Giuliano and Small (1991). Additionally, in order to achieve a better comprehension about socioeconomic forces behind the formation of urban employment subcenters in Curitiba, a segmented analysis was carried out for identifying employment subcenters. In this analysis, the employment segmentation consists in the following categories: level of skill (related to the worker's level of education), gender and economic sector (will be analyzed the industrial, commercial and service sectors).

This study contributes to the empirical research of polycentric structures in the Latin American context while examining a major Brazilian city. The analysis of Curitiba, which has a strong urban planning culture, sheds light into the relationship of TOD and polycentricity. The research adds to the literature over the debate in the choice of the most appropriate procedures in order to assess employment subcenters with the comparison between the methodologies proposed by McMillen (2001) and Giuliano and Small (1991). Further, in a similar manner as the one proposed by Krehl (2016), the sensitivity analysis that was carried for the proposed parameters in McMillen (2001) highlights the need for such task once the urban shape and settlement of cities worldwide varies, therefore, the parameters initially set might not account for such differences. Lastly, while most research focus in the identification

² According to the Atlas of Human Development in Brazil (part of the United Nations Development Programme - UNDP), the municipal HDI rank for Brazil in 2010 is (the state capitals are marked with an asterisk): 1st, São Caetano (0.862); 2nd, Águas de São Pedro (0.854); 3rd, Florianópolis* (0.847); 4th, Balneário Camburiú (0.845); 5th, Vitória* (0.845); 6th, Santos (0.840); 7th, Niterói (0.837); 8th, Joaçaba (0.827); 9th, Brasília* (0.827); 10th, Curitiba* (0.824).

of employment subcenters (such as McMillen (2001), Redfearn (2007), Krehl (2016) and Lv *et al* (2017)), we deepen such topic with the segmentation analysis of specific economic sectors.

The employment database contains data on formal employment at the firm level provided by the Ministry of Employment for the year of 2010, representing 50,553 firms and 658,061 employees in the city. These data were geocoded based on information about ZIP codes and using the street-level shapefile obtained from the Curitiba's Institute of Research and Urban Planning (*Instituto de Pesquisa e Planejamento Urbano de Curitiba - IPPUC*). The ZIP codes allowed to match them with the employment database that also had the same variable for each firm.

Including this introduction, this thesis is organized in six sections. Second section describe historical aspects related to the TOD policy adopted by Curitiba. Third section is dedicated to the literature review. Fourth section presents the empirical strategy used in this research. Fifth section presents and discusses the results. The sixth section addresses the conclusions.

2 CURITIBA AND THE TRANSIT-ORIENTED DEVELOPMENT

Other aspect that distinguishes Curitiba from other Brazilian cities is the strong urban planning culture, dating back to 1857. In that year efforts were taken in order to transform the irregular urban sprawl from a circular to a planned quadrangular pattern. Other urban transformations were related to enhance sanitary conditions occurred in 1886. Nevertheless, the first urban plan implemented in the city was during the 1930's (MACEDO, 2004).

During the following decade a new urban plan was designed and implemented in the city. The plan proposed by Alfred Agache was elaborated between 1941-1943 and became known as the Agache Plan (from Portuguese, *Plano Agache*). Among the plan's premises was the development of a radial network of roads connecting CBD to other locations of the city that would be separated according to their functions³. This policy had in its premises the development of employment subcenters in specific parts of the city, hence, promoting polycentrism. A few years later this plan would be terminated, and a new one would take place.

In the beginning of the 1950's Curitiba had over 180 thousand inhabitants and by 1980s its population grown to 1.024.975, almost sixfold in a thirty-year period. The city also faced a growth rate of 5.38% in the 1970's, the highest in the country (MACEDO, 2004). This rapid growth spurt influenced the proposal of a new Master Plan which was developed between 1964 and 1966 and started to be implemented in the early 1970's. This new Master Plan was headed by Jorge Wilhelm and was known as the Wilhelm Plan (from Portuguese, *Plano Wilhelm*). This new urban policy was a result of the problems that were already being faced by the rapid populational growth. Within the core of the plan is the zoning regulations that intertwine a mixed land-use pattern between commercial and residential use, the road system and the public transportation network⁴.

According to Rabinovitch (1996, p. 53) the key principles involving the *Master Plan* were: decongestion of the central area; infrastructure development; economic support to urban development; demographic control and management; imposing a linear urban growth trend. Furthermore, the plan had in view the regulation of economic activities through land use policies and zoning restrictions. One example is the creation of a specific neighborhood to

³ According to Macedo (2004, p. 540-541), the plan would separate the city in secondary centers according to their activities. There would be centers specialized in commercial, industrial, residential and institutional activities.

⁴ Curitiba has had international recognition for the Bus Rapid Transit (BRT) and the efforts around its development since the 1970s when the first bus lines started to operate and the incentives towards mixed land-use pattern alongside it. For further references see Cervero and Dai (2014), Duarte and Ultramari (2012), and Khayesi and Amekudzi (2011).

accommodate industrial venues, the Industrial City of Curitiba⁵ (from Portuguese, *Cidade Industrial de Curitiba* – CIC), located approximately ten kilometers from the CBD⁶. Therefore, this new Master Plan also stimulated polycentrism.

The main driving force of the linear growth was the relationship between the land-use policy and the Transit-Oriented Development (TOD) policies. The linear growth was imposed through five transit axes that departed from the CBD towards the north-south, east-west and southeast directions. The plan was developed to consider the use of public instead of private transportation as the main driving force while distributing people and employment in the city through land-use regulations that were connected to the road hierarchy.

At that time, the municipal office faced budget restrictions which limited investments in public transportation, such as light rail or subways⁷. The only option left was to use buses. Nevertheless, the system was designed to mimic a subway network, transporting a large number of people across the city in a small window of time through the use of buses with high passenger capacity that travelled in segregated lanes. This concept was further referenced as the Bus Rapid Transit (BRT) system, in which Curitiba was the second city in the world to develop.

In each transit axe was developed a trinary road system with a main road and parallel to in one block away on each side there are fast lanes for cars travelling on opposite directions. In the main road there are segregated bus lanes for the BRT system and alongside it two slow lanes for cars (speed limit of 40 km/h) followed by parallel parking lanes. Also, the ordinance allowed for high-rise buildings in main road, promoting population density among the axes. The master plan also stimulated mixed land-use as it encourages to site commercial businesses in the first two floors of those buildings, distributing economic activities away from the CBD and towards other areas of the city. There was a strong incentive for buildings through Floor Area Ratio (FAR) bonuses for properties that hosted economic activity, leading to higher verticalization. Further, the height of buildings decline in a linear manner as one locates further from the axes⁸.

⁵ According to Rabinovitch (1996) the formulation of the CIC in 1973 stimulated the transition of Curitiba from agriculture towards a industrial city. The CIC was created “in response to a policy of limiting further heavy and/or hazardous industrial activities within the borders of the municipality, and to attract more non-polluting industries to a specific industrial area” (RABINOVITCH, 1996, p. 52).

⁶ The previous Master Plan developed in 1941 and 1943 differed in the transportation strategy when compared to the 1966 Master Plan, nevertheless the former plan also had contemplated the development of employment subcenters. See Macedo (2004).

⁷ Cervero and Dai (2014) mention the capital costs-per-rider for BRT, light rail and heavy rail (metrorail) to be in the top quartile of financing performance. For the BRT system it was needed 45 jobs or residents per hectare within 800 meters of the stations while for light rail it was a density of 125 and for heavy rail a density of 150. Further, according to the authors, the BRT system is also cost-effective for lower densities and suits well for cities with lower densities or sparse distribution of population.

⁸ A recent report analyzing the construction patterns between the years of 2000 and 2016 developed by IPPUC addressed that within that period was observed an urban sprawl in the number of construction developments.

Considering the routes in the system, the BRT network follows a trunk-branch pattern. The trunk of the system is the highly demanded express routes that depart from the CBD and travel in the segregated corridors in each transit axe. The branch system has two main routes, the feeder and the inner-district routes. The latter allows passengers to go from one neighborhood to another without having to travel to CBD. Both travel in a concentric pattern and connect to the trunk system in bus stations built in each axe every two to three kilometers, exchanging passengers from the branches to the trunk. Once a person enters the system it can swap bus routes as many times needed without having to pay for more than one fare. The main bus terminals, trunk and feeder routes can be seen in Figure 1.

Other important point of the policy was the road hierarchy promoted by the BRT network. The arterial roads were the five main axis and core of the system. Followed by the priority roads whose purpose was to link the streets of the arterial axis. Finally, the collector streets accounted for general purposes and to connect the structural roads to neighborhoods without reaching the CBD (RABINOVITCH, 1996).

In the plan's conceptualization, the high population density in the main road should also contribute to the public transportation system to be self-financing since it would be expected that the residents nearby the transportation network would be prone to use it. Nevertheless, the work of Duarte and Ultramari (2012) show evidence of the contrary, with data for the 2009 Origin-Destination (OD) Survey⁹, they point out that the system is utilized in its majority by individuals that do not live nearby the network, and most start their journey in the feeder lines.

Other efforts went towards the redesign of locations that were already built to enable better access of in the BRT facilities, increasing the efficiency of the system¹⁰. Further, the Master Plan assimilated in its zoning restrictions the expansion of the network into land parcels that had not reached their full potential, thus ensuring the long-term commitment of the TOD.

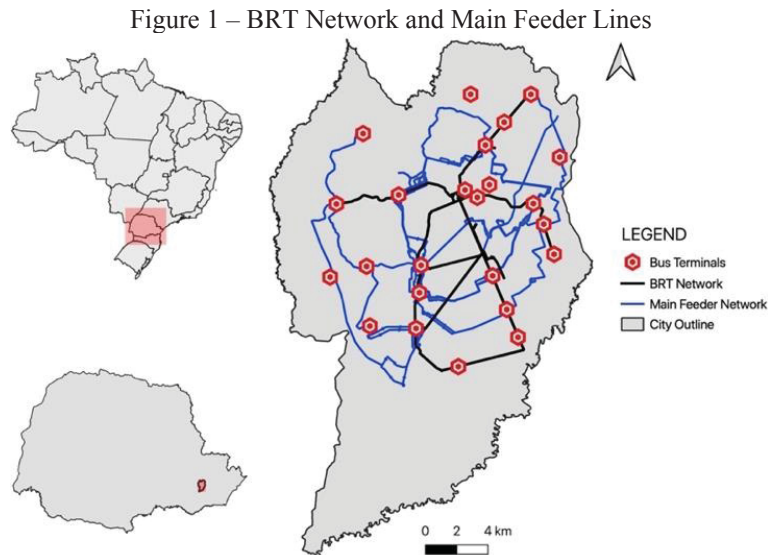
The city of Curitiba is the capital of the State of Paraná, located in the southern part of Brazil, as seen in Figure 1. The city has been widely known in the last decades through the development of the BRT system, nevertheless the city has been implementing urban planning

Nevertheless, when considering the FAR, most of those developments concentrate in the areas near the structural axes, as it would be expected since such restrictions are enforced by land-use policies (IPPUC, 2019).

⁹ The survey was conducted by IPPUC, for further details see Duarte and Ultramari (2014).

¹⁰ According to Rabinovitch (1996, p. 53) the development of the plan initiated in "previously existing streets and only minor physical modifications". Nevertheless, those modifications proved to be efficient in the increase of travel satisfaction, as shown by Cervero and Dai (2014). When comparing to the BRT system of Bogota (Colombia) to Curitiba's, in the former the network is located in "in mostly economically stagnant zones that were largely built out has suppressed land development. So has the sitting BRT in busy roadway medians, which limited land supplies for leveraging TOD and resulted in mostly unattractive pedestrian environments immediate to stations. Minimal pro-active station area planning or incentives for private property-owners to redevelop parcels also tempered TOD activities" (CERVERO and DAI, 2014, p. 132).

policies since mid 1850s and more strong measures after the 1940s. Within the Brazilian context, in 2010 Curitiba had an IDH of 0.823 and was ranked as the 10th highest among all Brazilian municipalities and 4th considering only the state capitals¹¹. Also, at the time it was the eighth largest city in the country, with 1.917.185 million residents¹².



Source: IPPUC (2019) and IBGE (2015). Elaborated by the authors.

As it can be seen in Table 1, the Metropolitan Region of Curitiba (MRC) has the fifth (seventh) highest automobile (motorcycle) fleet in the country. While considering the data for the BRT System across the highest populated cities in Brazil, the length of Curitiba's BRT network is of 74 kilometers, which ranks as the third largest system in the country, with a daily demand of 566,500 trips, ranked fourth in the nation. Such numbers show the strength of the system in the city, which in length lies behind only São Paulo and Rio de Janeiro (which had a population six and four times greater than Curitiba in 2010, respectively) and in the daily trips demanded is also behind Belo Horizonte (which has a smaller system in length, but larger population).

¹¹ According to the Atlas of Human Development in Brazil (part United Nations Development Programme - UNDP), the municipal IDH rank for Brazil is (the state capitals are marked with an asterisk): 1st, São Caetano (0.862); 2nd, Águas de São Pedro (0.854); 3rd, Florianópolis* (0.847); 4th, Balneário Camburiú (0.845); 5th, Vitória* (0.845); 6th, Santos (0.840); 7th, Niterói (0.837); 8th, Joaçaba (0.827); 9th, Brasília* (0.827); 10th, Curitiba* (0.824).

¹² According to IBGE (2018b) in the 2010 census the first seven cities ranked according to population are: São Paulo (12.176.866), Rio de Janeiro (6.688.927), Brasília (2.974.703), Salvador (2.857.329), Fortaleza (2.643.247), Belo Horizonte (2.501.576), Manaus (2.145.444).

Table 1 - Number of private vehicles and BRT Network information for the most populated metropolitan regions of Brazil

	Population		Private Vehicles				BRT Network			
			Motorcycles		Automobiles		Length		Passengers (daily)	
	Total	%	Total	%	Total	%	Total	%	Total	%
São Paulo	19,683,975	10.32	592,696	5.31	3,201,784	14.14	180	22.93	3,625,034	33,69
Rio de Janeiro	11,835,708	6.20	255,558	2.29	1,358,449	6.00	168	21.40	3,178,600	29,54
Belo Horizonte	5,414,701	2.84	236,236	2.12	785,911	3.47	39	4.97	1,047,374	9,73
Porto Alegre	3,958,985	2.08	166,895	1.50	687,753	3.04	55	7.01	540,000	5,02
Recife	3,690,547	1.93	114,839	1.03	307,406	1.36	50	6.37	409,620	3,81
Fortaleza	3,615,767	1.90	141,834	1.27	290,410	1.28	10	1.27	186,777	1,74
Salvador	3,573,973	1.87	77,214	0.69	305,753	1.35	-	-	-	-
Curitiba	3,174,201	1.66	146,958	1.32	624,417	2.76	74	9.43	566,500	5,27
Campinas	2,797,137	1.47	160,793	1.44	569,376	2.51	13	1.66	200,000	1,86
Goiania	2,173,141	1.14	182,060	1.63	339,391	1.50	24	3.06	328,300	3,05
Brazil	190,755,799	100	11,152,161	100	22,641,598	100	785	100	10,759,654	100

Source: IBGE (2010) and BRT DATA (2020). Elaborated by the authors.

Considering infrastructure patterns and socioeconomic conditions, Curitiba is one of the most developed cities in Brazil. For all the households in the country, 80,04% of them have piped water, as seen in Table 2. This index is even higher for the richer regions in Brazil, the South and Southeast, 84,58% and 88,59% respectively. Nevertheless, the state of Paraná has a higher access than within both regions with 98,04% and Curitiba is even higher, 99,04%. Further, when considering the access of family units to durable goods, such as fridges, the city has a higher index when compared to the other regions and the country. The same results apply when considering the presence of televisions in households¹³. An important variable to consider the high development of the city is the access to internet in the family units through computers which in Curitiba is 59,14% while in Brazil is 30,73%¹⁴.

Other positive indicator of the last Brazilian census relates to education, nevertheless regional disparities play a significant role, as seen in Table 3. Among the proportions, the most developed regions Southeast, South and Midwest have the best outcomes. While 50,24% of Brazilians are either illiterate or have not completed elementary school, most are concentrated in the Northeast, 59,06%, and North, 56,49%, while Curitiba has 31,69%, lower than any other region. For those that graduated elementary school but not high school the national average is 17,40% and there is not much variation within the national average among the regions and in Curitiba.

¹³ A particularity within the regions is the difference between the number of fridges and televisions, the north and northeast regions (the poorest in the country) have significantly more televisions than fridges. While in Curitiba is the opposite, but with a small difference.

¹⁴ In this case there are strong regional factors to be considered with the North and Northeast with the households in those regions having roughly half the national average.

Table 2 – Piped Water and durable goods for 2010 in Brazil, state of Parana and Curitiba

	Households									
	Total (a)	(%)	Piped Water in at least one room		Durable Goods					
			Total (b)	a/b (%)	Fridge		Television		Computer with internet access	
				Total (c)	c/a (%)	Total (d)	d/a (%)	Total (e)	e/a (%)	
Brazil	57.320.555	100,00	45.881.593	80,04	53.696.250	93,68	54.486.243	95,06	17.615.480	30,73
North	3.977.362	6,94	1.934.588	48,64	3.331.124	83,75	3.468.069	87,20	613.992	15,44
Northeast	14.922.475	26,03	10.663.297	71,46	12.911.972	86,53	13.769.442	92,27	2.504.534	16,78
Midwest	4.332.833	7,56	3.440.923	79,42	4.160.875	96,03	4.105.760	94,76	1.362.339	31,44
Southeast	25.197.306	43,96	22.323.526	88,59	24.581.083	97,55	24.535.464	97,37	9.976.615	39,59
South	8.890.580	15,51	7.519.260	84,58	8.711.197	97,98	8.607.508	96,82	3.158.000	35,52
Parana	3.298.304	5,75	3.233.762	98,04	3.215.214	97,48	3.162.211	95,87	1.169.499	35,46
Curitiba	576.190	1,01	570.608	99,03	569.542	98,85	565.681	98,18	340.770	59,14

Source: IBGE (2010). Elaborated by the authors.

Further, 23,45% of Brazilians graduated high school but did not graduate college, in Curitiba the number of individuals in this category is 29,86%. The national proportion of college graduates in Brazil is 8,31%. In this case regional disparities are high, with the most developed regions reaching almost the double of graduates than in the North and Northeast. In Curitiba there were 20,05% of residents that graduated college. The results for Curitiba in either of the latter two categories are expected. Major cities and metropolitan areas commonly report higher levels of human capital and, consequently, wages when compared to rural and other urbanized areas.

Table 3 - Education characteristics for individual-level data for 2010 in Brazil, state of Parana and Curitiba

	Individuals									
	Total (a)	(%)	Education							
			Illiterate or has not completed elementary school		Completed elementary school but not high school		Completed high school but did not graduate college		Graduated college	
		Total	(%)	Total	(%)	Total	(%)	Total	(%)	
Brazil	161.981.299	100,00	81.386.577	50,24	28.178.794	17,40	37.980.515	23,45	13.463.757	8,31
North	12.669.874	7,82	7.156.980	56,49	2.127.288	16,79	2.669.387	21,07	639.482	5,05
Northeast	44.217.039	27,30	26.114.886	59,06	6.764.709	15,30	8.933.710	20,20	2.186.418	4,94
Midwest	11.870.960	7,33	5.654.109	47,63	2.097.927	17,67	2.882.315	24,28	1.155.082	9,73
Southeast	69.528.259	42,92	31.138.332	44,79	12.742.116	18,33	17.883.715	25,72	7.280.843	10,47
South	23.695.166	14,63	11.322.270	47,78	4.446.755	18,77	5.611.389	23,68	2.201.932	9,29
Parana	8.962.586	5,53	4.369.062	48,75	1.623.215	18,11	2.054.939	22,93	869.660	9,70
Curitiba	1.531.838	0,95	485.443	31,69	271.175	17,70	457.452	29,86	307.175	20,05

Source: IBGE (2010). Elaborated by the authors.

