The Journal of Transport and Land Use http://jtlu.org
Vol. 15 No. 1 [2022] pp. 17–34

Which dots to connect? Employment centers and commuting inequalities in Bogotá

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Abstract: Accessibility and equality evaluations have been primarily focused on residential location. However, workplace location might be an equivalent contributor to inequalities in the travel experience and accessibility. Traditionally, transport planning connects high-demand areas with the best-quality and capacity transport infrastructures. Literature supports that employment centers (EC) receive mainly workers in certain middle-to high-income occupations. This condition results in a type of segregation pattern associated with trip destinations and modal choice similar to those reported for the household location. This paper investigates commuting from a different standpoint, emphasizing the need to consider workplace location and employment distribution within cities. We identify five main EC in Bogotá, Colombia, and explore their association with the commuting mode choice of three population groups using mixed logit models. Results indicate that people who work in any EC tend to use more public transport (PT). Nevertheless, the probability of selecting PT differs among groups. Specifically, for low-income commuters, PT represents lower utility than that for middle-income commuters if their job is located in an EC. The fact that the population most likely to be public transport captive does not find this alternative as attractive as the middle-income segment needs further investigation for better policymaking.

Article history:
Received: September 22, 2021
Received in revised form: October 19, 2021
Accepted: November 10, 2021
Available online: January 24, 2022

1 Introduction

Latin American cities have undergone an accelerated urbanization process in the last decades, causing fragmented spatial development, congestion, mobility inequalities, and increasing emissions (Sarmiento et al., 2021; UN Habitat, 2012). To mitigate this situation and fulfill the United Nations' Sustainable Development Goals (SDG), in particular, the SDG11 (sustainable cities and communities) and SDG10 (reduced inequalities), understanding the relationship between the urban spatial structure, modal choice, and equality has become a priority in the research and policy agenda.

Workplace location is of special interest in this matter as it is the main activity of a large part of the population and could be a crucial contributor to inequalities in travel experience (Legrain et al.,

http://dx.doi.org/10.5198/jtlu.2022.2100
ISSN: 1938-7849

The *Journal of Transport and Land Use* is the official journal of the World Society for Transport and Land Use (WSTLUR) and is published and sponsored by the University of Minnesota Center for Transportation Studies. This paper is also published with additional sponsorship from WSTLUR.

2016; Lin et al., 2017; Vermesch et al., 2021). People from all over the city commute to employment centers. But those commuters don't include people of all income levels in the same proportion. Just as cities are segregated by neighborhoods with different degrees of wealth, the destination of employment can also be marked by income. Also, employment centers have traditionally had more public investment in transport infrastructure, public transport services, cycle paths, and well-maintained roads (Garrett & Taylor, 2012; Oviedo et al., 2019). This model has contributed to encouraging spatial segregation in some cities, leading to self-reinforcing cycles of urban development, rising housing prices that have created marked differentiation between wealthy and poorer population segments. Evidence from the US has shown that employment centers receive mainly workers from middle-to-high income (Cervero et al., 2010; Hu & Schneider, 2017). In Bogotá (Colombia), the continuous investments in Bus Rapid Transit (BRT) and other forms of public transport around highly attractive corridors reinforce cycles of segregation and concentration of formal economic activities (Oviedo et al., 2019). It suggests that the study of segregation in workplaces should be considered in the same way that household segregation has been for more equitable societies (Sabatini, 2006).

A city's population and economic activity patterns have significant implications on commuting travel time and cost. The current debate on the process of job decentralization has brought attention to the equality implications of transport policies. The expansion of road networks has resulted in a car-dependent transport system, particularly in the Global North, in which car availability has become a necessity for many households. On the other hand, in developing cities, the high dependence on public transport, its high (income relative) cost, and excessively long walks is a growing socioeconomic issue that places poorer households a significant burden to reach their workplaces, generating large accessibility inequalities at origin (Guzman, Oviedo, & Rivera, 2017; Guzman & Oviedo, 2018).

This paper investigates commuting mode choice emphasizing the need to account for Bogotá's employment centers distribution and individual's workplace location, differentiating by income level. This is a new perspective towards a much less explored exclusion facet: segregation patterns associated with trip destinations similar to those reported for the household location. We explore the commuting patterns of population segments concerning those centers. Thus, we enhance our knowledge about the connection between employment centers, work trips, and inequalities in the context of a city in the Global South.

Specifically, we use mixed logit models controlling for the employment center presence to analyze the association between workplace location and commuting mode choice and whether the relationship differs among income groups. In consequence, this research aligns with other studies relating to city-level variables and individual discrete choice decisions. Results can inform decision-makers to develop targeted policies for improving commuting conditions of specific income groups departing from macro-level planning.

The paper outline is as follows. First, we discuss the literature on urban form, its relationship with commute mode choice, and inequalities. Second, we introduce the study area, emphasizing the income group's attributes. Then we present the data sources and methodology. After that, we provide results about urban center identification and discrete choice models. Finally, the last section contains conclusions and policy implications.

