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Does the introduction of bus rapid transit affect car use? Travel mode choice among high-income households in Bogotá, Colombia

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Abstract

Many developed countries have introduced bus rapid transit systems in major cities to reduce congestion and air pollution. Several of these are based on the *Transmilenio* bus rapid transit system in Bogotá, capital of Colombia. However, the effect of the *Transmilenio* on car use, especially among wealthier residents, is not clear. This study therefore aimed to examine the effect of the *Transmilenio* on choice of transport among wealthier households in Bogotá. We used multinomial regression analysis to identify the factors affecting transport choice. We found that older and wealthier residents were more likely to use cars, and younger residents were more likely to use public transport or bicycles. Men were also more likely to use bicycles, which may be due to perceptions about the safety of cycling in Bogotá. Pedestrian density was associated with greater use of both bicycles and public transport, perhaps because people feel safer where there are more pedestrians. Buses were more likely to be used in areas with high office density. This may show that ordinary buses and the *Transmilenio* are used for different purposes and in a complementary way. To increase public transport use, we recommend that the local government in Bogotá increases the safety and reliability of public transport, through measures such as the adoption of fixed timetables and educating passengers about behavior. Improving pedestrian infrastructure in areas around stations may also encourage use of public transport.

Key words: Bogotá, bus rapid transit, car use, public transport, socioeconomic status.

1. Introduction

1.1. Research background

Economic growth has encouraged the private-car ownership in developing countries (Carty, 1999; Clayton *et al.*, 2014). Local governments in the global South now need to develop plans to improve mobility around cities. One of the most popular solutions is bus rapid transit (BRT) schemes. In cities in Africa, Asia and Latin America with limited financial and institutional resources, the number of BRT schemes has increased dramatically in recent decades (Table 1, Fig.1). Many researchers have found that elements of the built environment, such as the availability of alternative transportation options, have a significant impact on car ownership in developing countries, and may counter the impact of income growth (Guerra, 2014; Yang *et al.*, 2017; Zegras, 2010). A lack of alternative modes of transport encourages citizens to depend on private means of transport (Shirgaokar, 2014).

Some researchers have examined the effect of BRT schemes as alternative urban transportation modes (Harbering and Schuter, 2020; Vergel-Tovar and Rodriguez, 2018), but BRTs have a limited effect on travel patterns in urban environments. In developing countries, many studies on BRT schemes focus on equality of access to major urban facilities, especially for vulnerable populations (Casas and Delmelle, 2014; Hernandez and Titheridge, 2016; Motte *et al.*, 2016; Vermeiren *et al.*, 2015; Zolnik *et al.*, 2018). They suggest that car ownership is associated with lower use of BRT schemes, but the relationship between BRT schemes and car use remains unclear.

1.2. Purpose of this study

This study examines transport mode choice among high-income residents, who have extensive access to private cars, of Bogotá, Colombia, to answer the following research questions:

- How much impact does a BRT scheme have on car use? and
- How can a BRT scheme have a greater impact on car use?

We used a mixed methods approach in this study. To

Table 1 Characteristics of BRT schemes across different regions (2020)

	Passengers per day	Cities	Total length (km)
Africa	491,578	5	131
Asia	9,471,593	44	1,625
Europe	1,613,580	44	875
Latin America	21,032,465	55	1,829
North America	988,683	21	683
Oceania	436,200	5	109

Source: ALC-BRT & Embarq, 2020

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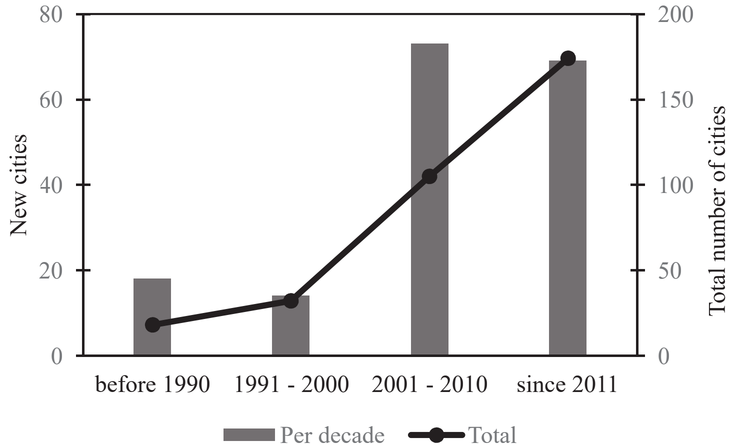

Fig. 1 An increase in the number of cities with BRT schemes by decade.
Source: ALC-BRT & Embarq, 2020

determine which aspect increases the use of cars and public transport, we used quantitative analysis and a multinomial logit model. We then used content analysis, a qualitative approach, to explain the impact of the variables found in the quantitative analysis and to understand views about each means of transport. We explain more details of the analysis at Chapter3.

1.3. Study area

Bogotá had a fragile public transport system from the 1950s, with transport dominated by private bus companies. In 2000, to solve the chaotic transportation situation, the city introduced a BRT scheme named *Transmilenio*. It played a huge part in increasing the international prominence of BRT schemes (Gilbert, 2008; Hidalgo and Sandoval, 2004; Hidalgo et al., 2013; Paget-Seekins, 2015).