Another characteristic to be analyzed is the labor market of Curitiba. In Table 4 it was considered only those individuals that are Economically Active (EA). Focusing on the Brazilian context, there are 7,65% of people that are EA but are not working, while the lowest rates are for the southern region (4,68%), the city of Curitiba is slight above (4,86%) but lower than the state of Parana (5,01%). As it would be expected, the inverse relation is reported for those individuals that have an occupation.

Table 4 - Labor market characteristics for individual-level data for 2010 in Brazil, state of Paraná and Curitiba
Individuals (ten years old and above) that self-report as economically active

	Total (a)	(%)	Not working		Individuals with an Occupation					
			Total (b)	b/a (%)	Total (c)	c/a (%)	Working		Informal *	
							Total (d)	d/c (%)	Total (e)	e/c (%)
Brazil	93,504,659	100	7,150,820	7.65	86,353,839	92.35	39,107,321	45.29	17,418,119	20.17
North	6,861,443	7.34	599,102	8.73	6,262,341	91.27	1,812,257	28.94	1,531,034	24.45
Northeast	23,106,950	24.71	2,252,649	9.75	20,854,301	90.25	6,553,319	31.42	5,711,069	27.39
Midwest	7,364,831	7.88	489,206	6.64	6,875,625	93.36	3,024,052	43.98	1,466,673	21.33
Southeast	41,221,668	44.09	3,109,868	7.54	38,111,800	92.46	20,624,519	54.12	6,631,654	17.40
South	14,949,766	15.99	699,994	4.68	14,249,772	95.32	7,093,174	49.78	2,077,689	14.58
Parana	5,587,963	5.98	280,140	5.01	5,307,823	94.99	2,653,498	49.99	886,572	16.70
Curitiba	995,543	1.06	48,348	4.86	947,195	95.14	549,565	58.02	106,324	11.23

* Categories such as self-employed, entrepreneurs, employers, employees that do not receive any kind of payments and workers that produce for own consumption were not considered. Formal workers are those that have jobs ordered by legal framework the Consolidation of Labor Laws (from Portuguese, *Consolidação das Leis do Trabalho – CLT*), while informal employees are not in the CLT.

Source: IBGE (2010), Elaborated by the authors.

Moreover, taking into consideration only the individuals that have an occupation, those that have jobs ordered by legal framework the Consolidation of Labor Laws (from Portuguese, *Consolidação das Leis do Trabalho – CLT*) are formal while informal employees are not in the CLT. The lowest rates of formal employees are in the North (28,94%) and Northeast (31,42%) regions and are below the national proportion of (45,29%), while the Southeast (54,12%) and the South (49,78) have the highest rates. Curitiba is above the national and regional averages of formal employees, with 58,02%. The inverse relation applies for the informal workers.

Furthermore, Curitiba is the main economic driving force within the region, as it can be seen in Table 4. Curitiba comprises 73.49% of the formal employees within the region while it only has 59.36% of the economically active population. The difference between the data in the 2010 Census in Table 3 and the MTE-RAIS data in Table 5 sheds light that there are that are formal workers and also inhabitants of Curitiba and there are others that reside in neighboring cities but commute to Curitiba to their formal employment. Therefore, it should be expected

that there are employees that reside in other neighboring municipalities and commute to Curitiba to work.

These characteristics of Curitiba and its comparison between the percentages for Brazil, the five country regions and the state of Parana provide a brief context of whether the city is developed when considering a Latin-American developing country that has major regional disparities. The considerable percentage of households with access to water, the high level of human capital (within the country) and the strong labor market where the majority of the economically active are working and a low percentage of informal workers provide a brief context of Curitiba.

Table 5 - Total Employment and Economically Employed Population in the RIT (2010)

	Employment (formal)		Economically Active	
	Total	%	Total	%
Bocaiuva Do Sul	1,509	0.13	9,134	0.35
Campo Magro	3,688	0.32	20,852	0.81
Rio Branco do Sul	4,559	0.39	25,48	0.99
Mandirituba	5,137	0.44	18,519	0.72
Campina Grande do Sul	7,547	0.65	32,401	1.26
Piraquara	7,664	0.66	77,085	2.99
Quatro Barras	8,848	0.77	16,754	0.65
Fazenda Rio Grande	9,671	0.84	67,119	2.60
Almirante Tamandaré	11,272	0.98	85,51	3.31
Campo Largo	25,275	2.19	96,196	3.73
Colombo	37,529	3.25	178,212	6.91
Pinhais	41,461	3.59	99,181	3.84
Araucária	51,802	4.48	100,428	3.89
São José dos Pinhais	90,277	7.82	222,039	8.60
Curitiba	848,85	73.49	1,531,838	59.36
Total	1,155,089	100	2,580,748	100

Source: MTE-RAIS 2010; IBGE, 2019. Elaborated by the authors.

To summarize, the Master Plan of 1966 envisioned to have a mixed land-use policy associated with the BRT System but also considering the distribution of residents and employment, redesigning the shape of the city. As pointed by Cervero and Dai (2014) other cities, such as Bogota (Colombia) and Ahmedabad (India), that implemented the BRT System focused in mobility and not city-shaping investments as in Curitiba. As mentioned by the authors, both cities lack incentives to promote high population densities and to redevelop the surrounding areas alongside the transit corridors.

The BRT system started to operate in 1974 in the 20-kilometer-long north-south axis, it carried over 54.000 passengers per day (RABINOVITCH, 1996). With the expansion of the network towards the southeast, east-west, the RIT and the green line (started being developed

in recent years) in recent number for 2019 it carried an average per weekday of 1.365.615 passengers and a coverage of 300.773 kilometers. Further, the total fleet has 1.229 operating buses with a total fleet of 1.601 buses (URBS, 2019). Nowadays, the BRT network expanded to other municipalities around Curitiba. The adjacent cities embraced by the BRT including Curitiba are known as the Integrated Transport Region (from Portuguese, *Região Integrada de Transporte* – RIT).

The definition of Dou *et al* (2016, p. 380) for a Transit-Oriented Development (TOD) must include three dimensions: design (ease pedestrian use to improve travel satisfaction), density (commercial and residential activity in specific areas) and diversity (mixed land-use searching to reduce travelling time and increase ridership rates). Curitiba's urban development contemplates those three aspects. Moreover, the policy was designed in order to decentralize economic activity from the CBD in direction of the transit axes, while also combining land-use regulations, public transportation and high population density. This resulted in a highly demanded and self-financing public transportation while also matching high commercial and residential active in specific areas of the city.

Therefore, the 1966 *Master Plan* was not only conceived to promote an efficient public system transportation, rather it has been a plan implemented over the last fifty years that redesigned the shape of the city¹⁵.

¹⁵ Cervero and Dai (2014, p. 135) cite the comparison in the implementation of the BRT system in Bogotá (Colombia) and Ahmedabad (India) where both cities have failed to “leverage compact, mixed-use development near stations stems from BRT systems being viewed mainly as mobility rather than city-shaping investments. In both cases, engineering, costs-minimization principles generally won out over urban-planning, development-maximization ones. In the drive to economize on investment costs, the path of least resistances was often chosen”.

3 FROM THE MONOCENTRIC TO THE POLYCENTRIC URBAN PATTERN

The literature review in this chapter is subdivided into two sections, a theoretical and an empirical. The former analyzes the seminal studies in urban economics of Alonso (1964), Mills (1967), Muth (1969) and the theoretical model of urban structures of Fujita and Ogawa (1982). The latter subsection considers the studies that focus in land use and polycentricity such as Shukla and Waddell (1991) and Waddell and Shukla (1993); the studies of McDonald (1987) and Giuliano and Small (1991) which develop methodologies that identify employment subcenters through the analysis of employment densities. Finally, the estimation of subcenter through methodologies that consider nonparametric models as in Craig and Ng (2001), McMillen (2001) and Redfearn (2007).

3.1 THEORETICAL LITTERATURE REVIEW

The classical theoretical model depicted in Fujita (1989) and Brueckner (2011) was established by the seminal works of urban economics by Alonso (1964), Mills (1967) and Muth (1969). Their framework depicted a city where businesses locate in center, the Central Business District (CBD) and where workers reside around the CBD and commute to it in radial manner. This theoretical model was entitled as the monocentric model.

The work of Anas, Arnot and Small (1998) verifies that the current spatial structure of North American cities was modeled by the advances in transport and communication. The authors analyze the development of cities prior to the 1840's. At that time, economic activities settled near waterways where products were shipped through harbors faced lower freight costs. With the use of railroads, firms also searched to locate near stations to reduce their shipping costs. Nevertheless, intraurban shipping occurred mainly through horse and wagon which consumed a substantial amount of time and were unreliable depending on the weather conditions. In either case, scale economics through transportation costs of played a significant role in determining the location of firms near harbors and railroad stations, favoring a single business district. At the same time, the workers resided near the CBD and commuted by foot due to the limitation of individual transportation which occurred mainly by horses and horse carriages.

The evolution from horse-drawn to electric street cars and then the development of subway systems between the 1850s and the first years of the 1900s facilitated the concentration of residences far from the CBD but near radial transportation networks. Although, even with

the technological evolution of the telegraph which reduced the costs of communication between firms, they still relied on messenger in the intra-city communication, still reinforcing the clustering of economic activity. As Anas, Arnot and Small (1998) detail, within the CBDs the firms concentrated according to their business sector where the center was then divided into specialized districts. Thus, the city's spatial structure was monocentric with the middle-income workers residing far from the CBD and commuting to their jobs in a radial manner.

The internal combustion engine played a key role in the changes in the urban structure. The use of trucks and automobiles in intra-city transportation reduced commuting and transportations costs. The widespread of the assembly line in horizontal buildings, and with it the mass production of goods, encouraged firms to reduce the capital-land ratio and search for locations with low land cost. The reduction of communication costs with the advent of telephony and infrastructure investments in the and the expansion of rail and highway systems in suburban areas, enabled the firms to locate far from the city core. In this process of industrial firms relocating, the main economic businesses in the CBD transitioned to the service and commercial sectors.

Nevertheless, this process only intensified after the World War II. Therefore, Alonso-Mills-Muth monocentric (portrayed in the following paragraphs) was not far from the urban pattern seen in the major cities.

The models proposed by Alonso (1964) and Muth (1969) focus in the household that maximizes its utility function between the quantity of housing (a measure of the intensity of land-use) and other commodities (except transportation). According to Goldstein and Moses (1973) both models are quite similar. Both models consider the costs of transportation to the CBD equal in all directions and as a function of the wages and the distance. The commutes to consumption of goods and their cost of transportation within urban limits were not considered. This formulation allows to assess the trade-offs involved in the transportation costs and accessibility to the CBD. Furthermore, all markets are considered to be competitive; the consumption of housing has no constrains or externalities; and the prices of goods, wages and housing in the CBD are given.

The solutions of the utility maximization problem show that, in equilibrium, the reduction of the costs of living further away from the CBD are neutralized through a raise in the transportation costs, which increase the further a household locates form the CBD. This statement was formulated by Alonso (1964) as the bid-rent curve. With the latter argument in mind, in order to maintain the equilibrium, the model also indicates that the price of land must decrease with distance to the CBD.

The model proposed by Muth (1969) analyzes the price of land and the prices per unit of housing through the behavior of firms that produce housing. Those firms combine land and non-land inputs in a Cobb-Douglas production function. The optimal solution of the problem results in a price gradient for land.

In this formulation Muth (1969) assumes a unitary price-elasticity of the demand for housing and the marginal cost of transportation to also be constant. With these assumptions, Muth (1969) demonstrates that the intensity of land-use per unit of land declines the greater the distance from the CBD. This allows us to infer that the closer to the CBD the higher the population density and the smaller the dwellings.

The proposition made by Mills (1967) involves the interaction between three production sectors within a concentric city: goods, intracity transportation and housing. Their production functions are assumed to be in the Cobb-Douglas form. Besides, his model relaxes the hypothesis of constant returns to scale and land homogeneity.

If land is not homogeneous it raised the possibility that the parameters in the production function are not constant to all firms within a city and that they might vary depending on the location. In the case of a city with a positive efficient parameter the firms have decreasing returns to scale, but they will locate in the site where the parameter is positive. If the parameter has no influence on the production function, firms will have increasing returns to scale. The result in either case is that firms concentrate in a neighboring area, the CBD.

The model also assumes that all factor markets are competitive, the wage rate and capital rental rate are exogenously defined, the amount of labor and capital of a city is determined by the number of workers and capital stock that it can bid for. The land rent is determined endogenously and is related to the distance from the CBD.

The goods market is assumed to be a monopoly where the firm produces given a fixed demand. Furthermore, the rent paid in the CBD removes any possible monopoly profits the firm might gain. Given the production function determined by the model, the greater the increasing returns of scale of the firm the more demand inelastic they are in order to pay for the marginal products of the factors. The limiting case of a perfectly competitive market, which his formulation might account for, requires that the coefficient parameters to determine constant or decreasing returns of scale.

The intracity transportation links the suburbs to the CBD in a radial structure. As Mills (1967) states, there is a great possibility of substitution of input-output coefficients between land, labor and capital. Although, he acknowledges the possibility that different sites might require a different combination of coefficients in order to the transportation system to be

efficient. Nevertheless, he assumes that land is the only input in the transportation, therefore workers only commute to the CBD by cars.

The production of housing occurs in rings distant from the CBD. The housing production function considers not only the production of housing but also the production of goods near customers in order to avoid transportation costs. Therefore, those goods are produced in the residential area.

The use of land in the suburbs is determined through land bids. In case that the CBD desired to expand its area, it must bid land away from the suburbs. And in the city fringe the suburbs must be able to bid land away from agricultural production. The land rent of the agricultural land is exogenously given.

The housing market is assumed to be competitive in the input and output market. Mills (1967) assumes that the variations in the demand for housing consumption do not vary but the proportion in which land and capital are consumed in order to produce housing does.

The model proposed by Mills (1967) follows the assumption made by Alonso (1964) and later incorporated by Muth (1969) that in equilibrium a household might reduce its cost of transportation moving closer to the CBD, but this reduction will be offset by the raise in the housing cost.

Further assumptions made determine that all land should be used. In the case of the land in the CBD, it will be used in transportation and in the production of goods. Similar, the land in the suburbs used to produce housing and transportation. Finally, the model does not take into account any geographical or topographical obstructions in the city.

The solutions of the model proposed by Mills (1967) to the size of the CBD imply that the amount of land dedicated to the production of goods increases in decreasing rates the greater the distance to the city center. The results for the model analyzing the demand side of the goods market and assuming the firm maximizes profit. Mills (1967) states that the demand for land in the CBD in order to produce goods is inversely related to their prices. In other words, the higher the land values in the CBD, the lower their demand for the production of goods.

Also, if the prices of factor ratios of input and output of the firms are in competitive markets the size of the CBD will be such that the land around it will be enough to transport workers to the CBD. This result sheds light in the impacts of traffic congestion and its implications for the model only allow for the transfer of land from the production of goods to the transportation.

The result for the equation estimated for the land-rent in the suburbs show that there is a decline in the prices according to their distance from the CBD. Until Mills' (1967) land-rent

values decreasing in an exponential function was the standard assumption. Nevertheless, his model indicated a slower-than-exponential decline, even though his model considered the possibility of an exponential decline.

The implication of the land-rent curve to be slower-than-exponential allows for the possibility of houses closer to the CBD to have a smaller area without a sharp rise in their prices as one approaches the city center, as it would happen in the exponential model.

Another conclusion derived from Mills' (1967) model relates to the population density. A common assumption made before him was that population also declined in an exponential way. Again, the equation yielded by his model pointed to a linear decline in population density from the city center.

The Alonso-Mills-Muth Model¹⁶, nowadays considered the classical theory of urban economics, analyses a concentric city where a predetermined single location concentrates the firms, the Central Business District (CBD). The households locate in the other concentric circles around the CBD, the suburbs. Another assumption One of model is that the land is homogeneous and ready to be occupied¹⁷. Further, the transportation system is assumed to be in a radial form in which there are no congestions and is used by workers exclusively to commute to the CBD.

The model departs from the analysis of a household utility maximization between housing and a numeraire composite good. Income is assumed to be the same for each worker independent of their location and it is spent in the numeraire, land and transportation costs. Within the utility maximization the distance from the CBD is accounted for in the costs of transportation and the land rent (also known as bid-rent curve).

The latter argument in the previous paragraph implies that the costs of transportation raise the greater the distance traveled to reach the CBD. The inverse can be verified in terms of the prices of housing which reduce the greater the distance to the CBD. Therefore, within the model framework it can be inferred that there is an inverse relationship between the costs of transportation and costs of housing.

Nevertheless, the model states that maintaining a fixed utility independent of the distance to the CBD, the raise in the cost of transportation is offset by the reduction in the price of land-rent. The opposite applies in the case of household located close to the CBD.

¹⁶ For an extensive explanation of the model see Fujita (1989) and Brueckner (2001).

¹⁷ One the problems faced by their models is assuming that the city is homogeneous, not taking into consideration the topography, which might influence possible results given that it might affect the location of households.

Another result that can be shown in the model relates the land rent and the sizes of land plots. The land rent declines as the distance from the CBD increases. While the opposite can be inferred about the sizes of lots, they become larger the greater the distance to the city center. Notwithstanding, Alonso (1964), Mills (1967) and Muth (1969) acknowledged the possibility that cities could incorporate other concentrations of employment within its limits besides the CBD. Moses and Golstein (1973) indicate the modification that Muth (1969) made to his model in order to incorporate smaller centers of employment located in the residential area. However, they are considered too small and have no effect on prices or land area occupied to exert any influence over space.

Likewise, Mills (1967) cites an example of shopping centers and their possibility to exhibit increasing returns to scale sufficient enough to hinder housing from an area, but this force is not enough to be defined as a central location. According to the author, considering the framework of the proposed model, considering such modifications would complicate its solution once it would be necessary to consider the distance between such economic activity and its distance to the CBD and its neighbors.

The review by Berry and Kim (1993) and Anas, Arnot and Small (1998)¹⁸ sheds light to the polycentric urban pattern. Both researches display several works that corroborate that polycentricism is not a phenomenon, it is a recurring urban pattern in major American cities.

Theoretical model developed by Fujita and Ogawa (1982) and empirical research by Shukla and Waddell (1991) and Waddell and Shukla (1993) explore modifications to the monocentric model. One of their modifications to the model is the possibility of cities that concentrate workers in more than one employment center.

The work developed by Fujita and Ogawa (1982) proposed a theoretical static microeconomic model focused in the analysis of land use in a non-monocentric city. In their framework the location of the firms and households are defined endogenously.

The city is assumed to be linear and the economic agents are firms and households. The interaction between firms is known as within-sector interactions, resulting in agglomeration economies. The interactions between households and firms take place in the labor market, where households supply labor and firms pay wages. The market in both forms of interaction are considered to be perfectly competitive throughout the city.

Households are assumed to maximize their utility between land and a composite good. Three main assumptions of the model are: (1) in each family unit it is assumed that only one

¹⁸ The work of Anas, Arnot and Small (1998) comprises a section describing the historic conditions of the urban structure in the United States.

individual supplies its work; (2) the wage from its labor is the only income of the household; (3) there is only one type of travel within the family, the commute from home to work. The wages are determined by the land rent at a site and the size of lots (assumed to be a positive constant) consumed, the price and quantity of the composite goods that are consumed and the relationship between the commuting time and the distance from the household to the work site. Therefore, if households maximize their utility by the consumption of the composite good the results yield the appropriate values of the residential and work sites.