2 Job location, commuting, and inequalities

Since 1980, identification and analysis of employment centers have been in the research agenda (McMillen, 2006) as its relation to other urban features such as residential location and transport systems, open promising paths to more sustainable and planned urban growth (Cervero, 2013; Guo et al., 2020;

Handy, 2005). The relationship between housing, employment locations, and modal choice is an important equality issue for urban sustainability, since people from different income levels experience extremely unequal conditions, in terms of job access and distinctive mobility patterns (Guzman & Bocarejo, 2017; Lucas, 2012). With compact activity patterns, a job decentralization policy can be very harmful, particularly for the poorest.

There are several methodological approaches to define employment centers. Craig and Ng (2001) used density peaks in both jobs and population. Gordon and Richardson (1996) used trip generation density, while Wang (2000) used GIS surface modeling. The most common is a threshold methodology proposed by Giuliano and Small (1991). Their proposal establishes two criteria: job quantity (e.g., minimum total employment of 10,000) and job density (e.g., 10 employees per acre). The application of these simple criteria is often modified, based on contextual knowledge, to map what is locally considered to be a significant employment center (Avendaño Arosemena, 2013; Nielsen, 2019).

Employment center identification indicates that cities are reshaping continuously, in most cases to a polycentric urban form (Hu et al., 2018). This pattern, however, is not standard and changes from city to city (Fernández-Maldonado et al., 2014; Schwanen et al., 2001). In Latin American (LA) cities, the study of the job decentralization phenomenon needs some special considerations, given the marked limitations in economic development, public transport services, vehicle ownership rates (Inostroza et al., 2013), and data (Sarmiento et al., 2021). Fernández-Maldonado et al. (2014) examined the location of employment centers in Ciudad de México, Lima (Perú) and Fortaleza (Brasil), founding a remarkable differences between the LA and the US context. The employment centers in LA cities were located within a radius of 15 km from the Central Business District (CBD), whereas in US cities employment centers are frequently found 20 km or farther away from the CBD.

Specifically, in commuting, travel behavior, and activity location, intense debate is found as studies have yielded mixed results. Polycentrism, understood as deconcentration of urban economic land use to suburban locations, have both, positive and negative effects on travel time, travel distance, and car use over public transport and active modes (Ding et al., 2017; Hu & Schneider, 2017; Nielsen, 2019; Schwanen et al., 2001; Wang, 2000; Wolday et al., 2019). This evidence comes mainly from Global North countries and some emerging economies, predominantly China (Ding et al., 2017; Guo et al., 2020; Yang & Cao, 2018; Zhang et al., 2019). Recently, authors have claimed that the relation between polycentrism and travel patterns should be differentiated by population groups considering its implications on the mobility equality gap (Legrain et al., 2016; Vermesch et al., 2021). Gobillon and Selod (2014) contend that disadvantaged residents in US cities predominantly residing in the inner-city and dependent on public transport are often disconnected from job opportunities of suburban areas. In line with this, Mattioli (2017) found that constraints in public transport together with dispersed job opportunities lead to increasingly "forced car ownership" because is the most efficient way to reach the opportunities. This creates situations where a household owns and operates a car, despite having limited financial resources (Currie & Delbosc, 2011). In the LA context, usually, low-income households are forced to live in the urban periphery with often fewer public transport services and too few job opportunities in their surroundings (Vecchio et al., 2020). This limits their trip production to the essentials, affecting not only their participation in economic opportunities but also education, health care, and social networks (Combs, 2017).

The above evidence suggests that city employment location, commuter income level, and transport system configuration are important factors in mode choice and equality. Nevertheless, the literature on travel behavior and equality evaluations has been primarily focused on the residential location (Legrain et al., 2016; Lin et al., 2017; Vermesch et al., 2021). Therefore, understanding the relationship between income level and modal choice accounting for the place of work is essential from a policy perspective to developing strategies focusing on low-income job accessibility. This study contributes to the literature on modal choice and equality by combining work locations with detailed travel patterns data for Bogotá, identifying and using the employment centers in the city as covariates in discrete choice models. Results could be useful to transport, urban planners, and decision-makers to expand the understanding of the employment center's role in commuting mode choice and equality across income groups in the LA context. The proposed approach allows examining the differentiated effects between the transport mode and commute across income levels.

3 Bogotá context

Bogotá, the capital of Colombia, has an urban area of 380 km^2 with an average density of 19,500 inhab/km^2. Yet, population densities across the city are not uniform, and they are lower in the function of (high) income. In Bogotá, the lowest population densities are where land prices are the highest, which also are the areas where most of the employment is located. Therefore, well-located housing is affordable only for high-income households. Figure 1 (left) depicts the spatial distribution of residential land uses using the government official stratification system which is named socioeconomic strata (SES). It facilitates the administration of public utilities subsidies through differential rates between high and low SES zones, and between residential and commercial users. The SES goes from 1 to 6, where SES 1 zones correspond to those of lesser quality and SES 6 to the best conditions in terms of the physical characteristics of buildings and quality of urban space surrounding (Cantillo-García et al., 2019). Therefore, built environment attributes are similar inside those zones and different from each other. We will use this zoning to test for spatial autocorrelation in the modeling section.