Transmilenio has biarticulated, or coupled, buses and complementary feeder buses (see Fig. 2), and covers 441km of roads (Transmilenio S.A., 2020b). The feeder buses allow citizens in peripheral urban areas, among which are largely classified as low-income (Misas-Arango, 2011), to access the *Transmilenio* terminal stations without any additional fees.

The city's transportation master plan from 2006 included an integrated public transportation system, or SITP (*Sistema Integrado de Transporte Público* in Spanish). This is an integrated system with different transportation services to provide effective coverage for all daily trips in Bogotá (Transmilenio S.A., 2013).

Like many other cities in the global South, Bogotá, the capital of Colombia, has high population density and rapid population growth (Fig. 3). In Bogotá, residential areas are classified into six levels or socioeconomic strata (SES)[1]. SES distribution shows a spatial segregation pattern within the city (Fig. 4). Regarding a huge economic disparity within the city, the municipality establishes different rates for public services and subsidies by socioeconomic group.

Bogotá displays strong spatial segregation in terms of population and employment density. Most employment is concentrated in the north-eastern area, where the population density remains relatively low, including the business center and the residential areas inhabited by the wealthiest population. In contrast, the south-western periphery shows high population density with lower income households living in informal settlements with poor living conditions (Guzman and Bocarejo, 2017).

2. Transportation in Bogotá

2.1. Transport policies

Table 2 shows the details of transportation systems in Bogotá. SITP covers huge area (1,890.39km of system, and 22,000,000km of trips per month), followed by *Transmilenio* which supports 12,000,000km of trips a month with 114.4km of system lanes.

In total, 35% of Bogotá's budget for 2020 is assigned for transport and mobility (Alcaldía de Bogotá, 2020a). Bogotá's municipal government intends to reinforce inclusion, security, sustainability, and accessibility in this sector. The Development Plan mentions improvement and maintenance of the *Transmilenio* and SITP, constructions of new bicycle lanes, and encouragement of bicycle use. A total of 5,000 public parking spaces for bicycles will be added within *Transmilenio* stations, and 280 km of new bicycle lanes will be constructed to raise the percentage of trips by bicycle by 50% (Gobierno abierto de Bogotá, 2020). With the expectation of reducing travel time, a new cable car will be constructed in the southern part of

Fig. 2 Public transportation in Bogotá a: *Transmilenio*, b: Feeder bus, c: SITP.

Sources: a: El Tiempo, 2015; b: El Espectador, 2019; c: RCN Radio, 2020

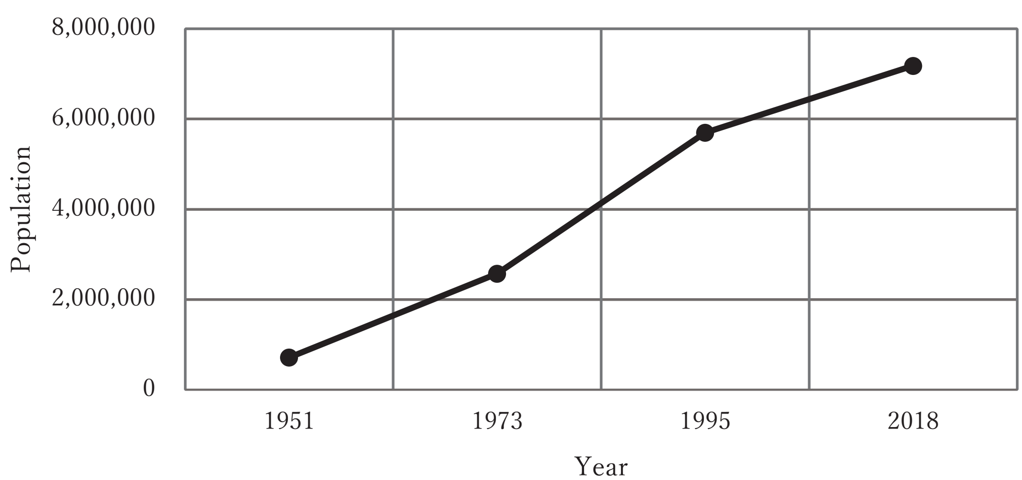

Fig. 3 Population growth in Bogotá.

Source: Alcaldía mayor de Bogotá, 2018 and DANE, 2019

the city where is very hilly filled with narrow streets and steeps (El Tiempo, 2019).

Car license plate recognition was first implemented in 1998 to limit car use during peak hour and to restrict car use to two days a week. Thanks to this, the average speed increased to 25 km/h in 2002 from14 km/h in 1998 (Misas-Arango, 2011).