Each firm produces an output that is exported by constant price using labor and land as an input. It is assumed that the city has full employment. One of the aspects to be considered in polycentric cities is the concept of economies of agglomeration, which Fujita and Ogawa (1982) incorporate in a function denominated *locational potential function*.

The locational potential function relates the density of firms to a *potential parameter* that is also linked to the distance between them. Hence, the function depends on the value of the parameter and the distribution of firms in space. This parameter is essential in order to assess the possibility of a multi-employment-centered city as its magnitude influences the locational decision of firms. The location that maximizes the profits of firms incorporate the locational function once it represents a cost reduction¹⁹ in the production process due to the proximity among other firms.

The equilibrium conditions of the urban structure are determined through the bid-rent curves of the firms and households. The bid-rent curves depend on the household density function, business density function, the land rent value in that site, the wage paid by firms in that location, the ratio between workers who commute to a firm in a specific site and reside on that location divided by the total population that resides in that site and the utility level to be estimated²⁰.

The possible configurations that Fujita and Ogawa (1982) assess are the monocentric, mixed urban configuration, incompletely mixed urban configuration, duocentric urban configuration and a tricentric configuration. The latter has two possible configurations. The first consisted of a city with a CBD and two employment subcenters (SBD). The second could be seen as one city with three subcenters of equal importance or as three separate cities each with

¹⁹ As Fujita and Ogawa (1982) mention, the reduction in costs do not involve land rent and wages.

²⁰ Other equilibrium assumptions are that the land in the urban fringe will be devoted to agriculture and it may be transformed in urban land use. The agricultural land rent is defined exogenously. The land can only be devoted either to households or to firms, there is no mixed-use land pattern. And the land must be occupied by the highest bidder at that location. For the entire set of equilibrium conditions see Fujita and Ogawa (1982, p.167-169)

its own CBD. In each case there are several possible optimal solutions that enable each urban configuration

Finally, the model proposed by Fujita and Ogawa (1982) is assertive to accommodate the possibility of cities that concentrates employment in locations other than the CBD or also for them to be dispersed. Another important conclusion of their model, in a monocentric city in equilibrium as population and the rate of commuting change the city is more likely to alter its urban structure to other types of configurations.

As shown in Annas, Arnott and Small (1991), the initial models proposed by Alonso (1964), Mills (1967) and Muth (1969) depicted the urban spatial structure of cities, roughly until World War II. Afterwards, the technological advances enabled the shift of economic activity towards decentralization. This trend is theoretically depicted and mathematically proven possible in the work of Fujita and Ogawa (1982).

3.2 EMPIRICAL LITTERATURE REVIEW

In this subsection the empirical literature will be divided into two other subsections. First, it will be presented the works that advanced in the literature over estimation procedures. In the second subsection, the focus shifts for empirical work asserting employment subcenters when applying employment data in methods presented in the first subsection or modifications from those models.

3.2.1 SUBCENTER IDENTIFICATION METHODOLOGIES

In this section the attention turns to literature that estimates employment subcenters empirically. First, we investigate the works of Shukla and Waddell (1991) and Waddell and Shukla (1993) that analyze polycentricity through land-use. Afterwards we consider the work of McDonald (1987) and Giuliano and Small (1991), the first researches that focus in the employment distribution in the urban space. While McDonald (1987) consider peaks in either gross employment density or employment-population ratio to determine employment subcenters, Giuliano and Small (1991) use minimum density in census tracts and total density of a cluster of tracts. Lastly, we depict recent methodologies that consider the use of nonparametric models such as Craig and Ng (2001), McMillen (2001) and Redfearn (2007).

The work of Shukla and Waddell (1991) investigates the strength of the monocentric urban pattern and also searches to verify if the Dallas-Fort Worth has employment subcenters.

The study focuses on the underlying reasons that motivate the employment decentralization through the locational choices of industrial²¹ firms using a multinomial logit. Their unit of analysis are the ZIP code zones.

According to the model proposed by Shukla and Waddell (1991), the probability of different firms of different types of activities to locate in a specific ZIP code is related to the share of firms of that industry that locate in that zone. A firm will choose the location that maximizes the profit function. The latter considers the production function, that takes into consideration the purchased land and non-land inputs and the possible effects of agglomeration economies. Also, the price of labor and capital is assumed to be invariant across the region while the price of land may vary²².

The variables that are taken into consideration in order to assess the probabilities of a firm locating in a ZIP zone were separated into three groups. The first group consider variables to test the strength of the monocentric model. The variables included are the level and squared²³ distance of the ZIP zones to their respective CBD, either Dallas or Fort Worth. Another variable included was the distance to the Dallas-Fort Worth Airport. It was also included a dummy variable for the presence of a major highway in that ZIP zone.

The second group of variables try to measure the availability of land in each ZIP zone. The parameters included in this group should capture the zoning and topographic land restrictions that might allow the use of land for employment close to residential area or to hinder the use of land, respectively. The variables included are the percentage of developed area and the share of usable land area in a ZIP zone.

The third group of variables tries to capture the effects of the economies of agglomeration and to measure what other characteristics might attract firms to locate elsewhere than the CBD. In the distance variable it is considered a distance decay parameter to be determined according to each set of variables. In the populational set, the distance decay parameter is 0.25. Other variables such as median household income; percentage of black individuals; employment in construction, manufacturing and wholesale; employment in mining, transport, communication and utilities and Finance, Insurance and Real Estate (FIRE); and employment in retail trade and service use a decay parameter of 0.75.

²¹ Shukla and Waddell (1991) use the one-digit Standard Industrial Classification (SIC) level.

²² In order to estimate the multinomial logit function for a specific firm of a specific industry in a determined location the authors use an indirect profit function and also assume that each business face the same non-land prices and that the amount of labor necessary is determined by the technology. See Shukla and Waddell (1991, p. 233-234).

²³ According to Shukla and Waddell (1991) the level and squared variables were introduced to verify the intensity of concentration of firms.

The results of the multinomial logit proposed by Shukla and Waddell (1991) point in the direction of industry decentralization in relation to the Dallas CBD, except in the case of FIRE. Nevertheless, the industries in the Fort Worth area follow a monocentric urban pattern.

The study also corroborates to the transportation-oriented decentralization. Access to freeways incentive the location of firms, with the highest estimates for wholesale, trade, retail and manufacturing. The Dallas-Fort Worth Airport also influences in the location of firms, especially for the wholesale firms.

The variables for the economies of agglomeration contribute to explanatory power of the proposed model. The proximity between firms of the same industry was significant for manufacturing, wholesale, retail and services. Again, the exception is the FIRE industry.

Furthermore, Shukla and Waddell (1991) state that the influence exerted by the Dallas CBD is mitigated within a distance of 10 to 15 miles. According to them, this serves as the necessary evidence that the CBD is one of many centers of employment. Therefore, confirming their initial hypothesis that the Dallas-Fort Worth metropolitan area is polycentric.

The other empirical work that analyzes polycentric urban structures from the land-use perspective is the research by Waddell and Shukla (1993). Their main objective was to investigate the behavior of manufacturing firms in the locational choice as the subcenter attributes vary and also whether industries cluster due to sector specific characteristics. They also consider a possible combination between both aspects.

The manufacturing firms are classified according to the three-digit SIC level. The unit of investigation is the ZIP code area for the region. Through the use of aerial images and the use of a Geographical Information System (GIS) they were able to single out residential, industrial and vacant land use. Further, the combination of employment and socio-economic data available at the ZIP code-level was added to the land database through the intersection of polygons. The areas with the top 1% of employment concentration were considered as subcenters.

In order to measure to what extent firms react to locational attributes it was employed a discrete choice model. The variables included in this model try to capture the size and urban development of the center through its total area in square miles and the percentage of the area that was considered as developed. Broad proxies of employment characteristics of the center were included, such as the total employment and net employment. Also, other variables were added in order to assess economies of agglomeration through percentage of labor²⁴ in a center

²⁴ This variable is divided into three categories in order to capture the percentage of employment in the manufacturing, wholesale trade and FIRE sectors.

and another one that measures the access to labor markets through the distance populational decay between subcenters.

A multinomial logit model is used to capture possible specific industry related attributes that act as incentives form them to cluster in specific subcenters. To capture firm size, it was considered two dummy variables of employment. Firms with 100 up to 500 employees are considered big and those with more than 500 workers are very big.

Furthermore, variables related to particular industry characteristics were considered. In order to measure the intensity of labor and capital employed in a sector the average hourly wage and the consumption of fuel. Another variable is included in order to capture those industrial activities that are more inclined to be close to their input market. A variable is included to measure the share of building assets and rent payments of businesses to capture their space requirements. A dummy variable for industries that are considered as technology-oriented is considered as well.

In the logit model two spatial variables are considered as well. The Standard Distance is employed to measure the concentration of firms in space with respect to an industries centroid instead of a subcenter centroid. High values for the standard distance indicate that firms of a specific industry appraise several attributes to determine their location, and, therefore, are dispersed in space.

The other spatial variable is a contiguity index. High values of this index suggest that industries cluster together. Also, combined with low values of the standard distance implies that that sector has one large center that clusters all firms. In the case of high standard distance values, the industry displays a multi-centered concentration. If the contiguity index is low this implies that an industry is either located in a small area or that its firms follow a disperse pattern in space. In case of a low standard distance value the industry is concentrated. For high values of the standard distance firms are spread in the urban space.

Further, Waddell and Shukla (1993) estimate a “*mixed*” model in order to measure the probability of firms of a specific industry with specific attributes to concentrate in space when general subcenter attributes are accounted for.

In the case of the discrete choice model the results point that manufacturing firms tend to locate in areas with higher infrastructure and developed land than those locations with greater proportions of available land. Also, they tend to locate in sites where there is lower total net employment, suggesting that in those locations manufacturing firms might benefit from economies of agglomeration. Further, manufacturing and wholesale trade benefit from inter-

industry linkages. Nevertheless, Waddell and Shukla (1993) infer that the linkages could be the result of urban zoning restrictions or market-oriented interactions.

The reported estimates for the multinomial logit model indicate that the industries with high-level of average consumption of fuel tend to locate in the CBD and those with low wages establish elsewhere. The high-technology firms also avoid the CBD and concentrate in the north region of the city where there is a high-skilled labor pool. Further, industries that are input-oriented or building-oriented prefer to locate in the suburbs with easy access to major transportation roads.

The results for the “mixed” model shown in Waddell and Shukla (1993) contribute to understand that depending on the industrial sector analyzed specific industries might favor sector related attributes and other locational characteristics. Therefore, SBDs might be specialized or diversified²⁵. According to the authors, in either case there is evidence of economies of agglomeration.

The work of Shukla and Waddell (1991) and Waddell and Shukla (1991) analyze the urban pattern through the analysis of land use patterns and firm behavior. There is not a clear criterion in order to assess what is a subcenter and what statistical methodology applicable in order to infer their locations once they measure the probabilities of sector-specific firms to choose their location in specific ZIP code zones.

Further, in order to determine employment subcenter the main focus is related to the employment location in the urban space. Therefore, to determine employment subcenters the focus shifts to the analysis of employment density rather than land use patterns as it will be demonstrated in the following paragraphs.

Several studies developed a methodological approach to determine employment subcenters within the urban context. Within this context, the methodologies proposed in the studies of McDonald (1987), Giuliano and Small (1991), Craig and Ng (2001), McMillen (2001) and Redfearn (2007) were appraised in the foregoing paragraphs.

The study of McDonald (1987) proposes an empirical method to identify employment subcenters. In order to assess the issue, the author determines that local peaks in either gross employment density or employment-population ratio could readily determine subcenters. Simplifying, a site could be considered as an employment subcenter if the employment-

²⁵ Anas, Arnot and Small (1998) acknowledge that despite the presence of multiple employment centers in a city the importance and diversification of the CBD still remains as the main center. Its influence over price gradient as well as employment and population density are higher than the impact caused by subcenters. Even so, in its majority, employment in polycentric cities is disperse. Therefore, even in a multi-centered urban pattern, employment is mostly dispersed through the city.

population ratio or gross employment density does not decline the further a location is to the CBD.

Further, gross employment density and the employment-population ratio are calculated considering the employment in manufacturing and the total employment in each location. The local peaks occur when the indicator for a particular site exceeds the value of the contiguous observations on at least one of the two categories in each indicator.

The identification of subcenters proposed by McDonald (1987) has several issues. In the case of the gross densities his calculations are subject to tract sensitivity once the total areas of each zone and the contiguous zones, which the densities are compared to, might vary. Also, if the choice of contiguous zones is modified, the results might differ as well. Further, his procedure is not subject to statistical testing in order to assess the subcenters significance.

The procedure of Giuliano and Small (1991) to determine subcenter candidates is quite straightforward and replicable to other study regions. They define an employment center as a set of contiguous zones that share a common boundary of least a quarter of a mile. Each zone has to have a minimum total gross employment density of ten employees per acre. Also, all the zones combined to form the subcenter must have at least 10,000 employees. The zones that do not meet the minimum density per acre or the minimum number of total employees are not classified as an employment center.

Giuliano and Small (1991), in the opposite direction of McDonald (1987), choose not to compare the employment density to contiguous sites and also not to consider the employment-population ratio a viable approach.

Nevertheless, their choice for the cutoffs is discretionary. The authors consider a reduction in the total employment in a cluster in order to keep the CBD of other three counties significant. Further, the study of Cervero and Wu (1998) also uses density cutoffs of seven workers per acre and 9,500 workers in contiguous tracts for the San Francisco Bay Area. According to McMillen (2001) and Redfean (2007), the arbitrariness involved in the choice of values for the thresholds might be due to previous knowledge of the area studied.

Another problem from Giuliano and Small (1991) that arises is that the further a site locates from the CBD the lower its employment density. Hence, the minimum density per acre and total employment per center are difficult to achieve²⁶. This difficulty is further enhanced by their use of census tracts. Therefore, their methodology fails to detect employment concentrations in distant areas of the CBD and to identify sites that represent a local peak in

²⁶ McMillen (2001, p. 20-22) compares the possible alterations in the threshold values and its implications in assessing subcenters for Milwaukee using the procedure proposed by Giuliano and Small (1991).

comparison to the surrounding area. Taking into consideration that most of the employment in an urban area is not concentrated, rather dispersed, choosing such criteria favors the identification of SBDs closer to the CBD. The comparison made by Redfearn (2007) between results of the procedures of Giuliano and Small (1991) and McMillen (2001) confirms the previous affirmation.

The work developed by Craig and Ng (2001) tries to remove the high degree of subjectivity in the studies of McDonald (1987) and Giuliano and Small (1991). They use a non-parametric employment density quantile splines regression.

In their employment density regression, the authors estimate the logarithm of the employment density of a census tract conditioned to its distance from the CBD. Their choice of functional form is a cubic spline. Since one of the independent variables is the distance to the CBD the model yields concentric circles around the CBD. Those rings that present an employment gradient greater than what would be expected²⁷ have a subcenter. Further, they choose the sites with the highest employment²⁸ density within that ring as the SBD.

The focus of their procedure relies on the analysis on the probability distribution of the observations on the top 95th percentile of the density function, thus they concentrate in the outliers. According to the authors this is an advantage since they aim at the median and not the mean of the distribution.

Another positive contribution by their procedure is the use of a non-parametric approach which captures the high employment density areas in comparison to their neighbors. Further, this type of statistical procedure allows parameters to vary, considering that a micro-level employment data is being used, this allows to account for geographical restrictions (such as large bodies of water) in the estimated employment density surface of a region.

Nevertheless, their method can only assess rings with high employment density gradients, it cannot determine specific sites as subcenter candidates. In order to do so, within those rings that have gradient peaks they choose the census tracts with the highest employment density, there still remains a certain level of discretionary power in determining subcenters as in McDonald (1987) and Giuliano and Small (1991).

²⁷ According to Craig and Ng (2001, p. 102) the ring that present an “employment gradient greater than what would be expected from a smoothly declining density quantile spline and use the variation in the gradient to define the location of an employment center”.

²⁸ Craig and Ng (2001, p.102) mention that “using the upper quantile spline, however, greatly increases the chances the chosen point is one that influences the top quantile spline, and so is consistent with finding an employment concentration”.

The methodology proposed by McMillen (2001) tries to identify subcenters and it can be applied to different cities without the use of threshold values and prior knowledge of the specificities of the city. His two-stage semi-parametric procedure identifies statistically significant sharp local rises in the employment density while conditioning to the distance from the CBD. Even though McMillen (2001) considers census tracts as his unit of analysis, his methodology is also suited for different units of analysis and takes into consideration the possibility that the distance from the CBD may influence variations in the employment density.

The first stage of the procedure developed by McMillen (2001) serves as benchmark for the number of subcenter candidates. In this step, the procedure uses a non-parametric Locally Weighted Regression (LWR)²⁹ to smooth the natural logarithm of employment density over the distance to the CBD. The subcenter candidates are sites that exceed the smoothed employment with residuals significantly greater than zero at least a five percent significance level. However, this first step does not identify if those sites have a statistically significant effect over the outline of the employment density function. This first step is also efficient in order to remove possible sensitivity of the results caused by the sizes of the tracts.

In the second step McMillen (2001) uses a semi-parametric procedure to determine the employment density in a tract and as independent variables are included the distance from the CBD and other two Euclidean distance variables in linear and inverse forms. In the first variable, to measure the distance from the i -th variable to the CBD the author considers an LWR, this is the non-parametric term. The two Euclidean distance variables in linear and inverse forms relate the distance from the i -th variable to the j -th candidate subcenter estimated in step one, these two terms are estimated via OLS. At this moment, he proposes a highly flexible function to estimate the distance between the observations to the CBD. As McMillen (2001) indicates, it can be used the LWR, cubic splines or a kernel procedure. In his work it was chosen a Fourier function. Further, a stepwise procedure is applied in order to determine the subcenters. The candidate sites that score the lowest t -values in a 20% level of significance are removed. The intercept and the Fourier terms are forced to remain in the regression in each stage.

Therefore, the procedure developed by McMillen (2001) removes the discretionary power and also allows for statistical tests of significance opposed to what was seen in the methodologies of McDonald (1987), Giuliano and Small (1991) and Craig and Ng (2001)

²⁹ The use of the LWR contributes to identify rises in the employment density function considering only observations that are close to the unit of analysis. Also, it accounts for the difference in the employment density gradients through the area studied.

The methodology proposed by Redfearn (2007) also uses a nonparametric procedure (a locally weighted regression) to determine employment subcenters through the metropolitan region of Los Angeles. He defines subcenters as a contiguous set of census tracts that have an employment density significantly higher than the surrounding tracts, similar to McMillen (2001). Therefore, his main goal was to determine employment concentrations that are significantly higher than the neighboring areas. Further, Redfearn (2007) also analyzes the extent of each subcenter.

While analyzing the census tracts of the greater Los Angeles area he aggregates them in grids that do not alter the employment density structure of the region. In the first step, he estimates two Locally Weighted Regressions (LWR) one considering as an independent variable the North-South direction and in the second estimate the East-West directions. Redfearn (2007) considers a 24% window size and a tricube kernel weight. Further, his procedure also captures the extent of a subcenter, which McMillen (2001) fails. The highest points in the estimation of the first step are considered to be candidate subcenters.

In the second step he analyzes the employment density surface. At this moment, Redfearn (2007) focuses in the census tracts that are inside the grids. Through an iterative process, partitions of tracts that are inside the grid and are neighbors with the local maxima previously estimated are considered to be part of a subcenter. Further, the census tracts of a subcenter have to be contiguous. In order to do so, Redfearn (2007) estimates the same two LWR of step within each grid, obtaining the local surface of the employment density.