Figure 1 (right) shows the large share of job opportunities concentrated along BRT transport corridors, especially in the east edge of the city, where higher-income households locate. The work-related activities in Bogotá are highly concentrated in a specific area (Guzman et al., 2018). In that areas have consolidated several small-scale employment centers (Avendaño Arosemena, 2013; Dowall & Treffeisen, 1991; Ruiz Estupiñan, 2015). While in the urban periphery, employment activity has failed to consolidate along time (Ruiz Estupiñan, 2015).

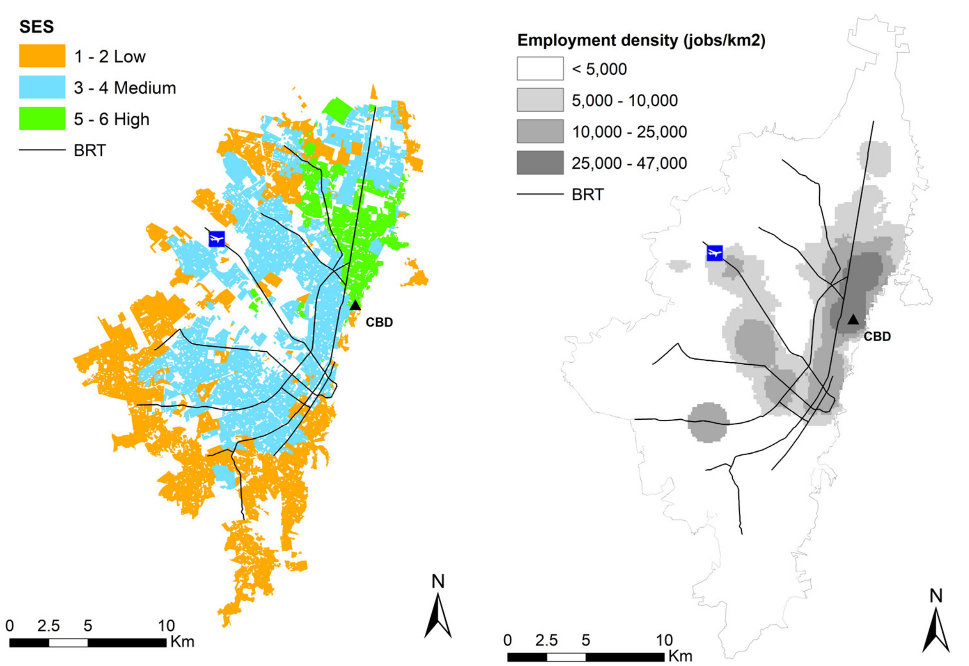

Figure 1. Socio-Economic Strata at block level in Bogotá (left), employment density (right)
Source: The authors with information from Bogotá's official data (IDECA)

For this study, we defined three income groups, departing from the nine original household monthly income ranges presented in the 2019 Bogotá Mobility Survey (EM2019). The first level is the low-income group, which includes households with a monthly income that earn less than COP 2.0 million (<USD 573). The middle-income group consists of households with income between COP 2.0 million to 4.9 million (USD 573 – 1,405). Finally, the high-income group contains all households with an income higher than COP 4.9 million (>USD 1,405). This classification does not change results for the grouped segments while simplifying analysis and reducing the sample size bias.

The descriptive statistics in Table 1 provide a preview of the commute differences across population groups. While 42% of the high-income population use car for their daily work trips, only 8% of the low-income workers do. It is related to the fact that in Bogotá, the low-income segment owns 38 cars per 1,000 inhabitants, while the indicator for the city is 148/1,000 inhabitants. Public transport is by far the most common transport mode for middle and low-income groups. Remarkably, low-income commuters use non-motorized transport modes in a higher proportion than other groups. Notwithstanding that, they travel the longest house-to-work distance (8.7 km on average).

Table 1. Descriptive statistics of workers by income group

Dimensions	Variable	Low-income	Mid-income	High-income
Transport mode	Car	7.9 %	22.4 %	41.9 %
	Public transport	67.9 %	58.6 %	40.6 %
	Bicycle	10.9 %	8.3 %	5.6 %
	Walk	13.3 %	10.6 %	11.9 %
Car availability	Available	20.9 %	56.1 %	82.9 %
	Not available	79.1 %	43.9 %	17.1 %
Bicycle availability	Available	44.8 %	55.5 %	61.2 %
	Not available	55.2 %	44.5 %	38.8 %
Average commute distance [km]*		8.7	7.7	6.7

* Euclidean distance
Source: Adapted from 2019 Mobility Survey

Congestion levels in Bogotá are high although most of the 13.3 million daily trips in the city (2019) are made using sustainable transport modes (72.2% by non-motorized and public transport and just 20.5% by car, taxi, and motorcycle). The public transport operates under an Integrated Public Transport System (SITP in Spanish) with the integrated fare of all its sub-systems, TransMilenio (TM, the BRT system) and regular buses. Although SITP services cover the whole city, route frequencies are low in some peripheral zones, providing a poor level of service. The SITP main sub-system, the BRT, was designed to connect the densely populated areas of the periphery with the hotspots of formal employment located in a "V" shaped area that goes from the west to the east in the middle of the city and then goes to the north (see Figure 1, right).