According to Redfearn (2007), the subcenters are those sites with the highest number of census tracts that minimize the residual sum of squares. When adding a census tract to the local maximum to form a partition, four other variables (two intercepts and two slopes) must also be included in the LWR to be estimated. Thus, the author considers the Akaike (AIC) and Schwartz (SIC) information criteria to evaluate the inclusion of more parameters in the model and its adherence.

The resulting partitions for each information criterion are different. While the SIC tends to include fewer variables resulting in smaller subcenters, the AIC criterion incorporates more, generating larger SBDs. Since each criterion generates partitions of different sizes, in order to determine the area of a subcenter, Redfearn (2007) uses the average employment density between the partitions for each information criterion. Until this moment the final subcenter has not yet been identified.

Redfearn (2007) tests different combinations of partitions. In the first partition the author considers the census tract with the local maxima as the reference. By including another

census tract in the second interaction, Redfearn (2007) centers the reference point in the core of the first partition. This process of incorporating different census tracts, testing optimal partitions, and centering the reference point for each block is repeated until a partition does not change for two consecutive iterations or, in case of consecutive changes, maintaining those census tracts that appear regularly.

Next, Redfearn (2007) uses a difference in means bootstrap test to verify whether the estimated subcenters actually have a higher employment gradient than the close neighbors. In addition, the author also estimates an exponential model to compare the results and verify the robustness of the test via bootstrap considering the heterogeneity of center size.

Redfearn's (2007) results point to 78 sub-center candidates after the first step. After performing the iterations on the second step and after applying the difference in means test there still remain 41 statistically significant employment subcenters.

As mentioned by Redfearn (2007), his results shed light to the most distinct subcenters according to their employment density. While the Los Angeles CBD concentrate over 50 jobs per acre there are smaller subcenters with an employment density over 3 jobs per acre. Therefore, his methodology raises several classes of employment subcenters.

Further, Redfearn (2007) compares the results of his model for Los Angeles with McMillen's (2001). The two approaches have similar results in the identification of major primary employment subcenters. Nevertheless, McMillen (2001) fails to find secondary and tertiary centers. According to Redfearn (2007) the nonparametric model proposed by McMillen (2001) is better suited in highly urbanized areas.

Another methodology that could be considered in this study is the Exploratory Spatial Data Analysis (ESDA) through Local Indicators of Spatial Autocorrelation (LISA) – mainly through Moran's I. Nevertheless, when considering the urban space, it should be noted the effect of CBD (which is not accounted in when applying ESDA), since it exerts significant influence in the distribution of infrastructure, residences, individuals and employment. Also, the results may be influenced when considering the weight matrix and number of neighbors.

The works of McMillen (2001) and Redfearn (2007) sheds light in the problems faced while using density cutoff values and the traditional parametric negative exponential estimation in order to identify employment subcenter. Both agree that the model specification should be nonparametric, accounting for variations in the urban area that might influence employment location. Thus, recent literature searching to identify employment subcenters has shown that the use of nonparametric models is better suited for such task, despite recent work not applying such procedures.

While working only with distribution of employment in the city proper of Curitiba, and not its metropolitan region, accounting for a smaller number of workers our interest is to determine primary employment subcenters which comprise more workers in a highly urbanized area. Further, the model in hand should consider the relationship between such subcenters and their distance to the CBD. This relationship should be considered since the latter represents the highest concentration of employment in cities and the dispersion or concentration of employees in secondary centers might be conditioned to the distance to the main center. Therefore, the estimation procedure proposed by McMillen (2001) appears to be the most suited to assess subcenters³⁰.

It is clear that the methodologies proposed by McDonald (1987), Giuliano and Small (1991), Craig and Ng (2001) and McMillen (2001) shift the focus of assessing employment subcenters through land use patterns to employment data analysis.

At this moment little has been explored about the underlying conditions that motivate the appearance of employment subcenter in the urban context. As Giuliano and Small (1991) point out, there are economic forces underlying the development employment subcenters in the urban context. The main drive for this process relates to the externalities of urban congestion and its impact in the economies of agglomeration. Anas, Arnott and Small (1998) sheds light in the role that governments might play in order to promote policies to create employment subcenters. Therefore, we consider that urban planning might play a fundamental role to promote urban polycentricism. In this sense, the study of employment centrality for the city of Curitiba (Brazil) is very interesting in this context.

3.2.2 EMPIRICAL RESEARCH

Several studies have been developed to assess the presence of polycentric cities analyzing the spatial distribution of employment in the urban space. Most of these studies are concerned to cities in developed countries and few have explored the polycentric urban structure of cities in developing countries, particularly to Latin America. Although, in the following studies their chosen methodology might not correspond to the ones exposed in the previous subsection, most relate to them.

³⁰ Other studies employ McMillen's (2001) two-step semi-parametric procedure, see Krehl (2016) in the German metropolitan region of Cologne, Frankfurt, Stuttgart and Munich. Also, the work of Lv *et al* (2017) analyzes the Beijing Metropolitan Area.

A common problem that arises in the analysis of employment is the data availability, there are several works that tackle the issue using population data, such as the work of Veneri (2017) for OECD countries, Liu *et al* (2018) that analyze 22 Chinese cities and also by Salvati and De Rosa (2017) for Athens, Barcelona and Rome that use census data from 1896 to 2011. Other researches use origin-destination or work-commuting survey data in cities of European countries as in Burger *et al* (2011), Veneri (2013), Duarte and Fernández (2017) and Mulicek and Maly (2017)³¹ and in developing countries as Sinclair-Smith (2015) for Cape Town (South Africa) and Zhong *et al* (2015) for Singapore. There are researches that also use land-use patterns as Yue *et al* (2010) for Hangzhou (China) and Agyemang *et al* (2019) for Khumasi City-Region (Ghana). Innovative work uses different sets of data, such as Lan *et al* (2019) that applies night-time images for 20 Chinese cities or Xie *et al* (2019) that use night-time images and social media data for the Chinese cities of Shenyang, Wuhan, and Xi'an. In this subsection the soon to be presented researches must meet two criteria: (1) apply employment data, (2) and consider small units of analysis³². Only a few exceptions will be made.

In the United States, several studies assessed the presence of employment subcenters as the ones previously mentioned researches of Shukla and Waddell (1991) and Waddell and Shukla (1993) that focus on the Dallas-Fort Worth area. McDonald (1987) analyzes Chicago. The investigation of Los Angeles is examined by Giuliano and Small (1991) and McMillen (2001). The latter also considers the cities of Chicago, Dallas, Houston, New Orleans, San Francisco and Los Angeles.

Shearmur and Coffey (2002) analyze the distribution of employment in the Canadian cities of Montreal, Ottawa-Hull, Toronto and Vancouver. The authors use a minimum density cut-off method of 5,000 workers when combining census tracts and an employment-population ratio greater than one to determine employment subcenters. The authors use work-location data at the census tract level for 1981 and 1996 of four aggregate economic sectors: manufacturing; consumer services; finance, insurance and real estate (FIRE); and producer services. According to the authors, their results leads them to conclude that the regions of Montreal and Ottawa-Hull exhibit a similar pattern, a polycentric shape but with a strong CBD in which economics activities tend to be proximate. They classify the city, despite having subcenters, as

³¹ Burger *et al* (2011) uses data commuting data for Welsh and English cities; Veneri (2013) for Milan and Rome; Duarte and Fernández (2017) in Saragossa, Bilbao, Madrid, Barcelona, Seville, Malaga and Valencia; and Mulicek and Maly (2017) for cities in Czech Republic.

³² Ideally, the smallest unit of analysis should be either a census tract or grid cells. Nevertheless, such data is not available for some countries, where the smallest unit of analysis could be at the sub-regional- or a municipal-level.

monocentric. In the case of Toronto, the authors conclude that there are several important centers in the city besides the CBD, therefore, the city is indeed polycentric. Finally, Vancouver also exhibits a strong CBD, although, differently from Montreal and Ottawa-Hull, there are fast growing employment subcenters located far from the CBD which capture a significant amount of the employment growth in the city.

In the European context, the work of Baumont, Ertur and Gallo (2004) use Exploratory Spatial Data Analysis (ESDA) to study the distribution of employment and population in the city of Dijon (France). The data in the study is from 1999 when the metropolitan area of Dijon which had a population around 250,000 inhabitants. The choice of the authors for the ESDA is similar to the concern of McMillen (2001) and Redfearn (2007): statistical criteria that support the evidence of employment subcenters. Their results regarding employment density point that Dijon is monocentric given that the estimated subcenters have low impact in the attraction of residents near them.

For the Metropolitan region of Barcelona (BMR), Garcia-López and Muñiz (2010) analyze the debate between polycentricity and scatteration of employment between 1986 and 2001. They use and adaptation to the cut-off method of Giuliano and Small (1991) to identify employment subcenters proposed by Muñiz *et al* (2008). The authors consider tracts as subcenters when they meet two criteria: (1) the employment density in the tract has to be higher than the employment density in the area analyzed; and (2) the total employment in the unit has to concentrate at least 1% of the employment in the region analyzed. Despite not being the sole objective of the study, Garcia-López and Muñiz (2010) do identify employment subcenter for the BMR, but since rate of employment growth over the years in the subcenters have been lower than the rates for decentralized (other places than the CBD or SBDs) employment, the city exhibits a trend towards a scattered pattern.

The study of Krehl (2016) for the German cities of Cologne, Frankfurt, Stuttgart and Munich applies the methodology proposed by McMillen (2001). The author finds that the regions are indeed polycentric, but the centers estimated by the model appear to be of local relevance, capturing a small percentage of the employment. Further, most of those subcenters are located in the fringe of the metropolitan areas. With these results in hand, Krehl (2016) defines that, despite having SBDs of local relevance, the urban shape of the cities analyzed are monocentric, with the core city and its CBD being dominant in the employment localization.

The work of Veneri (2017) explores the distribution of population (instead of employment) density in Functional Urban Areas (FUAs)³³ for OECD countries³⁴ for the 2001 and 2011 census. In order to identify urban population subcenters the author considers the linearized negative exponential function through the natural logarithm form, further estimating the regression via OLS. The author only estimated the presence of candidate subcenters in FUA with more than 500,000 inhabitants. The final list of subcenters were those candidates with population in the 90th percentile within the FUA analyzed. Veneri (2017) determines that instead of population residing in pre-existing subcenters estimated in 2001, people are concentrating in recently formed subcenters. Despite not focusing on the employment data due to unavailability for several countries, the author assumes that individuals follow employment, which it might also be inferred, within his results, that employment is decentralizing and concentrating in small or local subcenters instead of concentrating in pre-existing SBDs.

Other empirical work that focus in the location of employment in developing countries are scarce. In the Chinese context and also considering data for employment location, the city of Beijing is examined in several researches. Huang *et al* (2015) searches to identify employment subcenters through three models: (1) the linearized monocentric negative exponential regression, (2) a linearized exponential polycentric regression and (3) another regression to test if the subcenters influence the employment density. The residuals significant at the 5% confidence interval in the former regression are considered as employment subcenters candidates. In order to identify candidates with low employment that are surrounded by tracts with little or no workers, the authors apply the same thresholds as Muñiz *et al* (2008). In the second step, the authors test if the subcenter candidates influence the distribution of employment in the surrounding areas³⁵. In the third model the authors include only the distance to Tiananmen Square and the distance to each unit of analysis (which in their work are grid cells of 1.5km by 1.5km). According to Huang *et al* (2015), Beijing still exhibits a strong monocentric pattern even with the identification of five employment subcenters, this assertion results from the small increase of 4% in the explanatory power of the polycentric model when compared to the monocentric.

³³ For the precise definition of FUAs see Veneri (2017).

³⁴ Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Kingdom and United States

³⁵ As independent variables Huang *et al* (2015) consider the distance inverse distance from the observations to the subcenter candidate, to Tiananmen Square, to nearest subway station, highway and to the airport.

The study conducted by Lv *et al* (2017) searches to identify employment subcenters through the methodology developed by McMillen (2001). The authors use employment data from economic census conducted in the years of 2004, 2008 and 2013. As the unit of analysis, they consider the subdistrict level. Within their results the authors identify that Beijing is polycentric, having identified 14 subcenters in 2004, 16 in 2008 and 17 in 2013.

The work of Liu and Liu (2018) analyzes the outcome of policies that were implemented in Beijing to stimulate polycentricity. The authors use employment data for 2001 and 2010 and use the city blocks as the unit of analysis. As the subcenter identification method, their choice was the cut-off methodology. Liu and Liu (2018) use two thresholds. First, the employment density in a block for a given year must be higher than the employment density in the city. In a second step, the total employment for contiguous units for a year t must be higher than 0.5% of the city's total employment. Since the authors are testing if the planned and unplanned subcenters are economically relevant, they estimate a polycentric model to test for the relevance of both the employment and population density in the period analyzed. Liu and Liu (2018) conclude that the urban planning policy has promoted polycentrism and, within the identified SBDs, the planned subcenters had a stronger effect in the distribution of employment and population.

Hu *et al* (2018) investigate how the urban shape of Beijing impacts commute flows. They use data for transit information (bus stops, routes and schedules) in 2008, individual-level information about commute flows for 2010 and employment location for 2000 and 2008. Since the main objective of the work is beyond asserting polycentricity, attention will be attained only for such topic within their work. In order to identify employment subcenters, the authors use the methodology proposed by McMillen (2001) but with a modification in the second step³⁶. The first step of his procedure is reproduced in its entirety. In the second step the authors determine that subcenter candidates are those tracts identified in the first step that cluster and have a minimum employment density threshold of 0.5% of the employment of the region analyzed. In their results, Hu *et al* (2018) also identify that Beijing is polycentric.

In Huang *et al* (2017) the main focus of the work is to analyze the impact of subcenters in the population distribution in the urban space. Nevertheless, part of their effort is directed towards the identification of subcenters. In order to achieve such task, the authors use employment data for the years of 1996, 2001 and 2010. Their choice of methodology is a cut-off method in which the thresholds vary in order to identify possible subcenters in tracts located

³⁶ As pointed by Hu *et al* (2018), their modification in the second step is replicated from Lee (2007).

far from the city core. Further, the authors used a grid of height and length of 1.5km as the unit of analysis. Focusing solely in the appearance of subcenters, the authors show that Beijing had six subcenter in 1996. The number of SBDs grew to 11 in 2001 and to 16 in 2010. The share of employment in the identified subcenters grew from 11.2% in 1996 to 38.5% in 2010. Hence, the SBDs throughout these years have grown not only in quantity but also in size. Also, the authors mention that most subcenters are located close to the city core, but between 2001 and 2010 there has been subcenter formation in outer areas of Beijing. Finally, the authors acknowledge that the appearance of subcenters after 2001 was due the urban planning efforts towards promoting polycentrism.

Moving towards West Asia, Alidadi and Dadashpoor (2018) investigate one of the most populous cities of the region, the Metropolitan Region of Tehran (MRT – Iran). The authors consider employment data at the sub-municipal level. In order to identify possible subcenters in the region, they consider several widespread methodologies, such as the density thresholds proposed by Giuliano and Small (1991), the threshold method of Muñiz *et al* (2008), GWR (subcenters are those observations that have residuals one deviation higher than the mean) and ESDA. After testing all those methodologies, their choice was a two-stage procedure involving ESDA, in the first step, and density thresholds similar to Muñiz *et al* (2008), in the second step. Alidadi and Dadashpoor (2018) also consider other four regressions (linear, exponential, gravitation and logarithmic) to test for monocentricity and polycentricity. Within their results, they conclude that the CBD of MRT has a low explanation power and, therefore, the region is polycentric. Nevertheless, despite the polycentric model scoring a R^2 of 0.52 and their two-step procedure identifying significant subcenters, the authors mention that the city is more likely to have a scattered or dispersed urban employment pattern.

In Latin America, the most prominent work is the study of Fernandez-Maldonado *et al* (2014) which investigates the distribution of employment in the cities of Mexico City (Mexico), Lima (Peru) and Fortaleza (Brazil) using Giuliano and Small's (1991) procedure. They apply employment data obtained from economic census and population census. Searching to identify the type of urban structure the authors try to determine the level of concentration of employment using the concentric ring definition proposed by Glaeser *et al* (2001), which is the share of employment concentrated in within a 0-5-, 5-16- and 16-56-kilometer radius of the CBD. For the Metropolitan Region of Mexico City (MRMC) the authors replicate the results of previously identified subcenters in the work of Aguilar and Alvarado (2005)³⁷, in which 35 subcenters

³⁷ Aguilar and Alvarado (2005) also apply the threshold method of Giuliano and Small (1991).

were identified. In the case of the Metropolitan Region of Lima (MRL), Fernandez-Maldonado *et al* (2014) identify 13 subcenters. Finally, for the Metropolitan Region of Fortaleza (MRF), they identified 11 subcenters. In terms of Gleaser *et al* (2001)'s classification, all the metropolitan regions are classified as dense, most of the employment locations and subcenters concentrating in the first two rings. Also, they identify that manufacturing subcenters play a significant role in the appearance of subcenters, opposed to the North American case where they are closely related to the service economy. Finally, the authors conclude that the urban structure of Latin American cities are moving towards a polycentric structure.

The city of Recife (Brazil) is investigated by Belmiro *et al* (2016). The main objective of the work is to identify employment subcenters and to verify if the propositions of the theoretical framework of urban economics are valid. Again, it will only be refrained to the part of the work related to the identification of subcenters. In order to achieve such task, they apply two density cut-offs. First, they consider the procedure of Giuliano and Small (1991) with the same thresholds. Second, they use the ratio of Shearmur and Coffey (2002), where the identified subcenters in the first step must have an employment-population proportion greater than one. Within this framework, they were not able to find any subcenters for the city, therefore, Recife is monocentric.

Lastly, the city of São Paulo (Brazil) is taken into consideration in the study of Campos and Chagas (2017). The purpose of the study is to identify employment subcenters in a broader economic sense and not only as local peaks of employment. First, they identify candidate SBDs through the ESDA approach. Second, they estimate a hedonic price model through a Spatial Lag of X (SLX) to determine the final list of subcenters. In this second step they consider as independent variables the distance from a residence to the CBD, the SBDs identified in the first step, the distance to amenities, distance to transportation networks and a vector for the characteristics of the residences. Further, since they are estimating a spatial panel, they control for fixed effects and for the possibility of the errors to not be normally distributed and for them to be spatially autocorrelated. In the first step, the authors identified 35 subcenter candidates. After the second step, the results yielded seven subcenters. Therefore, through the methodology applied by Campos and Chagas (2017), the city of São Paulo can be defined as polycentric.

In this chapter it was exposed that in European and North American context, the identification of polycentric cities has been a topic of research for over thirty years. Also, several procedures have been developed exploring American cities. In the European context, those methodologies were adapted and applied to the study areas, the same has happened for developing countries. The analysis of employment subcenters in developing countries is recent

and focused mostly in Chinese cities and in the Latin America, when compared to other regions of the world. Nevertheless, the research in developing countries remains incipient when considering what it has been explored in Europe and North America.

4 IDENTIFICATION STRATEGY

In the present study, the presence of employment subcenter within Curitiba's urban space will be determined through the two-stage semi-parametric approach developed by McMillen (2001). In order to test for robustness, modifications in the model's parameter will be made. Further, it will also be considered an OLS estimation for comparison.

4.1 DATA

Considering that the analysis in this study relies on spatial distribution of the employment density, first is necessary to geo-reference the employment through the city. Using the data provided for the year of 2010 by the Brazilian Ministry of Employment (MTE) which conducts an annual report at the firm³⁸ level, known as MTE-RAIS, gathering socioeconomic data of their formal employees³⁹.

The socioeconomic variables included in the individual-level survey and that will be considered in this study are the gender, date of birth, race or skin color, occupation category and level of education. Other variables are also included, such as the individual's workplace. This variable will be used in the merge with the firm-level dataset.

In the firm-level dataset, for each business was provided their ZIP code, enabling their geo-referencing. Since the employee dataset has specified the firm where each individual works it was possible to merge both datasets and geo-referenced the employees. Nevertheless, we did not consider businesses that had no formal employees; those that closed throughout the year; and firms that provided human resources⁴⁰ were excluded from the sample. Further, an issue was raised with public employees. In the case of employees of the Federal University of Paraná (from Portuguese, *Universidade Federal do Paraná*), they were registered to a single address. The university has several *campi*, therefore, employees were registered where in a location where they physically do not work. The same issue was seen for the Secretary of Education of the State of Parana (from Portuguese, *Secretaria da Educação do Estado do*

³⁸ As mentioned, the data is collected at the firm level. In the case of a firm with multiple production plants, franchises or offices that are in a different address or facility the data is recorded separately even though they belong to the same company.

³⁹ According to the methodology proposed in MTE-MTE-RAIS formal employees are considered those that have their job information in their employment/work card, public employees, temporary workers with a predetermined contract expiration and single workers contracted through syndicates (IBGE, 2019).

⁴⁰ The firms classified in the UN-ISIC (2008) at the three-digit level as 783 described as "Other human resources provision" were removed provided that the employees provide services to other firms. Therefore, their workplace is not at the provided address by the firm.

Paraná - SEED), but in this case all the employees in the state were registered in Curitiba. Searching to minimize possible bias caused by data we chose not to consider formal employees at public offices that were not hired by the Unification of Labor Laws (from Portuguese, *Consolidação das Leis do Trabalho*). The initial data provided 138.094 firms and after the removal of such categories it remained 50.497 firms. Finally, the remaining firms were geo-referenced through the merge of the ZIP codes of the firms and Curitiba's streets that were provided by IPPUC in shapefile format.

The employee-level dataset provided 1.360.845 individuals that were formally employed in Curitiba throughout the year of 2010. The data was then narrowed to formal employees that were participating in the labor market in December 31st 41, resulting in 848.850 observations. Also, after the merge between the firm- and employee-level datasets, those observations that were not assigned to a firm were removed. After those steps, 584.881 employees were geo-referenced.

Finally, the last step in the geo-referencing process, the choice of the unit of analysis to be considered. The employment was geo-referenced using grid cells of one kilometer by one kilometer⁴². The grid shapefile of Brazil provided by IBGE makes a distinction between the size of urban and rural areas. While the latter has a height and length of one kilometer squared, the urban areas are in grid cells of height and length of two hundred meters. Those cells were merged to form a cell with height and length of one kilometer. This process transformed the city into 502 grid cells⁴³. Further, this dataset has information about the number of residents in each cell, enabling future comparisons between employment-population ratio across the urban space.

⁴¹ In the survey for the firms it is listed workers that are actively enrolled in December 31st. Therefore, in order to match the number of workers between both datasets, it is necessary to remove those workers that were dismissed during the year.

⁴² Using a grid cell of 1km² is not expected to influence the results of the estimation since the city of Curitiba has a north-south extension of 35km and east-west extension of 20km (PMC, 2019).

⁴³ The shapefile of the city proper was juxtaposed on the shapefile of the grid cells and those cells that did not intersect the city proper were eliminated. Thus, the city has a higher population than that reported in the last census survey since it includes grids of other municipalities. Nevertheless, in the last census Curitiba had 1,751,907 inhabitants and the total population in the grid cells is 1,756,200. Since those inhabitants are in marginal cells, they are not expected to influence the analysis of the employment-population ratio.

Table 6 - Summary of variables available in each dataset considered in the present work

Dataset	Source	Variables
Firm-level	MTE-RAIS	Firm's ZIP code
		Number of formal employees in December 31st
		Classification of Economic Activities
Individual-level	MTE-RAIS	Gender
		Date of Birth
		Income
		Years of Education
		Individuals formally employed in December 31st
Curitiba's Streets	IPPUC	Classification of Economic Activities
Curitiba's Proper	IBGE	ZIP codes
Grid cells	IBGE	Curitiba's city limits
		Grid cells of Curitiba and neighboring municipalities

Source: MTE-RAIS (2010), IPPUC (2018), IBGE (2019). Elaborated by the authors.

The choice of using a grid was to remove possible tract sensitivity when considering census tracts as in McDonald (1987), Giuliano and Small (1991) and McMillen (2001). Since each grid is one kilometer squared, the employment density results in the number of employees in each unit. The study of Krehl (2016) analyzes employment subcenters through McMillen's (2001) procedure also employing grid cells. The methodology proposed in McMillen (2001) allows for different units of analysis and the use of grid cells should not cause any impact in future results. The datasets in the present work are shown in Table 6.

4.2 ESTIMATION PROCEDURE

The negative exponential model considered in the following estimates relates to the seminal works by Alonso (1964), Mills (1967) and Muth (1969). The model has the following functional form:

$$y_i = \beta_0 e^{DCBD_i + u_i} \quad (1)$$

The modification to their model is the transformation of the dependent variable (y_i) in natural logarithm form. The independent variable remains as the distance to the CBD. The parameters (β_0 and β_1) in the linearized version of the negative exponential model can be estimated through OLS. The linearized negative exponential model is:

$$y_i = \beta_0 + \beta_1 DCBD_i + u_i \quad (2)$$

The first stage of the procedure developed by McMillen (2001) serves as benchmark for the number of subcenter candidates. In this step, the procedure uses a non-parametric Locally Weighted Regression (LWR) to smooth the natural logarithm of employment density (y_i) over the distance to the CBD ($DCBD_i$). The use of the LWR contributes to identify rises in the employment density function considering only observations that are close to the unit of analysis. Also, it accounts for the difference in the employment density gradients through the area studied.

This initial smooth is also efficient to remove possible sensitivity of the results caused by tract size. The method developed uses a large window size, the nearest 50% of observations of a given site i are attributed a weight. The further an observation is from the site i , smaller its weight. This large window size leads to a smoother employment density estimate, allowing to identify the sites that have significantly positive residuals, that is, outliers. These sites are possible subcenter candidates.

In this step, McMillen (2001) uses the distance between the centroid of grid cell i to the CBD⁴⁴ as the explanatory variable. The LWR regression in the first step is:

$$y_i = g(DCDB_i) \quad (3)$$

The subcenter candidates are sites that exceed the smoothed employment with residuals that are significantly greater than zero at a five percent significance level⁴⁵. In order to avoid multicollinearity when several sites are in close proximity, McMillen (2001) narrows the candidates to those that have the highest residuals within a three-mile radius, approximately five kilometers.

Until this moment it has been identified possible subcenter candidates through local rises in the employment density function. However, this first step does not identify if those sites have a statistically significant effect over the outline of the employment density function. The second step uses a semiparametric regression to determine the significance of the subcenter candidates obtained in the first step, as it follows:

$$y_i = g(DCDB_i) + \sum_{j=1}^S (\delta_{1j} D_{ij}^{-1} + \delta_{2j} D_{ij}) + u_i \quad (4)$$

⁴⁴ The nearest cells centroids that contain employees are 1km distant from the CBD and the furthest cell centroid is 18.79km apart.

⁴⁵ The significance level is: $(y_i - \hat{y}_i)/(\hat{\sigma}_i) > 1.96$. Where \hat{y}_i is the estimated ln-density of y at site i and $\hat{\sigma}_i$ is the estimated standard error for the prediction in site i .

The third term in equation (3) estimates the distance between a subcenter candidate site i and a site j in level (D_{ij}) and inverse (D_{ij}^{-1}) form. The distance in level form displays those subcenters that have an effect over the region analyzed, while the inverse form displays subcenters that have a local impact in the employment density function. Hence, if δ_{1j} is significant, a subcenter is called a local subcenter, and if δ_{2j} is significant, a subcenter can be considered a global subcenter. The last term, u_i , is the error. The $DCDB_i$ continues to represent the distance between site i and the CBD.

In the second step McMillen (2001) uses a highly flexible function to estimate $DCDB_i$. As the author indicates, it can be used the LWR, cubic splines or a kernel procedure. In his work it was chosen a Fourier function. In the following estimates it was considered an LWR, the same as in the initial smooth. As Krehl (2016) points out, in the first step the focus was to estimate a smooth employment density, though, at this moment the focus is to approximate the employment density function the best way possible.

A problem that might appear is multicollinearity when multiple distance variables are incorporated in the regression caused by a large amount of candidate subcenter sites. To solve this issue McMillen (2001) uses a stepwise procedure in order to determine the subcenter candidates. The estimated coefficients of both distance variables (level or inverse) are positive when the site is close to a subcenter. The subcenter distance variable that scores the lowest t -value is excluded, even if the variable is statistically significant. The smaller regression is then estimated. This procedure is repeated until all subcenter distance variables are statistically significant at the 20% confidence level. Then, the subcenter candidates are those sites that have positive coefficients on either one or both D_j and D_j^{-1} after the stepwise procedure is finished.

Therefore, the procedure proposed by McMillen (2001) provides statistical criteria to analyze the presence of employment subcenters within a region. Nonetheless, this methodology overcomes *ad hoc* definitions to determine the presence of SBD is a site that has a significant impact in the estimated employment density.

Similarly, to the work of Krehl (2016), in this research it will be considered different values for the parameters in the estimations in order to determine the robustness of the results. There will be estimates for the initial window size, varying from 0.5 to 0.25 and 0.1. A lower window size will display a less smooth surface, possibly identifying less subcenter candidates since the estimated surface will be less smooth and will adapt better to the data. Also, the multicollinearity distance measures between observations will be altered from 5 to 3 and 1.6 kilometers. As the author mentions, this radius is arbitrary. In McMillen's (2001) work he

analyzes metropolitan areas with large area such as Chicago (12,450.07km²), Dallas (15,415.61 km²), Houston (16,871.183 km²), Los Angeles (13,750.25 km²), New Orleans (7,270.097 km²) and San Francisco (11,046.3 km²). In our study we consider the city proper of Curitiba (435.036km²) and not its metropolitan region. Therefore, this calls for testing lower choices for the bandwidth to avoid multicollinearity, once the radius considered by McMillen (2001) might not be the best suited for the size of Curitiba.

Also, since the methodology proposed by McMillen (2001) considers as dependent variable the natural logarithm of employment, other estimations will be considered. It will be taken into consideration the estimates for the distinct economic sectors in order to determine whether their distribution of employment across the urban space is monocentric or polycentric. The economic sectors that will have separate estimations, the number of employees and the proportion of employees in each of them are listed in Table 7.

Further, along the lines of the estimations for specific economic sectors, it will also be verified the distribution of employment in Curitiba according to the level of education of the formal employees. Several categories were aggregated into one, as it can be seen in Table 8. In that sense, the elementary level of education aggregates several categories that if considered separately would have a low number of individuals, such as the illiterates. It was also considered the highest level of education attained, hence, employees that started their undergraduate studies but did not complete them were listed in the High School category. The only category that has individuals with higher levels of education is the bachelor's degree that includes individuals with master's and PhD's degrees. As listed in Table 8, both have a small number of individuals in their respective categories.

Lastly, another aspect to be considered is the distribution of male and female workers in the urban space. At this moment it will be considered a separate estimation for both genders. The distribution between male and female workers within economic sectors and level of education⁴⁶ are shown in Table 9.

⁴⁶ The categories in the economic sectors and level of education follow the same construction as in Table 7 and Table 8, respectively.

Table 7 - Economic sectors aggregated according to the UN-ISIC

Economic Sectors							
	Section	Divisions	Description	Total	Proportion (%)	Total	Proportion (%)
Primary *	A	01 - 03	Agriculture, forestry and fishing	1,268	0.22	1,268	0.22
Industry	B	05 - 09	Mining and quarrying	213	0.04	129,617	22.16
	C	10 - 33	Manufacturing	75,843	12.97		
	D	35	Electricity, gas, steam and air conditioning supply	9,066	1.55		
	E	36 - 39	Water supply, sewage, waste management and remediation	3,602	0.62		
	F	41-43	Construction	40,893	6.99		
	Commerce	G	45-47	Wholesale and retail trade; repair of motor vehicles and motorcycles	142,165		
Services	H	49 - 53	Transportation and storage	33,219	5.68	311,831	53.32
	I	55 - 56	Accommodation and food services activities	30,882	5.28		
	J	58 - 63	Information and Communication	26,578	4.54		
	K	64 - 66	Financial and insurance activities	22,868	3.91		
	L	68	Real estate activities	2,681	0.46		
	M	69 - 75	Professional, scientific and technical activities	19,825	3.39		
	N	77 - 82	Administrative and support service activities	83,954	14.35		
	O	84	Public administration and defense; compulsory social security	4,998	0.85		
	P	85	Education	25,371	4.34		
	Q	86 - 88	Human health and social work activities	30,285	5.18		
	R	90 - 93	Arts, entertainment and recreation	4,991	0.85		
Services	S	94 - 96	Other service activities	26,058	4.46		
	T	97 - 98	Activities of households as employers; undifferentiated goods- and service-producing activities of households for own use	109	0.02		
	U	99	Activities of extraterritorial organizations and bodies	12	0.00		
Total				584,881	100	584,881	100

* The primary sector was not considered in our estimations.

Source: UN-ISIC (2008). Elaborated by the authors.

Table 8 - Level of education aggregated by categories

	Categories considered in the aggregation			Total	Proportion (%)
	Level of Education	Total	Proportion (%)		
Low skill	Illiterate	1.157	0,20	192.731	32,95
	From 1st to 5th grade (incomplete)	10.540	1,80		
	From 1st to 5th grade (complete)	17.788	3,04		
	From 6th to 9th grade (incomplete)	35.344	6,04		
	From 6th to 9th grade (complete)	74.999	12,82		
	High School (incomplete)	52.903	9,05		
Average skill	High School (complete)	271.222	46,37	301.499	51,55
	Bachelor's Degree (incomplete)	30.277	5,18		
High skill	Bachelor's Degree (Complete)	88.063	15,06	90.651	15,50
	Masters (complete) *	1.595	0,27		
	PhD (complete) *	993	0,17		
Total		584.881	100	584.881	100

* Due to the low number of individuals with master's and PhD degrees, both categories were considered in the bachelor's degree

Source: MTE-RAIS (2010). Elaborated by the authors.

Table 9 - Distribution of male and female workers according to economic sector and level of education

		Male		Female	
		Total	Proportion	Total	Proportion
Economic Sectors	Industry	99.638	30,46	29.979	11,69
	Commerce	75.354	23,03	66.811	26,05
	Service	152.159	46,51	159.672	62,26
	Total	327,151*	100	256,462*	100
Skill Level	Low	120.008	36,57	72.723	28,33
	Average	163.827	49,92	137.672	53,63
	High	44.351	13,51	46.300	18,04
	Total	328,186*	100	256,695*	100

* The individuals who work in the primary sector were not considered, hence the difference the total number of employees between the categories.

Source: MTE-RAIS (2010). Elaborated by the authors

McMillen (2001) also searches to determine the extent to which a variable related to the proximity of a subcenter improves the goodness of fit of the logarithm of the employment density function related to the distance of the CBD⁴⁷. Therefore, he uses a gravity variable to represent the possible outcomes linked to the proximity of a subcenter.

The gravity variable for the i -th observation is:

$$Gravity_i = \sum_{j=1}^S \frac{\hat{f}(x_j)}{D_{ij}^\alpha} \quad (5)$$

⁴⁷ As mentioned by McMillen (2001), this variable was inspired in the work of Shukla and Waddell (1991).

Where the term S is the number of subcenters in the studied region. The D_{ij} variable measures the distance between a subcenter j and the i -th observation. The parameter α represents a decay rate. This parameter is estimated starting at 0.25 adding 0.25 until it reaches the value of 3.0. The chosen value of the parameter is the one that contributes to the highest explanation power.

Finally, the $\hat{f}(x_j)$ represents the density of the subcenter observations, which were estimated in the first step. In this context, the definition of density is referred to as the number of observations that are nearby. When weighting the estimated employment density by a distance decay parameter it is expected that less weight will be placed on remote observations (such observations tend to be surrounded by grids with little or no employment).

The estimated regression with the inclusion of the gravity variable is:

$$y_i = \beta_0 + \beta_1 DCBD_i + \beta_2 Gravity_i + u_i \quad (6)$$

The inclusion of the gravity variable to assess whether the CBD is the main location that contributes to the spatial distribution of employment densities in the studied area. Hence, the inclusion of this variable contributes to acknowledge whether the CBD is the main driving force in attracting employment in the urban context.

Other two models will be considered to search for possible influence in the location of the subcenters, similar to the gravity variable proposed by Shukla and Waddell (1991). One variable will be included in this model in order to capture possible effects of the BRT Network. It will be a gravity variable which the distance measured will be from the i -th grid cell to the nearest BRT bus terminal, $Gravity(DBRT_j)$. Lastly, a model considering both gravity variables will be estimated.

$$y_i = \beta_0 + \beta_1 DCBD_i + \beta_2 Gravity(DBRT_j) + u_i \quad (7)$$

$$y_i = \beta_0 + \beta_1 DCBD_i + \beta_2 Gravity_i + \beta_3 Gravity(DBRT_j) + u_i \quad (8)$$

Lastly, given the relevance of the density cut-off methodology proposed by Giuliano and Small (1991), their procedure will be included in the present work. The choice to include such methodology is to compare the results between the former procedure and the one proposed by McMillen (2001).

The cutoff values considered by Giuliano and Small (1991) are a minimum density of 10 employees per acre and all zones when combined must have at least of 10,000 workers. Another issue is the boundary of a quarter of a mile considered in their model, which is not a problem since in the present work each grid cell has a border of one kilometer between each contiguous cell. This feature has been commonly not mentioned to be taken into account in several works that apply the Giuliano and Small (1991) methodology. The necessary adaptations should be considered when working with the metric system. Therefore, instead of the density of 10 employees per acre it will be considered a density of 2,480 workers per square kilometer, commonly referred to as the 10-10 threshold. Nevertheless, the number of workers combined by all zones will not be modified. Other values that can be considered are the 7-7 parameter, that is, an employment density of seven employees per acre (1,736 per square kilometer) and a total of 7.000 employees combined. Both will be considered for Curitiba.

It should be mentioned that the procedure of McMillen (2001) does not capture the extent of the subcenters, whether high employment density nodes. When comparing his procedure with the ones proposed by Giuliano and Small (1998) and Redfearn (2007), both estimate the size of the SBDs, accounting for a higher proportion of employment. Hence, it is expected that the share of employment from the McMillen (2001) procedure within the subcenters is significantly lower.

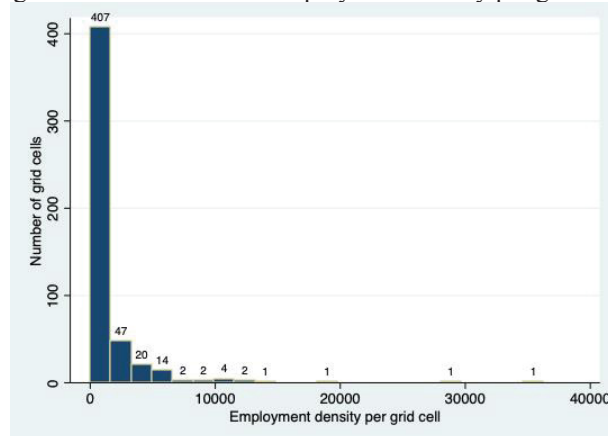
To summarize, to identify employment subcenters it will be considered the methodology proposed by McMillen (2001), with modifications in the parameters to test for the robustness of the results. Other estimations by Ordinary Least Squares (OLS) and the cut-off method by Giuliano and Small (1991) will be considered for comparison between the results.