4 Methodological approach

The proposed methodology comprises two components. First, the identification of employment centers to explore urban spatial employment dispersion across the territory. Then, the estimation of mixed logit models to test the association between employment centers and modal share. This approach is novel in the LA context to the best of our knowledge.

4.1 Data sources

Our primary dataset is the 2019 Bogotá Mobility Survey. It includes information about household sociodemographic characteristics, vehicle ownership, and travel patterns during a typical working day. Our sample comprises all workers that reported home-based commuting trips made on private car, public transport (either bus or BRT), bicycle, or walking, starting and ending in the urban area of Bogotá.

The EM2019 only reports information about the chosen transport alternative. Thus, for discrete choice modeling, it is necessary to estimate travel costs and time attributes for the non-selected alternatives by each trip. To deal with this, for motorized modes we retrieved distances and travel times through queries to the Google Distance Matrix API, using the information of trip departure time and the Traffic Analysis Zones (TAZ) involved on each trip. Then we derived car trip cost by multiplying the distance from the API and an average operational car cost (i.e., COP 578 per km, around USD 0.165). For bus and BRT, the travel cost corresponds to the official fares. For non-motorized alternatives, we obtained trip distances using the GIS-based shortest path algorithm in the Network Analyst module of ArcGIS. Then, travel times were calculated using a speed of 5 km/h and 12 km/h, for walking and bicycle, respectively (Guzman, Arellana, et al., 2021). Those two values are in correspondence with the average speed of non-motorized trips reported in the EM2019. Walking and cycling were not assigned any monetary cost.

We defined mode availability by car and bicycle ownership, according to the availability reported in the EM2019. Then, walking and bicycle were only available for trips shorter than 90 minutes, while the car and bus were only available for trips longer than 600 m. These thresholds resulted from an analysis of trip length and time histograms. Finally, public transport was defined as always available since all households have access to SITP system services. Table 2 summarizes the variables considered in the modeling stage.

Table 2. Worker sample characteristics

Dimensions	Variable	Description	Min	Max	Mean
Age & gender	Female	Yes=1	0	1	0.46
	Age	Years	18	80	40.34
Education level	High school	Yes=1	0	1	0.38
	University	Yes=1	0	1	0.47
	Post-graduate	Yes=1	0	1	0.15
Household income (monthly)	Low-income	< COP 2.0 million (<USD 573) Yes=1	0	1	0.50
	Mid-income	COP 2.0 million – 4.9 million (USD 573 – 1,405) Yes=1	0	1	0.31
	High-income	> COP 4.9 million (USD 1,405) Yes=1	0	1	0.19
Occupation	Low-skilled job or informal	Yes=1	0	1	0.10
	Formal sector employee	Yes=1	0	1	0.57
	Independent	Yes=1	0	1	0.27
	Not answer	Yes=1	0	1	0.06
Vehicle availability	Car availability	Yes=1	0	1	0.44
	Bicycle availability	Yes=1	0	1	0.51

Dimensions	Variable	Description	Min	Max	Mean
Transport mode	Car	Yes=1	0	1	0.19
	Public transport	Yes=1	0	1	0.60
	Bicycle	Yes=1	0	1	0.09
	Walk	Yes=1	0	1	0.12
Built environment	Population density in origin TAZ	People per Ha	0	2,219	320.4
	Population density in destination TAZ	People per Ha	0	2,219	149.2
	Job/population ratio in origin TAZ	Number of job positions divided by people	0	134.5	0.55
	Bus station density in origin TAZ	Number of bus stations per Ha	0	1.06	0.23
	Bus station density in destination TAZ	Number of bus stations per Ha	0	0.97	0.24
	BRT stations near	Household inside 1 km buffer of a BRT station (Yes=1)	0	1	0.52

Sample Size (Individuals) 9,386
1 USD = 3,487 COP in December 2020
Source: The authors with information of EM2019 and Bogotá's official website for open data (IDECA)

4.2 Employment centers identification

For identifying employment centers (EC henceforth), we used the number of work-related trips that arrive at any given TAZ as a proxy for employment, adding together a total of 2,365,900 jobs in the city. Then we applied a threshold-based methodology similar to Muñiz et al., (2008) for the Barcelona metropolitan area. The approach considers employment in absolute and relative levels as follows: EC are zones with employment density greater than or equal to the average density in the city (see Equation1) and with a level of workplaces ≥ 0.7% of the total for the study area (see Equation 2). Originally Muñiz et al. (2008) used a threshold of 1%, however for our application it was lowered to 0.7% as our study area consists of a higher number of zones of smaller size, 886 TAZ in Bogotá vs 164 municipalities in Barcelona.

$$D_m \geq \bar{D} \tag{1}$$

$$E_m \geq 0.7\% \, E \tag{2}$$

Where m denotes zone (TAZ in this case). D_m is employment density (workplaces/Ha) in zone m, $\bar{D}$ is the average employment density for the Bogotá, E_m are workplaces in zone m, and E is the total employment in the city.