5 RESULTS AND DISCUSSION

This section presents the results for the OLS, the two-step semi-parametric procedure, the robustness checks for the model. Also, it is presented the results for the gravity model and with other gravity variable that measure the distance from observations to BRT.

The works of Giuliano and Small (1991) consider the CBD as the tract with the highest employment density while McMillen (2001) prefers the historic CBD. The former definition of CBD will be considered in the present work. After georeferencing and comprising the number of employees per grid cell, the distribution of workers per cell is shown in Figure 2. The city has 502 cells, and 407 of those cells have little or no employment.

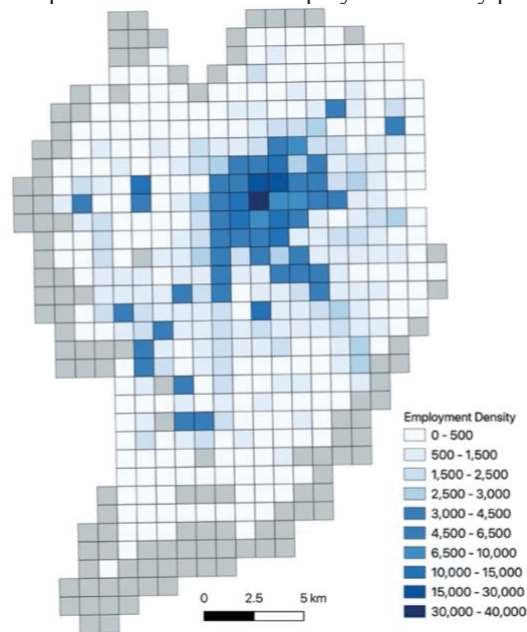
Figure 2 – Distribution of employment density per grid cells



Source: MTE-RAIS (2010). Elaborated by the authors.

The CBD has an employment density of 36,274 and, as it was expected, is located in the downtown area in close proximity to the five main axes of the BRT network, as it is shown in Figure 1. Besides the CBD, other 27 cells concentrate over 5,000 employees. The presence of such tracts suggests the possibility of the presence of employment subcenters in the city. The spatial distribution of employment density per grid cell can be seen in Figure 3.

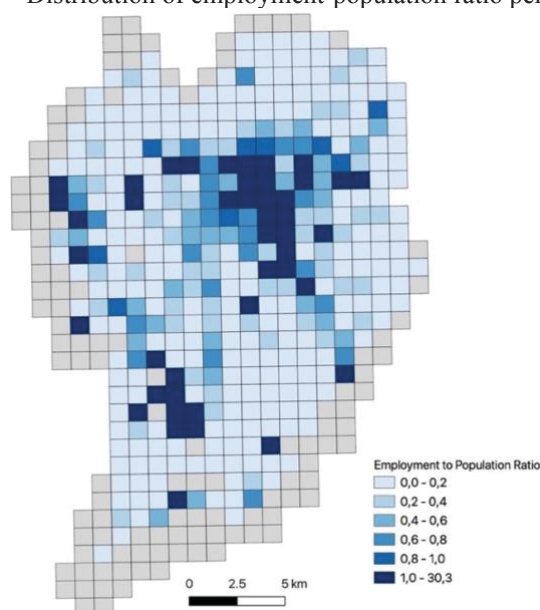
Figure 3 – Spatial distribution of employment density per grid cells



Source: MTE-RAIS (2010). Elaborated by the authors.

Another aspect to be considered in the distribution of employment in the urban space is the employment-population ratio. Muñiz *et al* (2008) considers as one of the determinants of employment subcenters those areas that have a ratio higher than one. Such sites are considered to be employment attractors⁴⁸. The employment-population ratio per grid cell in Curitiba can be seen in Figure 4. The downtown area and the CIC neighborhoods are the main regions of the city with cells with a ratio greater than one.

Figure 4 – Distribution of employment-population ratio per grid cell



Source: MTE-RAIS (2010). Elaborated by the authors.

⁴⁸ In the present work, such analysis is only descriptive, no inference will be made

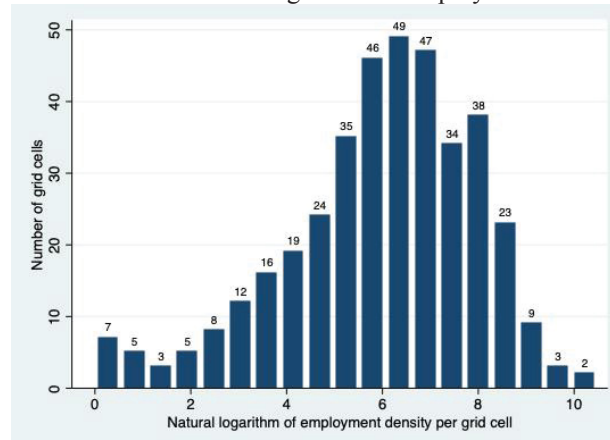
5.1 SUBCENTER IDENTIFICATION AND SENSITIVITY ANALYSIS

In order to estimate the first step of the procedure the distance between the i -th observation to the CBD was measured. Further, it is necessary to transform the employment density to the natural logarithm form.

The distribution per grid cell of the linearized employment density is shown in Figure 5, below. After this process, the distribution does not resemble the one from Figure 4, above. Hence, as Giuliano and Small (1991) consider the employment density, the logarithm of employment density appears to be more suitable for the identification of employment subcenters once it removes possible sensitivity issues from the size of the unit of analysis.

The first model considered in our estimates is the Ordinary Least Squares (OLS). The results for the estimates for the OLS model where the logarithm of employment density is regressed over the distance to the CBD can be seen in Table 10, below.

Figure 5 – Distribution of the natural logarithm of employment density per grid cells



Source: MTE-RAIS (2010). Elaborated by the authors.

Table 10 - OLS estimates

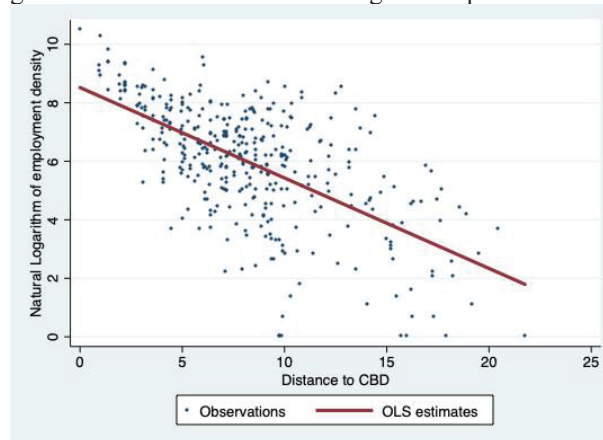
	Coefficient	Standard Error	t-statistic	p-value
Constant	8.521168	0.1835161	46.43	0.000
Distance to CBD	-0.3092238	0.0199266	-15.52	0.000
R ²	0.3860			
Adjusted R ²	0.3844			

Source: MTE-RAIS (2010). Elaborated by the authors.

As it would be expected, the model identifies a negative relation between employment density and distance to the CBD. Further, even with a high explaining power, the linear model fails to identify employment subcenters in the urban space. The graph for the OLS model can be seen in Figure 6.

In the first step of McMillen (2001)'s procedure the natural logarithm of employment density is regressed with the distance to the CBD as the independent variable through an LWR. In his procedure, McMillen (2001) considers a 0.5 window size with a five-kilometer radius to avoid multicollinearity. Since we considered the CBD as the tract with the highest employment density rather than the historic CBD, the same multicollinearity radius was also applied to it. Next, it will be tested the sensitivity of the results through two other radii, 3km and 1.5km, for the 0.5 window size.

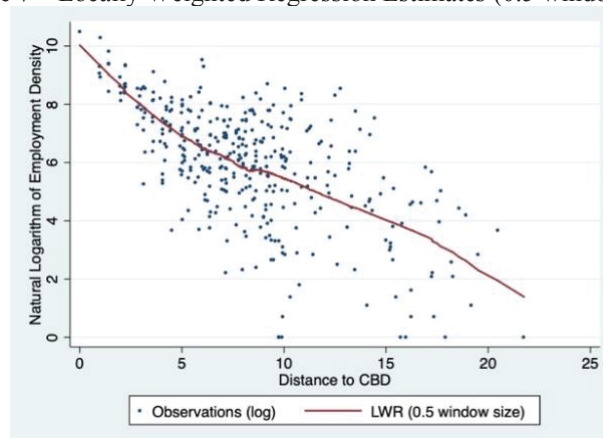
Figure 6 – OLS estimates for the negative exponential model



Source: MTE-RAIS (2010). Elaborated by the authors.

The first step of the procedure yielded 173 subcenter candidates significant at the five percent level, which were narrowed to ten after applying the 5km radius. The local smooth of the first step can be seen on Figure 7. After the stepwise procedure, five candidates remained with positive and significant coefficients, these are the subcenters for Curitiba. From those, three are considered as global and two as local subcenters.

Figure 7 – Locally Weighted Regression Estimates (0.5 window size)



Source: MTE-RAIS (2010). Elaborated by the authors.

When altering the multicollinearity radius, the number of subcenter candidates from the first step remain the same. In the case of the three-kilometer radius, 27 possible subcenter candidates were considered in the second stage. The stepwise procedure resulted in the total of eleven subcenters, six were global and five were local. Comparing the results of the two radii, only two subcenters that were significant with the 5km continued with the 3km radius. One subcenter was local in the 5km radius and turned to local and the other remained global.

Finally, in the 1.5km radius the first step resulted in 55 candidates. The second step determined 20 subcenters, which 12 were global and the remainder eight were local. When comparing the results between the 1.5km and 5km radii, one subcenter was not identified and other four were. One subcenter switched from local to global, the other three remained in their categories, two as global and one as local. Between the 1.5km and 3km, only four subcenters were significant in both radii. All four remained in the same category, two global and two local.

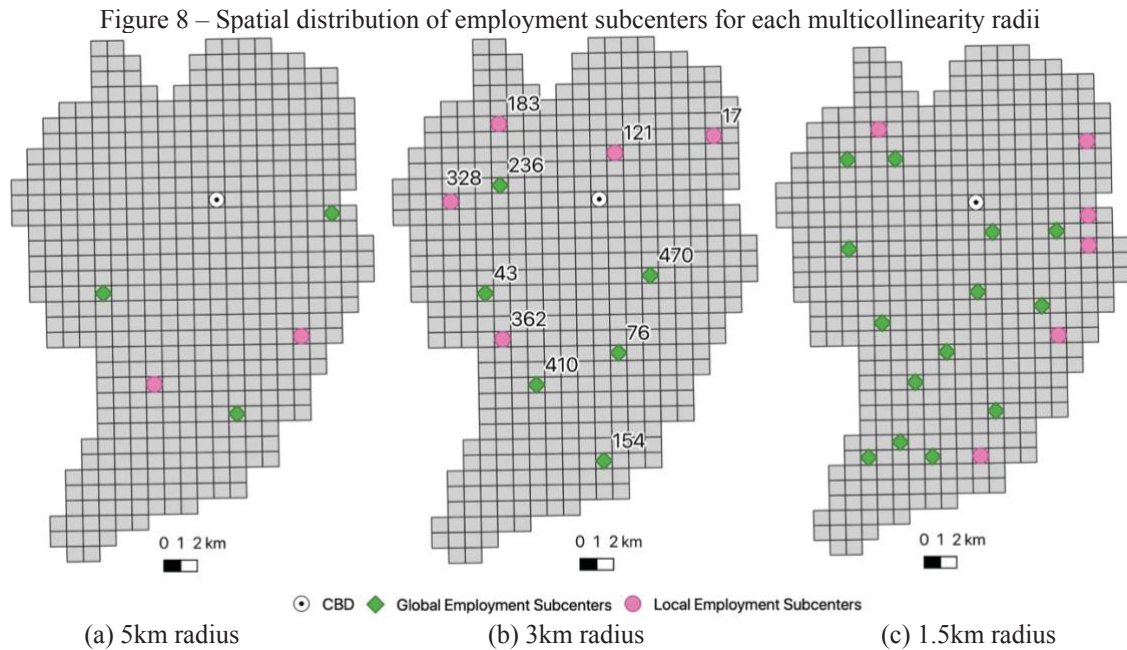
The sensitivity analysis for the different radii point towards significant differences in the findings for subcenters, the results can be seen on Table 11. Lowering to a 3km radius yields 11 subcenters and with the 1.5 radius it results in 20 subcenters. When analyzing the explaining power of each radii, the most significant increase is between the 5km and 3km radius with a 12.8% increase rather than between the 3km and 1.5km which raises by 9.1%. Similar results occur for the adjusted R² with a higher increase between the first two radii. Also, the total employment in the identified subcenters increase as the radius decreases, as it would be expected.

Table 11 – Sensitivity analysis for 0.5 window size

	5km	3km	1.5km
Subcenters (total)	5	11	20
Global	3	6	14
Local	2	5	6
Employment in subcenters (total)	17,615	43,310	54,940
Global (total)	9,758	30,609	44,090
Highest	5,913	13,644	10,755
Lowest	1,046	287	83
Local (total)	7,857	12,701	10,850
Highest	5,032	3,737	3,737
Lowest	2,825	443	287
R ²	0.5849	0.7129	0.8039
Adjusted R ²	0.5699	0.6866	0.7605

Source: MTE-RAIS (2010). Elaborated by the authors.

Therefore, the radius considered in the subsequent estimations for two other window sizes (0.25 and 0.1) and the spatial distribution of employment according to gender, level of education and specific sectors, will be the three-kilometer radius. The spatial distribution of the employment subcenters for the multicollinearity radii are shown in Figure 8.



Source: MTE-RAIS (2010). Elaborated by the authors.

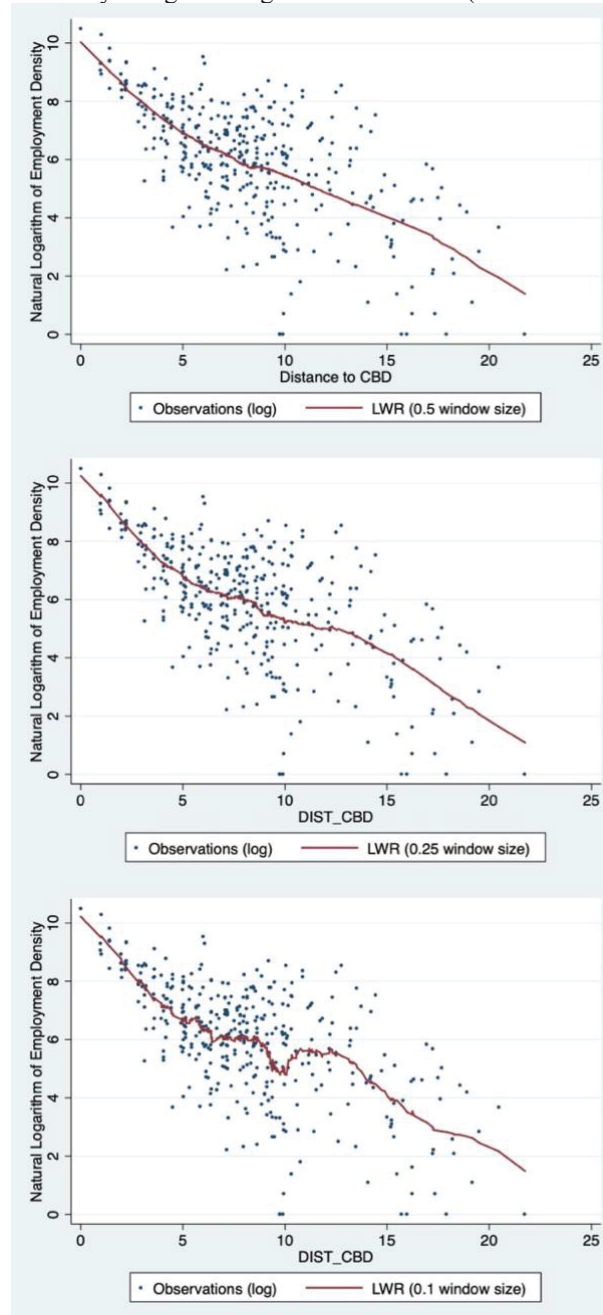
Continuing the robustness checks, for the other window sizes of 0.25 and 0.1, the first step of McMillen (2001)'s procedure is shown in Figure 9. As it can be seen, when lowering the window size, the employment surface is less smooth, adapting better to the data.

For the 0.25 window size, the first step pointed 168 possible subcenters⁴⁹. When applying the three-kilometer radius the number of candidates narrowed to 26. After the second step, the procedure estimated that Curitiba has 9 subcenters. From the total subcenters, 5 are global and 4 are local. The spatial distribution of the estimated subcenters for the 0.5 and for the two other window sizes are shown in Figure 10.

When comparing the results for the identified subcenters from the 0.25 window size, it identifies seven from the eleven subcenters from the 0.5 window size model. From the four subcenters that were not statistically significant with this window size, two were global (43 and 236) and two were local (121 and 183). Except for subcenter 183, the other three were among the centers with the highest total employment in Curitiba, as seen in Table 12. Lastly, subcenter 410 was identified as global in the 0.5 model but turned local for the 0.25 window size.

⁴⁹ Testing for a higher window size of 0.75 yielded 175 subcenter candidates in the first step, two more than the 0.5 window size.

Figure 9 – Locally Weighted Regression Estimates (various window sizes)



Source: MTE-RAIS (2010). Elaborated by the authors.

Finally, the window size of 0.1 initially estimated 149 significant candidate subcenters, which were reduced to 23 after the 3km radius. After the second step, the results show that Curitiba has 11 subcenters. From those subcenters, 11 are 6 global and 5 are local.

From the identified subcenters in the model with the 0.5 window size, four were not significant in this window size, two were global (236 and 470) and two were local (121 and 183). Again, those four subcenters are among the ones with the highest total employment in

Curitiba in the estimates with these parameters, see Table 12. Also, the 0.1 model identified four different subcenters that were not significant in the former model.

Therefore, the spatial distribution from the identified subcenters for different window sizes does now alter significantly, with two new different subcenters being identified for the 0.1 model and four for the 0.25. Between the different parameters, a couple of SBDs transition from global to local. Comparing the results between the window sizes of 0.1 and 0.5, the former has a higher R^2 and Adjusted R^2 , even though in magnitude the difference is small. Nevertheless, within the three different window sizes estimated, the model with the 0.5 window identifies subcenters with a higher amount of employment.

Table 12 - Subcenters identified with three different window sizes and a multicollinearity radius of three-kilometers

	0.1	0.25	0.5
Subcenters (total)	11	9	11
Global	6	5	6
Local	5	4	5
Employment in subcenters (total)	37,751	24,386	43,310
R^2	0.7107	0.7081	0.7129
Adjusted R^2	0.6883	0.6862	0.6866

Source: MTE-RAIS (2010). Elaborated by the authors.

The other researches, such as Krehl (2016) and Lv *et al* (2017), that also applied the methodology proposed by McMillen (2001) in its entirety, only the former consider testing the sensitivity of the results altering the window size and multicollinearity radius.