4.3 Mode choice model

We estimated two mixed logit models to examine the association between EC and mode choice. The probability of selecting an alternative is calculated as a weighted average of the logit formula evaluated at different values of β, with the weights given by a density function $f(\beta)$ (Train, 2009). Formally it is represented in Equation 3.

$$P_{nj} = \int \left(\frac{e^{U_{nj}}}{\sum_j e^{U_{nj}}} \right) f(\beta) d\beta \tag{3}$$

Where U_{nj} is the utility that person n assigns to alternative j, $f(\beta)$ is a density function, also known as the mixing distribution. We specified each alternative's utility function with an error-component structure, as expressed in Equation 4.

$$U_{nj} = \alpha X_{nj} + \mu_n Z_{nj} + \varepsilon_{nj} \tag{4}$$

where X_{nj} and Z_{nj} are vectors of observed variables relating to alternative j, α is a vector of fixed coefficients, μ is a vector of random terms with zero mean, and ε_{nj} is distributed iid extreme value.

For this study, the alternatives j are walking, bicycle, car, and public transport (PT). Although in the EM2019, BRT ridership is reported separately from the bus service, the Google Distance Matrix API only provides information aggregated as public transport, so it was not possible to have these alternatives disaggregated.

We used a step-wise approach for estimation purposes. Model 1 includes the following variables in the fixed coefficients part (Xnj): travel costs and times for each transport alternative, as well as gender, education level, income, and household size. The last four mentioned variables are related to the worker and act as control variables.

Model 2 adds two variables to the Model 1 specification. With the first variable, *job in cente*r, we tested the association of EC with mode choice. It is a dummy variable that indicates if the workplace of a person n is located in any previously identified EC. With the second variable, *job to center distance*, we seek to understand the association of workplaces in peripheral zones of the city. It refers to the distance between workplace location and the nearest EC. We also included interaction terms between *job in center variable* and *income level* to capture heterogeneity regarding mode choices. This set of variables is central to the research objective of understanding links between EC and mode choice for different income levels.

Finally, we included error components to capture unobserved preferences and correlations among transport alternatives. These are IID normal deviates multiplied by vectors of observed variables (Z_{nj}). In the specification, Z_{nj} is operationalized as two dummies that account for a possible geographic autocorrelation of commuter decisions depending on their household location, if the household is located in the low-SES areas (see Figure 1, left) dummy *SES 1-2 low* takes a value of 1 and 0 otherwise. The same occurs with dummy *SES 3-4 Medium* when households are located in mid-SES zones. We used the Apollo package (Hess & Palma, 2019) in R for estimation, employing 500 random Halton draws (Hess & Train, 2011).

5 Results

The identification of the EC in Bogotá stands as the first result of this study. The thresholds described previously allowed us to select twelve TAZ, which define five different well-known economic centers (see Figure 2): 1) The traditional historic center; 2) Industrial zone; 3) National government buildings center; 4) Financial center, and 5) Specialized services center. Results did not show any relevant employment concentration in the urban periphery, making us think that urban spatial structure has not changed dramatically in the last decades (Guzman, Oviedo, & Bocarejo, 2017) and that Bogotá continues to be a predominantly monocentric city. That is, despite new urban developments in recent years, it cannot be considered a polycentric city. Note that in terms of public transport access, the BRT network connects directly to all identified EC, following a conventional CBD-centered public transport planning (Garrett & Taylor, 2012). The identified EC contains 10.4% of the total employment in Bogotá but only represents 1.5% of the urban area.

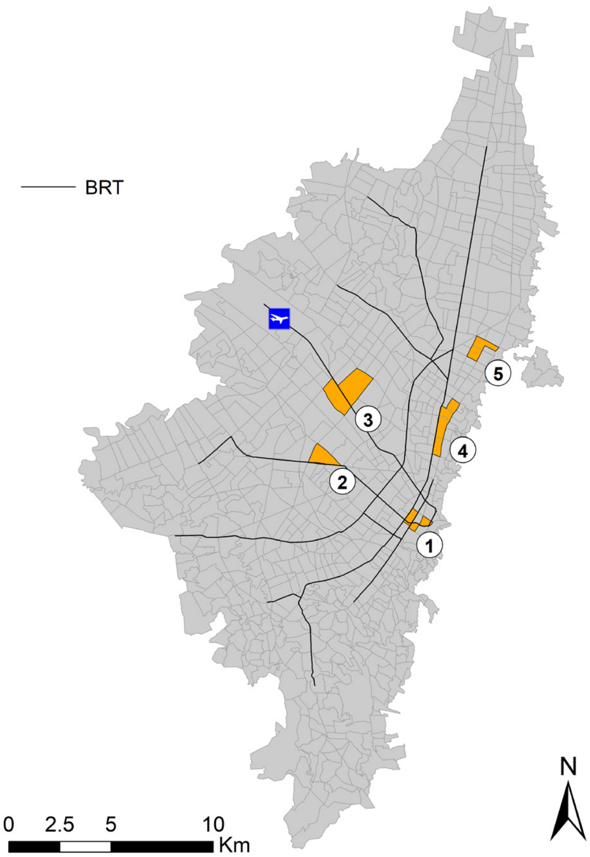

Figure 2. Employment centers in Bogotá
Source: The authors

Descriptive statistics in Table 3 show relevant facts about EC concerning travel patterns and housing/job location for each income group. We used Tukey's multiple comparisons and test for equality of proportions in R to prove differences across groups. First, the higher the income, the higher the proportion of employees working in the identified ECs, 9.7% (low-income) vs 13.6% (high-income). It is also noticeable that the household location of low-income households tends to locate at a longer distance from the selected EC (i.e., 5.6 km on average), and their jobs are also farther away from any center (i.e., 2.8 km on average). For high-income households, the situation is the opposite.

Table 3. Trip destination distribution by income group

Dimensions	Variable	Low-income		Mid-income		High-income	
Commute destination	Job in other areas	90.3 %	°°° +++	88.2 %	°°° +++	86.4 %	°°° +++
	Job in center	9.7 %	°°° +++	11.8 %	°°° +++	13.6 %	°°° +++
Commute distance [km]	Job in other areas	8.7	°°° .	7.7	°°°	6.8	°°° +
Urban structure	Job in center	9.2	°°° .	8.0	°°°	6.2	°°° +
	Household - center distance [km]*	5.6	°°°	4.1	°°°	3.1	°°°
	Job - center distance [km]*	2.8	°°°	2.4	°°°	2.0	°°°
	Household – BRT station distance [km]*	1.7	°°°	1.2	°°°	1.0	°°°

* Average euclidean distance to closest center or BRT station
p-value = 0 '°°°' 0.001 '°°' 0.01 '°' 0.05 '.' 0.1 ' ' 1 (Low-income vs Mid-income or High-income)
p-value = 0 '+++' 0.001 '++' 0.01 '+' 0.05 '.' 0.1 ' ' 1 (Job in other areas vs Job in center)
Source: The authors with information of EM2019

Additionally, Table 3 displays the average distance of households to a BRT station. Low-income households are the most distant from this high-capacity transport system. This is in line with other studies that have demonstrated that wealthy residents in Bogotá have better access to opportunities derived from urban development trajectories and inherited practices of transport planning (Arellana, Oviedo, et al., 2020; Guzman & Oviedo, 2018; Oviedo Hernandez & Titheridge, 2016).

Figure 3 shows the modal share associated with workplace location and income. For the high-income group, the commute share by car is 40% when the job is located out of selected ECs and rises to 42% when the job is in an EC. Conversely, the car use for low-income workers is always less than 10%. The above is expected due to the low motorization rate of low-income population. Interestingly, there is a broader share of non-motorized trips for low-income workers when the job is out of ECs (25% vs 18% in EC). The most noticeable fact for our research objectives is the percentage of public transport usage by middle-income workers. A significantly higher proportion of middle-income commuters choose PT when their job is located in an EC, i.e., 57% in non-EC areas vs 70% in EC.

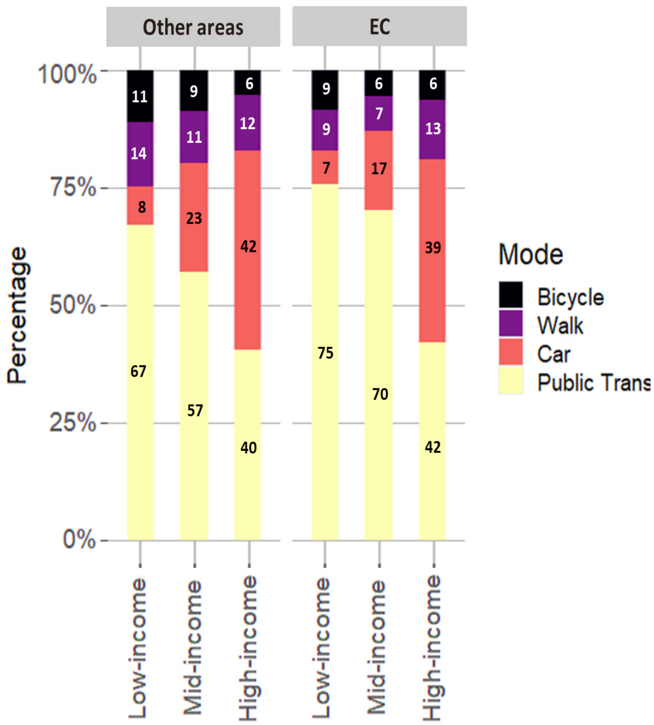

Figure 3. Modal share of work trips by income group and destination
Source: The authors with information of EM2019