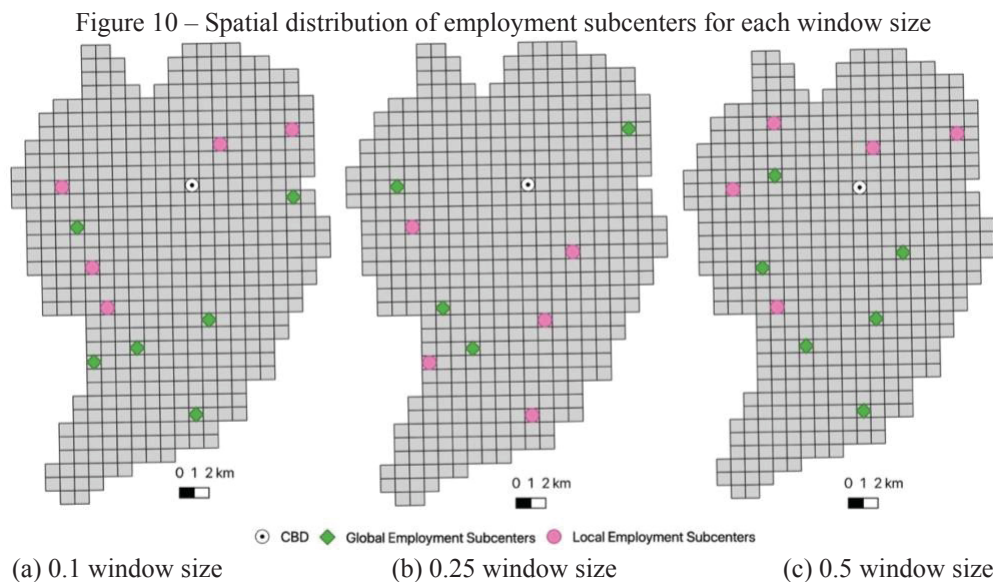
As Krehl (2016) mentions, the spatial structure of European cities is significantly different than American cities, where the former are older and with a higher supply and demand for public transportation, while the latter having a more dispersed employment pattern, a bigger city size, a car-oriented transit system and land-use policies that incentive the cluster of specific activities through zoning. As the author mentions, most German cities have mixed land-use patterns while combining with low-rise buildings. Such characterization might be extended towards other major cities in Europe, such as London, Paris and Rome, that have low-rise buildings through the city, except in specific locations. According to Krehl (2016) the German cities analyzed have subcenters, but they are economically tied to the CBD, hence, characterizing the cities as monocentric. While the work of Garcia-Lopez (2010) for the Metropolitan Region of Barcelona show that employment subcenters remain important in the urban space and have reinforced their importance over the years. Nevertheless, they also point that the region is growing towards a scattered employment pattern, transitioning from

polycentricity. In the American case, Fernández-Maldonado *et al* (2014) point that the subcenters in the North America are more independent from the CBD.

In the Latin American case, Fernández-Maldonado *et al* (2014) point that Mexico City (Mexico), Lima (Peru) and Fortaleza (Brazil) have most subcenters closer to the CBD (which might be due to the use of the Giuliano and small methodology). Further, they also show that most of the employment in those regions are within a 5km radius of the CBD and the same applies to Curitiba⁵⁰.

Other urban patterns of employment distribution could be verified for the Metropolitan Area of Beijing (China) in Lv *et al* (2017), which the authors show that the city is divided in road rings and that most of the employment is located until the fifth road ring. Despite the polycentric urban structure of MAB, when analyzing the entire metropolitan region, according to their estimates, the monocentric model accounts for 70% of the employment distribution, revealing a strong monocentric pattern. If the research area is to be restricted until the fifth road ring, the monocentric model reduces its explaining power to less than 50%.

Hence, when applying McMillen (2001)'s methodology, it should be considered altering the parameters to test the sensitivity of the results given that the urban shape of cities and their form of occupation (either residential or employment) varies from region to region.



⁵⁰ In the present work, for the available data, Curitiba concentrates 56.60% of the employment in a five-kilometer radius from the CBD. It is worth mentioning, the grid cell with the highest employment density is considered to be the CBD. A five-kilometer radius yields an area of 78.54 km² (Curitiba has a total area of 435.036 km²), which is 18% of the area of the city.

Henceforth, the results for the estimation with the 0.5 window size and the three-kilometer radius will be considered as the main results of the present research. This will be the benchmark model, since such parameters have demonstrated to be the best suited for the identification of employment subcenters in Curitiba.

The individual-level data enables to analyze other specificities of the subcenters, as shown in Table 13. In the identified subcenters, the proposed methodology can identify a significant range of SBDs and their total employment with only three of them having less than 3,000 formal employees.

Nevertheless, the CBD remains as the main concentration of employment, the subcenter with the highest employment concentration is the SBD 236, in the Industrial City neighborhood, which has 37,61% of the employment of the CBD. Therefore, despite the polycentric urban structure of Curitiba, the main employment concentration still is the CBD.

As expected, the CBD has transitioned to the service economy, which concentrates 71,93% of the employment in the grid cell. Further, most of the employment in the subcenters at the CIC neighborhood are in the industrial sector, but other sectors also display a considerable amount of employment in other sectors. For the commercial sector, only subcenter 76 has the majority of its employment concentration in that sector, accounting for over 70% of the workers in the region. While the service sector has the majority of the employees in six subcenters.

Table 13 - Descriptive analysis of employment in economic Sectors in the CBD and SBDs

	Total Employment in Subcenter (a)	Industry		Commerce		Service	
		Total (b)	Proportion (b)/(a)	Total (c)	Proportion (c)/(a)	Total (d)	Proportion (c)/(a)
CBD	36,274	1,496	4.12	8,685	23.94	26,093	71.93
Global							
43	5,913	5,361	90.66	376	6.36	176	2.98
76	1,277	64	5.02	895	70.20	316	24.78
154	287	65	22.65	73	25.44	149	51.92
236	13,644	10,277	75.32	813	5.96	2,554	18.72
410	5,032	4,961	98.59	71	1.41	0	0.00
470	4,458	528	11.84	633	14.20	3,297	73.96
Local							
17	3,737	1,150	30.77	759	20.31	1,828	48.92
121	5,025	773	15.38	796	15.84	3,456	68.78
183	443	101	22.80	139	31.38	203	45.82
328	3,496	2,237	63.99	420	12.01	839	24.00
362	3,442	1,191	34.60	389	11.30	1,862	54.10

Source: MTE-RAIS (2010). Elaborated by the authors.

When analyzing the skills of the workers, the results are shown in Table 13. The CBD has a high concentration of average and high skill labor, which combined accounts for over 70% of the employment. In the subcenters, most of the employees are in the average skill

category, only two have a higher proportion of low skilled workers. Another relationship that can be verified is between the average income and the proportion of high and low skilled workers. In the former, the higher the ratio the higher are the incomes.

From the Table 13 and Table 14, it can also be inferred that the subcenters in Curitiba display economies of agglomeration. Despite several SBDs having the majority of employment in one economic sector, the two other categories also have a significant concentration. Such argument is further corroborated by the heterogeneity in the skill level displayed in the subcenters. Therefore, the identified subcenters have a relatively diversified skill level and economic activity, in which the latter might be a vertically integrated production process related to the economic sector that has the highest concentration of employment. Further studies should be carried to empirically verify and formalize such relationship.

Table 14 - Descriptive analysis of employment skill level in the CBD and SBDs

	Total Employment in Subcenter (a)	Low Skill		Average Skill		High Skill		Average Income*
		Total (e)	Proportion (e)/(a)	Total (f)	Proportion (f)/(a)	Total (g)	Proportion (g)/(a)	
CBD	36,274	9,202	25.37	19,139	52.76	7,933	21.87	1,861.00
Global								
43	5,913	1,749	29.58	3,782	63.96	382	6.46	1,865.71
76	1,275	356	27.92	877	68.78	42	3.29	1,026.94
154	287	121	42.16	158	55.05	8	2.79	1,328.71
236	13,644	2,702	19.80	6,682	48.97	4,260	31.22	3,750.62
410	5,032	1,846	36.69	2,863	56.90	323	6.42	2,112.40
470	4,458	847	19.00	1,150	25.80	2,461	55.20	2,497.35
Local								
17	3,737	1,538	41.16	1,916	51.27	283	7.57	1,711.67
121	5,025	1,538	30.61	2,138	42.55	1,349	26.85	1,947.97
183	443	241	54.40	179	40.41	23	5.19	1,170.37
328	3,496	1,699	48.60	1,617	46.25	180	5.15	1,515.16
362	3,442	1,406	40.85	1,820	52.88	216	6.28	1,793.85

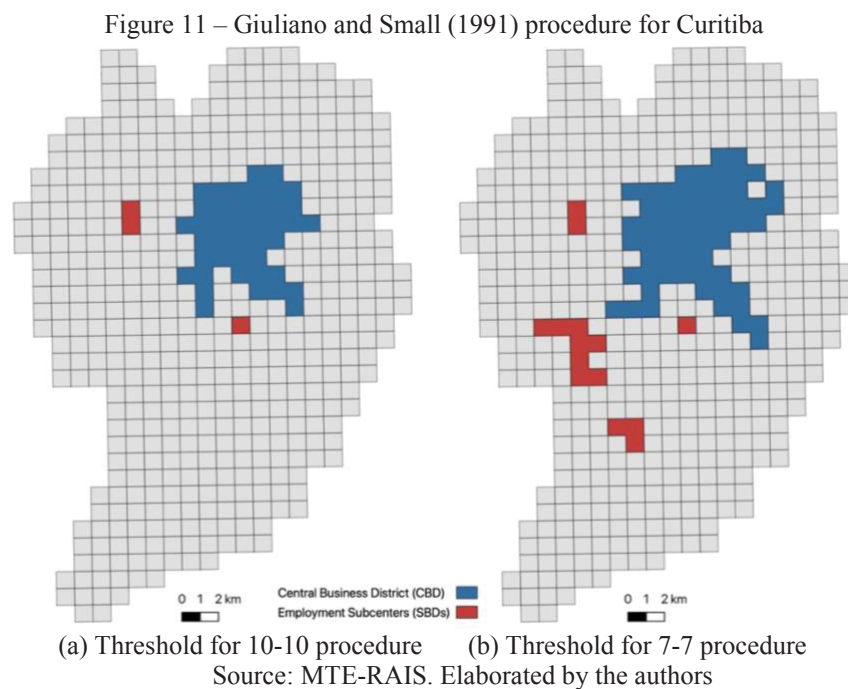
* Considers all employment in the subcenter

Source: MTE-RAIS (2010). Elaborated by the authors.

5.2 GIULIANO AND SMALL (1991) PROCEDURE

As it was previously mentioned, the Giuliano and Small (1991) procedure is one of the empirical strategies most applied in order to identify employment subcenters. As pointed by McMillen (2001) and Redfearn (2007), this procedure has several issues, such as the not identifying subcenters distant from the CBD and also the discretionary choice for the density cut-offs. In this section, the Giuliano and Small (1991) procedure will be applied for Curitiba and its results will be compared to the ones estimated with McMillen (2001)'s methodology.

In the present work two thresholds were considered for the Giuliano and Small (1991) procedure, one with an employment density of ten employees per acre with the tracts summing at least 10.000 employees⁵¹. Another with lower threshold values of seven employees per acre that together sum 7.000 workers. Lower values for the cutoffs have been considered in Cervero and Wu (1997), Shearmur and Coffey (2002) and Fernández-Maldonado *et al* (2016). The subcenters for both thresholds are shown in Figure 11.



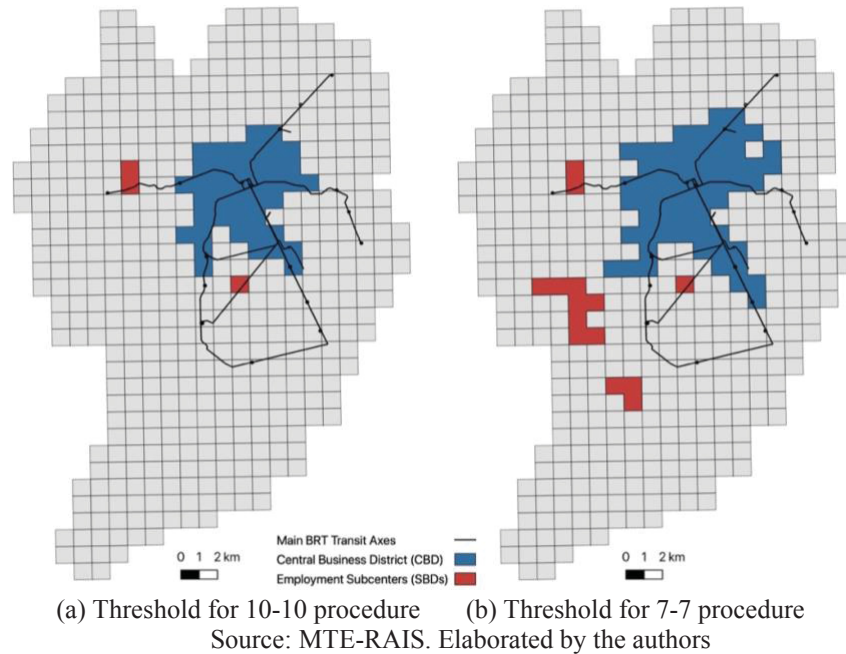
The results for the 10-10 proportion show a large CBD in blue and two smaller subcenters in red in panel (a) at Figure 11. Even with the issues regarding the Giuliano and Small (1991) procedure, Curitiba still exhibits a polycentric urban pattern. This urban shape is reinforced with the lower cutoff of 7-7. As shown in Figure 11 (b), with the lower density threshold the CBD has expanded its area, while the number of SBDs has increased to four.

From the results of the Giuliano and Small (1991) procedure it might also be inferred that the policies developed by the 1966 Master Plan to decentralize and extend the economic businesses from the CBD towards the transit axes, as shown in Figure 14. Also, in both thresholds the identified subcenters are located in the, except for one, located in the southern part of the city. Further, when considering other aspects such as employment density and employment-population ratio, there is a correlation to the main BRT transit axes as shown in

⁵¹ Tracts that only had a common vertex were not considered as contiguous.

Figure 3 and Figure 4, respectively⁵². As a result from the policy, the CBD occupies an extensive part of the city and concentrates most of the employment.

Figure 12 – Giuliano and Small (1991) procedure for Curitiba and the main transit axes of the BRT Network



Further, when comparing the work of Belmiro *et al* (2018) which applies the Giuliano and Small (1991) procedure to the city of Recife and the for Curitiba, the use of lower threshold values might yield better results. Since such values were designed to Los Angeles and, as mentioned by Fernandez-Maldonado *et al* (201), the Latin American cities have an urban shape closer to North America rather than Europe, it should be examined other cut-off values. Furthermore, lower bandwidths should be explored for the region when working only with formal employment data, as the countries in the region are marked by high rates of informality in labor market.

One of the results from Fernández-Maldonado *et al* (2014), that also is corroborated in by ours, is the presence of subcenters focused in industrial activity. With three subcenters located in the CIC, even if the total number of employees by the classification of the economic activity from ISIC results in other activities than industry it is more likely that such firms are located there as a result of economies of agglomeration generated by an industrial venue. Another common outcome from both researches, is the concentration of employment within a

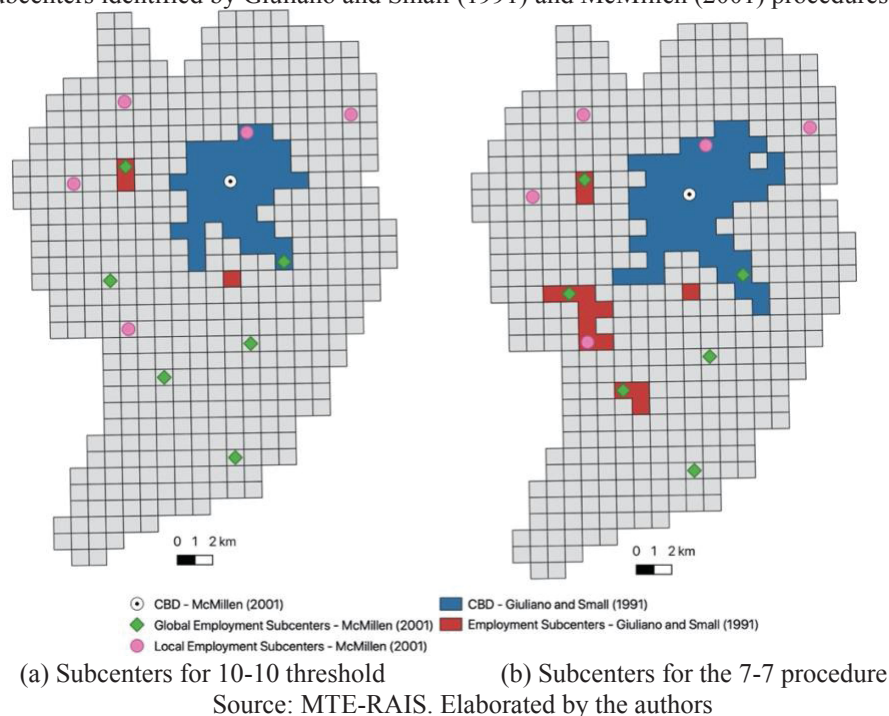
⁵² It is worth mentioning, such results are not having any statistical corroboration and should be interpreted carefully, as Anselin (1988) states that, in order to analyze spatial relationships, there is a need for variables to be given a mathematical form and hypothesis tests.

five-kilometer radius from the CBD, since Curitiba as it appears it might be a prevalent pattern in Latin American cities.

Following the steps of McMillen (2001) and Redfearn (2007), the estimated results are compared to the ones obtained from the Giuliano and Small (1991) procedure. As seen from Figure 13, for either threshold value applied, the methodology proposed by McMillen (2001) identifies all the subcenters from the Giuliano and Small (1991) procedure, except for one. Further, our results for the considered thresholds reinforces the arguments from McMillen (2001) and Redfearn (2007), that the chosen cut-off values are arbitrary and fail to statistically identify all significant employment concentrations in the urban spaces⁵³.

Therefore, in this subsection the main objective was to identify employment subcenters through the methodology proposed by McMillen (2001) and further test alter parameters for robustness checks. The most suited parameters that were considered in the estimations were the three-kilometer multicollinearity radius and a window size of 0.5 for the LWR. With these parameters eleven employment subcenters were identified in Curitiba, from those six are global and five are local.

Figure 13 – Subcenters identified by Giuliano and Small (1991) and McMillen (2001) procedures for Curitiba



⁵³ Both authors also refrain to another important argument: that the Giuliano and Small (1991) procedure is not suited for identifying subcenters at distant areas from the CBD. Since it was only considered the city proper of Curitiba and not the entire RIT region, the results from the present work are not able to insert in such debate. Notwithstanding, it is expected that when analyzing the RIT region to confirm the argument.

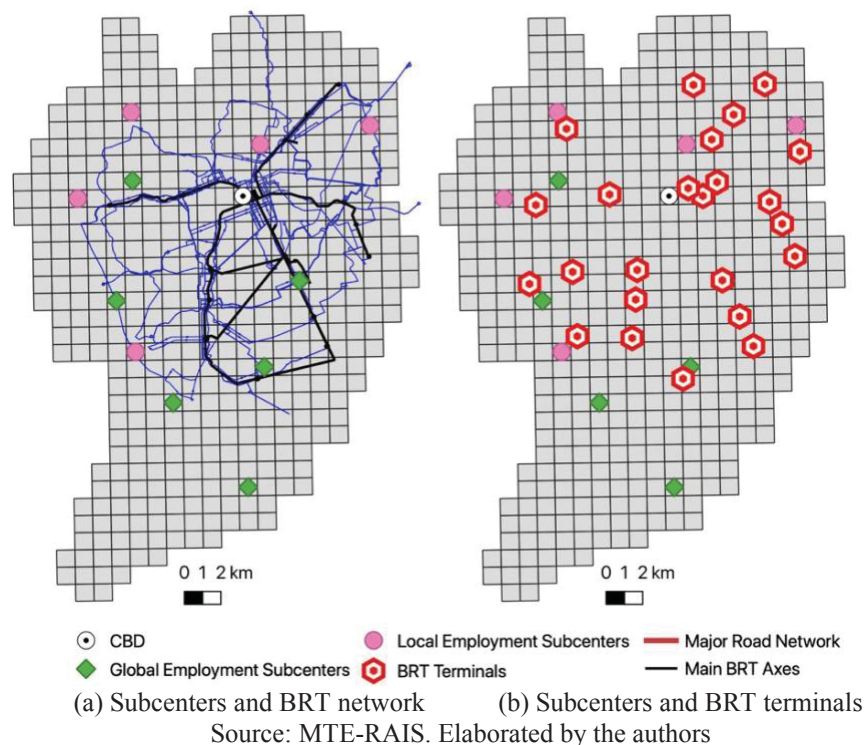
5.3 SPATIAL INTERACTION VARIABLES

In this subsection it will be investigated whether the CBD is the main attractor of employment in Curitiba through a spatial interaction variable as seen on McMillen (2001). Also, since the variable of the work of McMillen (2001) was inspired in the work of Shukla and Waddell (1991), this enables estimates to consider other features of the urban space that influence the distribution of urban employment.