Following the second step of our methodology, we estimated mixed logit models to test the associations of mode choice with EC variables and control variables (see Section 4). Table 4 presents the estimation results. Model 2, which includes the EC variables, improves the log-likelihood (L.L.) from -6,353.7 to -6,304.7. We performed a log-likelihood ratio test for model comparison, confirming that Model 2 has a significantly better fit. Although parameters in both models are of similar magnitude, the alternative specific constants of Model 1 are larger than in Model 2. In the restricted model (Model 1), the alternative specific constants (ASC) and the error terms account for not considered effects due to misspecification. In consequence, this model responds mainly by increasing the ASC estimates to represent the sample market shares. The difference in estimates will impact forecasting results if the urban form and transport alternatives change. Then, smaller ASC are desirable in this type of model (Ortúzar & Willumsen, 2011).

As Model 2 performs better than Model 1, we will focus our discussion on it. Overall, the model coefficients present the expected signs, and the significance is above 90%. ASC for each transport mode indicates that ceteris paribus, the car is the most preferred mode, and the bicycle is the less attractive.

Table 4. Mixed multinomial logit model

Attribute	Alternatives	Model 1		Model 2	
		Estimate	p-value	Estimate	p-value
ASC car	Car	0	-	0	-
ASC pt	PT	-1.713	< 0.001	-1.231	< 0.001
ASC bc	Bicycle	-3.136	< 0.001	-2.771	< 0.001
ASC wk	Walking	-2.774	< 0.001	-2.455	< 0.001
Non-random parameters					
women	Bicycle	-1.820	< 0.001	-1.800	< 0.001
high school	Bicycle	0.188	0.038	0.168	0.062
cost	PT & car	-0.272	< 0.001	-0.278	< 0.001
time	All modes	-0.011	< 0.001	-0.011	< 0.001
cost:low-income	PT & car	-0.131	< 0.001	-0.100	< 0.001
cost:high-income	PT & car	0.108	< 0.001	0.114	< 0.001
household size	Car	-0.407	< 0.001	-0.402	< 0.001
job to center distance	Car			0.233	< 0.001
job to center distance	NM			0.072	< 0.001
job in center	PT			0.621	0.001
job in center:low-income	PT			-0.488	0.044
job in center:high-income	PT			-1.057	< 0.001
Error components					
SES 1-2 low	PT & NM	5.145	< 0.001	4.648	< 0.001
SES 3-4 Medium	PT & NM	-8.215	< 0.001	-5.357	< 0.001
Log-likelihood		-6,353.7		-6304.7	
Pseudo-R^2		0.1253		0.1313	

: indicates an interaction or combined effect of two variables.
Non-motorized (NM) includes bicycle and walking
n = 9,386.

The analysis of the coefficients associated with the EC variables allows answering our research question. The *job in center* variable suggests that people who work in any EC tend to use more public transport, which is expected considering the adequate provision of the BRT services. However, this association differs among income groups as indicated by the interaction terms and previously discussed on the descriptive statistics (see Figure 3). The negative sign in the interaction term *job in center:high-income* indicates that the wealthy group will prefer car over other transport alternatives no matter their work location is. In turn, the negative sign of the interaction variable *job in center:low-income* suggests that ceteris paribus, the utility of public transport for low-income workers who travel to an EC is positive but not as high as that of middle-income. It is worrying that the population most likely to be public transport captive does not find this alternative as attractive as the middle-income segment as they are inelastic to public transport fare increases (Guzman, Beltran, et al., 2021). Meanwhile with the descriptive statistics (see Table 3) we only can hypothesize that it might be related to the low-income households' larger distance from the BRT network (1.7 km on average) and that only 9.7 % of them work on an EC.

A discussion of estimated coefficients for control variables shows that women are less likely to ride a bicycle than men (-1.820). This is in line with the growing literature about gender inequalities in transport that highlight women's more adverse conditions such as carrying children, sexual harassment, and more risk aversion (Higuera-Mendieta et al., 2021; Prati, 2018). Education also was significant (0.188). People with only basic studies are more likely to commute by bicycle. It is related to the fact that in the LA context less skilled people (low-income) cycle more frequently to work and support previous findings on the importance of this mode for accessibility levels of poor people in Bogotá (Rosas-Satizábal et al., 2020) and other Colombian cities (Arellana, Saltarín, et al., 2020).