The variable in Shukla and Waddell (1991) searches to determine other spatial factors that contribute to the location of subcenters other than the distance to the CBD. In order to do so, first is necessary to know what are the other spatial features that influence the agglomeration of employment in the urban space. As mentioned by Redfearn (2007), several employment subcenters locate in close proximity to major road networks. In the case of Curitiba the most important feature that should be considered, instead of major highways, is the influence of the BRT network.

In the case of the BRT gravity variable, the distance measured considered for $Gravity(DBRT_i)$ in equation (7) was the distance between the i -th observation to the closest bus terminal. The BRT network, the BRT terminals and the location of the employment subcenter in Curitiba can be seen on Figure 14.

Figure 14 –Employment subcenters identified with McMillen (2001) procedure and the BRT Network



The gravity variable proposed by McMillen (2001) investigates how the employment density behaves in the neighboring tracts of the subcenters. According to McMillen (2001) it is expected that when the gravity variable is included the coefficient for the $DCBD_i$ turns positive, in those cases the CBD is no longer the main determinant in the employment distribution in the city (otherwise the CBD remains as the main force of the employment distribution). For the distance to the BRT terminals a similar effect is expected.

The results for the estimates are in Table 15. The first column (I) displays the results for the basic linear model. The subsequent columns, II and III, analyzes separately the three gravity variables. Finally, the last column (IV) exhibits the results for the regression considering both gravitational variables.

In the second column, the same gravity variable as in McMillen (2001) is estimated. Despite the result for the $DCBD_i$ not being significant, the inclusion of the gravity variable turns its signal positive, which implies that the CBD is not the main determinant in the spatial trends of employment in Curitiba. The alpha parameter in each column relates to the new variable analyzed, therefore, in II the alpha parameter of 0.5 is for the Gravity variable, while in III is for the distance to BRT terminals. The estimation for the BRT terminals in column III yields positive results for the distance to the CBD. This result shows that the BRT network has a positive influence in the employment density. In the last column (IV), both variables account for a significant concentration of employment in the nearby tracts.

Therefore, in the urban space of Curitiba, there are other spatial features, the employment subcenters and the BRT terminals, besides the CBD that have an impact in the concentration of employment in the city.

Table 15 - Estimation for the Gravity variables considered for employment

	I	II	III	IV
Constant	8.5211 ***	0.5073 ns	4.9330 ***	-2.1752 *
Distance to CBD	-0.3092 ***	0.0009 ns	-0.1495 ***	0.1227 **
Gravity		0.2346 ***		0.2206 ***
Gravity BRT Terminals			0.4198 ***	0.3704 ***
Alpha	-	0.5	0.25	-
R ²	0.3860	0.4788	0.4233	0.5071
Adjusted R ²	0.3844	0.4759	0.4203	0.5031

* significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level; ns - not significant
Source: MTE-RAIS (2010). Elaborated by the authors.

McMillen (2001) also applies the same gravity variable for the population density (which is also in natural logarithm form). The column I in Table 16 displays the results for the basic model. As expected, as the distance from the CBD increases, the lower the population

density. In the second column, the estimates for the gravity yields the same result from the employment: the distance to the CBD, despite no statistically significant, turns positive. In other words, this result implies that population concentrates near the employment subcenters.

Table 16 - Estimation for the Gravity variables considered for population

	I	II	III	IV
Constant	9.4676 ***	-0.7735 ns	5.3312 ***	-0.9995 ns
Distance to CBD	-0.2267 ***	0.0453 ns	-0.0797 ***	0.0831 *
Gravity		0.1651 ***		0.1108 ***
Gravity BRT Terminals			0.4347 ***	0.3784 ***
alpha		0.25	0.25	-
R ₂	0.3437	0.3856	0.4117	0.4303
Adjusted R ₂	0.3424	0.3830	0.4092	0.4267

* significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level; ns - not significant

Source: MTE-RAIS (2010). Elaborated by the authors.

For the distance to the BRT Terminals, in column IV, the regression yields positive results for the variable. The estimated signal is expected, once the 1966 Master Plan was designed to promote higher densities around the BRT axes. For this variable the $DCBD_i$ is positive, which according to McMillen (2001) it can be inferred that the CBD is not the main concentration of population density.

In column IV, when the two gravitational variables are estimated together, the sign for the estimated coefficient for the BRT terminals and Gravity remain positive. The increase in the R₂ from the first three models to the one in column IV is in line with the TOD policy that has been in place and shows that the population is distributed across the city favoring urban sprawl and enabling individuals to not reside close to their workplace. Given this result, this spatial feature might indicate higher levels of spatial mismatch. Further research should assess such hypothesis.

In conclusion, with the estimated variables for the employment density in tracts close to employment subcenters point towards a city with strong employment subcenters that have a significant impact in the location of employment besides the CBD. This positive impact is enhanced with the results for the BRT network, which also draw a significant influence in the urban employment across Curitiba.

5.4 SUBCENTER IDENTIFICATION FOR SEGMENTED EMPLOYMENT

In this section the methodology proposed by McMillen (2001) will be applied to identify the distribution and concentration of employment according to gender, skill level (related to the level of education) and for economic sectors (industrial, commercial and service).

The motivation that lies behind this subsection is to identify specific employment concentrations within the variables listed above. Within polycentric process of Curitiba there might be specific employment characteristics that instead oblige to the monocentric pattern

5.4.1 URBAN EMPLOYMENT DISTRIBUTION ACCORDING TO GENDER

The male and female distribution of employment according to economic sectors as seen in Table 9, displays a more evenly distributed proportion of employment for man, while women concentrate in the commercial and service sectors.

Such distribution enables the hypothesis that male workers would tend to have more subcenters scattered through the city when compared to the female. This result is further enhanced by the distribution within the three skill levels, with women concentrating mostly in the average and higher levels of skill while man converge towards the lower and average skill.

The initial smooth for the male (female) workers yielded 169 (161) possible subcenter candidates. The three-kilometer reduced to 28 (24) candidates. After the stepwise, there were 15 (14) subcenters identified. From those, 8 (5) were global and 7 (9) were local. The summary for the identified subcenters for both genders can be seen in Table 17.

	Male	Female
Subcenters (total)	15	14
Global	8	9
Local	7	5
Employment in subcenters (total)	33,312	23,334
Global (total)	11,702	10,932
Highest	2,851	2,570
Lowest	72	147
Local (total)	21,610	12,402
Highest	10,788	5,443
Lowest	287	45
R ₂	0.7174	0.6918
Adjusted R ₂	0.6865	0.6658

Source: MTE-RAIS (2010). Elaborated by the authors.

The spatial distribution of the gender's employment subcenters are shown in Figure 15. When the identified male subcenters are compared to the benchmark model, six SBDs were found in common (76, 154, 236, 17, 121 and 362). From the total of 15 subcenters that were identified, only five subcenters had less than 1,000 workers and seven had more than 2,000. Therefore, most of the subcenters do not appear to be of local relevance.

For the female category, five subcenters were identified in common with the benchmark model (43, 154, 470, 17, 362). Within the subcenters, eight subcenters had less than one thousand employees while only five had more than 2,000. Again, the identified subcenters appear to be relevant in the urban space. Therefore, the female employment distribution in Curitiba is polycentric.

Several SBDs identified when considering the total employment rather than separated by gender, were not identified. Those SBDs were identified in the initial smooth and some remained after the multicollinearity radius. Those that were considered for the second step were only not determined significant after the stepwise procedure⁵⁴. Nevertheless, the model yields high values for the R_2 and Adjusted R_2 , close to the ones identified in the benchmark model.

Figure 15 – Male and female employment subcenters in Curitiba



⁵⁴ For the male category, the only subcenter(s) identified in the benchmark model and that was discarded for the stepwise procedure was subcenter 470. While for the female, the subcenters that were not considered in the second step were 76, 121, 183, and 410.

5.4.2 LEVEL OF EDUCATION AND EMPLOYMENT DISTRIBUTION

At this moment it will be verified the spatial distribution of employment regarding the level of skill. At the CBD it is expected to find a mixed pattern with workers in with average and high skill levels. Further, in the high skill level is expected to be verified a monocentric pattern. Also, the average and lower skilled employees are likely to found across the urban space and concentrating in other regions of town, the former close to the city edge.

The initial smooth for the low skilled workers identified 175 subcenter candidates which were narrowed to 28 after the three-kilometer radius. The second step identified 13 subcenters, seven were global and the remainder six were local, as seen on Table 17. Their spatial distribution can be seen in Figure 16. As it would be expected, the subcenters are mostly located far from the CBD. When comparing the results to the benchmark model, six subcenters (76, 154, 17, 183, 328 and 362) were identified in both. In the standard model, those six are also the ones with the lower wages among all subcenters. Further, only two subcenters are not in the service sector, one is industrial, and another is commercial.

Table 18 - Subcenter analysis for each skill group

	Low Skill	Average Skill	High Skill
Subcenters (total)	14	13	7
Global	8	7	7
Local	6	6	-
Employment in subcenters (total)	11,204	13,201	2,305
Global (total)	4,474	7,224	2,305
Highest	1,846	1,827	590
Lowest	83	130	51
Local (total)	6,730	5,977	-
Highest	1,699	1,916	-
Lowest	69	102	-
R ₂	0.6777	0.7243	0.6401
Adjusted R ₂	0.6464	0.6976	0.6122

Source: MTE-RAIS (2010). Elaborated by the authors.

The estimations for the average skilled workers, in the first step, yielded 167 subcenter candidates, further reduced to 26 after applying the multicollinearity radius. The second step identified 14 employment subcenters, which 8 are global and 6 are local. This model identified six (76, 154, 410, 17, 328 and 362) subcenters that also were a subcenter in the standard estimates. Further, from the 13 SBDs of average skilled workers, only five had less than 1,500 workers per grid cell. This result points that, average skilled workers concentrate in other parts of Curitiba besides the CBD.

model it has already been verified the predominance of the service economy in the subcenters. Therefore, our initial hypothesis is to reinforce the previous result.

In the industrial sector, the estimates yielded twelve subcenters where the global and local each had six subcenters. Their spatial distribution can be seen in Figure 17. As it was expected, most of them are located in the CIC neighborhood. Within the identified subcenters, four had more than 1,000 employees and only one those was not located at the CIC. The remainder SBDs appear to be of small relevance. This result enables to infer that the 1966 Master Plan has been successful in drawing industrial venues and, therefore, employment, to the CIC neighborhood.

In the commercial sector, the benchmark model had already identified one subcenter. When considering only the total employment in this sector, the estimates yielded twelve subcenters, eight are global and four are local. Within the identified SBDs, four have more than 1,000 workers, which interestingly have more employment than the one identified in the benchmark model. Hence, the commercial sector displays a polycentric shape, but the small number of SBDs that have a significant amount of employment in the region contribute to determine that the CBD is strong determinant in this employment sector. This argument is also corroborated by the total employment within the commercial subcenters, that reach over 9,300 workers, as seen in Table 19.

Table 19 - Subcenter analysis for each economic sector

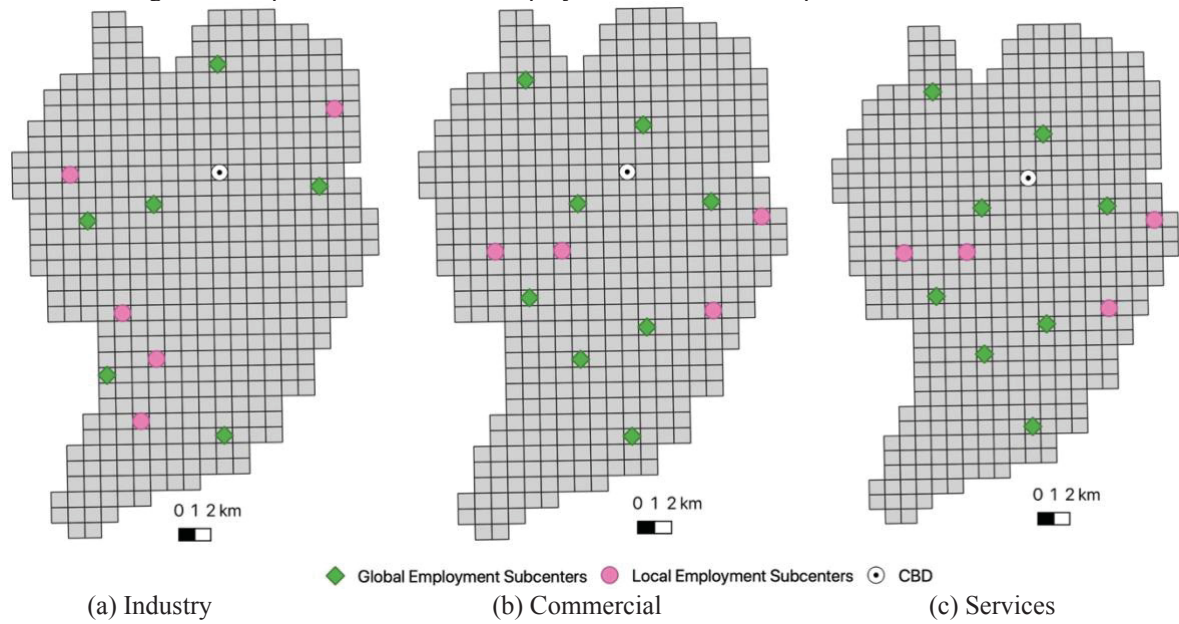
	Industry	Commerce	Service
Subcenters (total)	11	12	12
Global	6	8	8
Local	5	4	4
Employment in subcenters (total)	12,753	9,358	20,151
Global (total)	3,038	5,842	11,043
Highest	1,542	1,498	7,146
Lowest	52	73	149
Local (total)	9,715	3,516	9,108
Highest	4,961	1,498	3,456
Lowest	176	73	493
R ₂	0.5608	0.6620	0.7021
Adjusted R ₂	0.5261	0.6221	0.6750

Source: MTE-RAIS (2010). Elaborated by the authors.

The results of the benchmark model already showed that the service sector is polycentric. The estimates considering only service employment yielded twelve subcenters, eight were global and four were local. Further, four SBDs had more than 1.000 workers. Since

the results from Table 19, for the benchmark model, also show other significant concentrations of service employees, this sector displays a polycentric pattern.

Figure 17 – Spatial distribution of employment subcenters for specific economic sectors



Source: MTE-RAIS (2010). Elaborated by the authors.

6 CONCLUSION

This research was developed to comprehend the urban employment structure of Curitiba, a major Brazilian city, and the intertwine of the TOD policies that have been in place since early 1970s. Therefore, the main objective was to search the presence of employment subcenters and identify possible relationships between them and the BRT network. In order to achieve such task, it was applied the methodology proposed by McMillen (2001).

The initial hypothesis that Curitiba has employment subcenters was confirmed. In fact, there has been identified eleven subcenters, six of global relevance and five of local importance. When comparing the location of the North American subcenters, where the predominant activity is in the service sector, with the ones identified in Latin America, which as pointed by Fernández-Maldonado (2014), there is the presence of not only service and commercial but also industrial subcenters. Such results are also confirmed in the case of Curitiba, where four subcenters have the majority of workers in that sector. Nevertheless, six subcenters have most of their workers in the service sector while one other is specialized in the commercial sector.

Furthermore, the identified subcenters display a significant heterogeneity within their employment structure. There is the presence of a predominant economic sector, either in the industrial, commercial or service, but most do not have a strong majority. There also is significant diversity among the employees' level of education. Hence, both arguments point towards the possibility that subcenters display economies of agglomeration.

While the most common procedure in applied work is the Giuliano and Small (1991) density cut-off method, which relies in *ad hoc* criteria, the choice for McMillen (2001)'s procedure in the presence work is due its reliance in statistical criteria. As pointed by McMillen (2001) and Redfearn (2007), the former procedure might rely in a researcher's previous knowledge of the area in the cut-off choice. This argument is reinforced once the standard Giuliano and Small (1991) procedure and a lower threshold was applied for Curitiba. Both authors also point that this procedure fails to identify subcenters that locate in distant areas of the CBD since the criteria is the same for region analyzed. As it would be expected, McMillen (2001)'s methodology identified most of the SBDs in the Giuliano and Small (1991) procedure, except for one.

Despite the statistical inference from McMillen (2001)'s two-stage semi-parametric model, there are criteria that might vary, such as the window size and the multicollinearity radius. In the present work, different window sizes and multicollinearity radius were tested for the robustness of the results, similar to the work of Krehl (2016), and the optimal thresholds

were a 0.5 window size and a three-kilometer multicollinearity radius. Since the procedure was developed considering the north American context, different parameters should be tested, once the urban shape and the distribution of employment varies across different regions. As pointed by Fernández-Maldonado *et al* (2014) and Lv *et al* (2017), the Latin American and Chinese cities are dense, concentrating most of the employment close to the CBD, the opposite is verified for the German cities, as shown by Krehl (2016), in which the employment density are more evenly distributed across the metropolitan region.

In order to investigate if the subcenters have an influence in the employment density in surrounding tracts, the gravitational variable as in McMillen (2001) was considered. The construction of this variable was inspired in the work of Shukla and Waddell (1991), which enables the possibility of considering other spatial interaction proxies that influence the distribution of employment in Curitiba. Hence, searching to verify the interaction of the location of employment and the BRT network, a variable measuring the employment density in nearby tracts of the BRT terminals was considered.

The results sheds light to the fact that Curitiba's CBD is no longer the main determinant of the employment location. Therefore, the employment subcenters can be considered as a strong influence in the attraction of employment in the city besides the CBD. Further, the BRT terminals also have a strong influence in the concentration of employment in the neighboring area. This result indicates the role of TOD urban planning policy in shaping the polycentric structure of Curitiba.

Lastly, three separate estimations with McMillen (2001)'s two-step procedure were considered to identify the urban employment concentration for gender, level of skill and economic sectors. The gender estimates revealed that either male and female have important employment concentrations in Curitiba and, therefore, both are polycentric. The same applies for the low and average skill categories, while the high skill individuals appear to be monocentric (the identified subcenters have a total employment of 2,305). The results for the three economic sectors reinforced those the standard model yielded, identifying other significant employment concentrations across Curitiba.

From these results, other studies might take place, such as to verify the possibility of spatial mismatch and to further comprehend the factors that lie behind the economies of agglomeration in the subcenters. As public policy implication, subcenter 154 locates far from any of the BRT network features (main transit axes, feeder lines or bus terminals). Despite the low total employment (257) the location, somehow, should be embraced by the BRT system.

Therefore, the results achieved in this research reveals that the presence of employment subcenters in Curitiba seems to be a structural phenomenon promoted and induced by the TOD policy adopted in the city over several decades where the combination between BRT network system and mixed land use plays an important role.

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