The coefficients for travel cost (-0.272) and time (-0.011) have both negative signs expressing how these factors discourage mode choice. The interaction terms of cost with income indicate systematic taste variations among groups. Low-income workers' cost coefficient (-0.272 – 0.131 = -0.403) shows that they are discouraged more strongly about using a motorized mode with an increase in cost when compared to the middle-income (the reference group). In Bogotá, low-income households must walk a lot to reach public transport and spend more than 20% of their monthly income in motorized transport to reach their jobs, particularly in peripheral areas (Guzman & Oviedo, 2018). In contrast, coefficients for high-income workers indicate that they perceive changes in cost as less negative (-0.272 + 0.108 = -0.164). The marginal rate of substitution between cost and time as the subjective value of time (SVT) yields the following results: COP 29, 39, and 66 per minute, for low-, middle- and high-income groups, respectively.

Coefficients for the *job to center distance* variable show that when a job is located further towards the urban periphery, more attractive become the car and active transport modes. This result is somewhat unexpected for walking and cycling. Most literature is in line with Nielsen (2019), who found that long distances from a job to an EC result in a lower probability of cycling, walking, or using public transport. However, in Bogotá, given the tight budget restrictions, walking and cycling have become preferable transport modes for low-income populations usually located in the urban periphery (Guzman & Bocarejo, 2017). A similar situation was found for low-income workers in Kumasi, Ghana (Acheampong, 2020) and Barranquilla, Colombia (Arellana, Saltarín, et al., 2020; Arellana et al., 2021) . So far, these results add evidence on the necessity to consider for integral accessibility and equality analysis, where workplace location and EC distribution are less explored in literature but might be as crucial as studying household segregation in addressing transport equality gaps.

Random error components were included to test if mode choice of workers living in the same SES zones are correlated. As coefficients of *SES 1-2* and *SES 3-4* are both significant, the model suggests that households located in those areas are affected by additional preference heterogeneity sources. Two possible reasons for the unobserved heterogeneity that we were unable to test due to lack of information are parking spot availability, parking costs, and personal security. This last one is an issue in the low-SES areas, to the extent that people organize groups of travelers to move in early or late hours to feel safer, affecting their travel behavior (Oviedo Hernandez & Titheridge, 2016). In addition, we inferred a third possible source of preference heterogeneity based on the model specification and because the best model is when PT, walking, and cycling were grouped with a common error term. It suggests stronger substitution patterns between active and public transport alternatives. In this case, subjective variables might play a role as the three grouped modes are considered more sustainable. In consequence, we must highlight a study limitation, as we could not rule out the self-selection effect (Bagley & Mokhtarian, 2002), which implies that people with sustainable travel preferences select themselves into residential neighborhoods that support those propensities. Self-selection is a potentially important research bias that suggests that built environment characteristics tend to have a small direct impact on travel behavior since people's personal preferences and attitudes might be more significant in selecting a transport mode. Further studies should attempt to improve this approach, including the joint decision of house location and commuting mode (transport costs), controlling also for attitudes and perceptions.

6 Conclusions

This study added empirical evidence on the association between employment centers and commuting mode choice by income group in Bogotá. First, we explored the spatial configuration of the city, identifying five ECs. Then, we envisioned the underlying relations between the commuting modal share of different income groups and the urban spatial structure using descriptive statistics. Finally, we estimated mixed logit models to test the association of EC with commute behavior considering the sociodemographic characteristics of workers.

In terms of methodology, this study gives evidence on the importance of considering main job destinations (ECs) and focuses on the job location to get further insights into the study of inequalities. Besides, it showed the necessity of using models with error components as unobserved heterogeneity is ubiquitous in this type of study in the Global South, where lack of information is common.

We found differences among income groups in both workplace location and commuting transport mode. First, the share of high and middle-income workers that work on ECs is higher than that for low-income workers. Second, low-income workers find shorter commute distances in no EC areas where the BRT network is not present. Third, middle-income workers place higher utility to PT when traveling to an EC, descriptive statistics show they are closer than low-income workers to the BRT service that connects the ECs.

We derived some recommendations from the above findings. Primarily, it is imperative to investigate the commuting behavior of low-income populations, with close attention to the work location and its relationship with urban ECs. It will shed light on points where public investment can be effective in closing accessibility gaps, i.e., giving more resources to those in need instead of providing equal share for all groups (vertical equality). Secondly, in terms of public transport services, there is the necessity to improve the access to the high-capacity transport network focusing on connecting low-income trip production and attraction areas. If expanding the public transport network is not feasible, the advent of new technologies could provide the necessary granularity on information to identify the most disadvantaged mobilities (Chen et al., 2016) and find innovative transport options for them.

Alternatively, improving urban walking and cycling conditions will benefit low-income commuters. A 25% of them already commute on active modes when their job is located outside ECs. Finally, housing policies should also consider workplace locations and access to public transport for poorer households to increase housing opportunities and allow shorter distances to reach public transport infrastructures.

Acknowledgements

We would like to express our gratitude to the Bogotá Urban Planning Department (www.sdp.gov.co), for the funding and general support given for the development of this study through agreement 369 of 2018. In addition, we thank Professor Orlando Clavijo for his valuable comments to improve mixed model results.

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