2.2. Modal distribution and car ownership

According to the 2019 Bogotá Household Transporta-

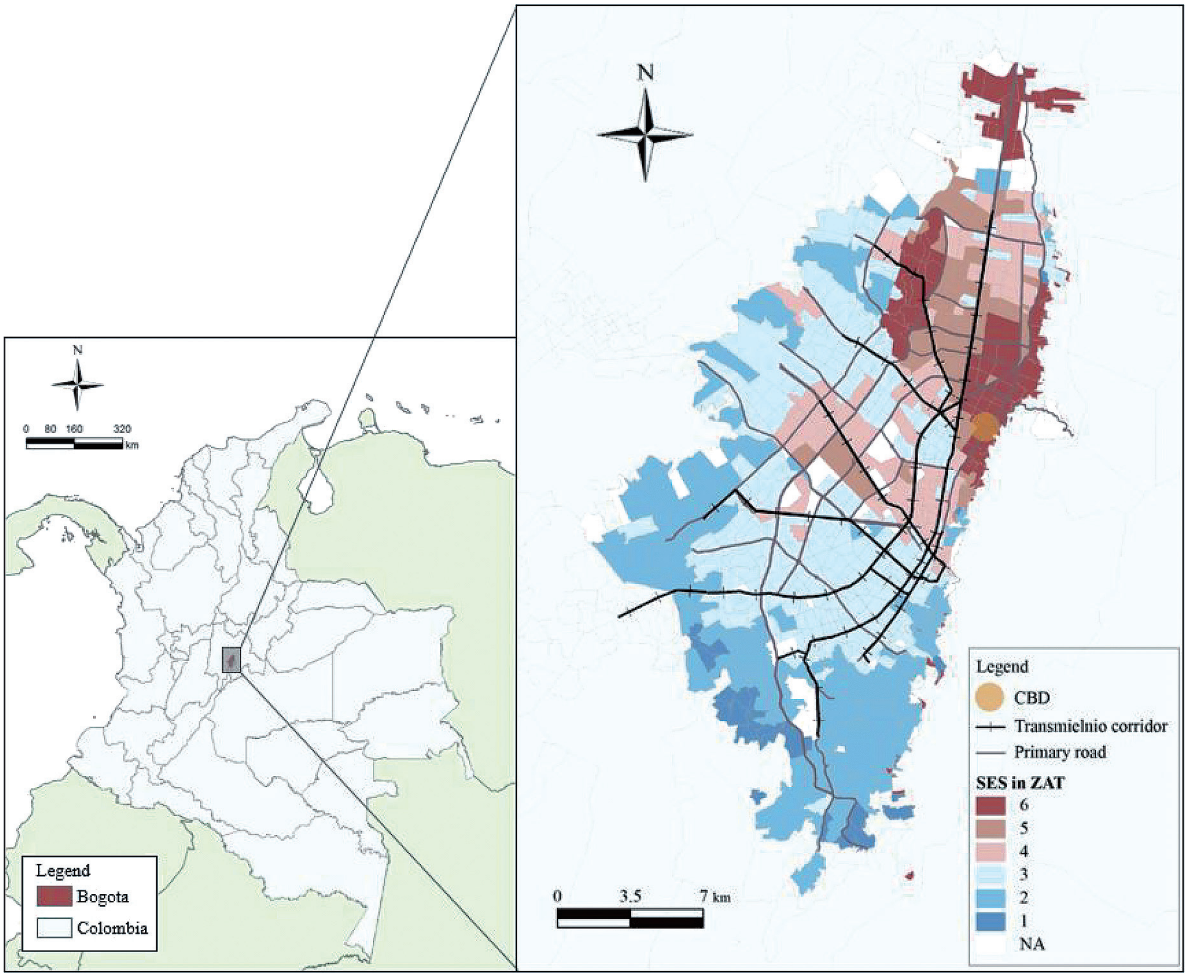

Fig. 4 Study area: Bogotá, Colombia (socioeconomic strata, CBD, Transmilenio corridors and primary road).

Source: Own elaboration with the information provided by Secretaría Distrital de Desarrollo Económico, 2020; Secretaría Distrital de Movilidad, 2020; Secretaría Distrital de Planeación, 2017

Table 2 Public transportation-related data from February 2020.

	Transmilenio	SITP	TransMiCable
System length (km)	114.4	1,890.39	3.3
No. of stations/stops	143	7,516	3
Total trips kms (month)	12,000,000	22,000,000	NA
Total dispatch (month)	606,000	695,000	NA
Average speed (km/h)	25.88	16.98	NA
Fee (Colombia Peso, COP)	$2,500	$2,300	$0

Source: Transmilenio S.A, 2020b

tion Survey, 12,054,288 trips were made in all types of vehicles. Fig. 5 shows the modal share. The most frequent form of transport was SITP (23% of trips), followed by *Transmilenio* (21%). With 3% of trips made by complementary feeder bus, half of all trips were made by public transport. Fig. 6 shows the modal share by SES. In lower SES, the percentage of SITP and *Transmilenio* use was high. In contrast, areas with the higher SES levels, more than 50% of trips were made by private cars.

3. Methods

We used the multinominal logit model[2)] because the dependent variables were all distinct and separable, and not nested, and this is the most common model under these circumstances (Kamruzzaman *et al.*, 2013; Thrane, 2015). To understand the views of high-income residents in Bogotá about different forms of transport and the relationship between these views and travel patterns, we conducted interview surveys with eight high-income residents.

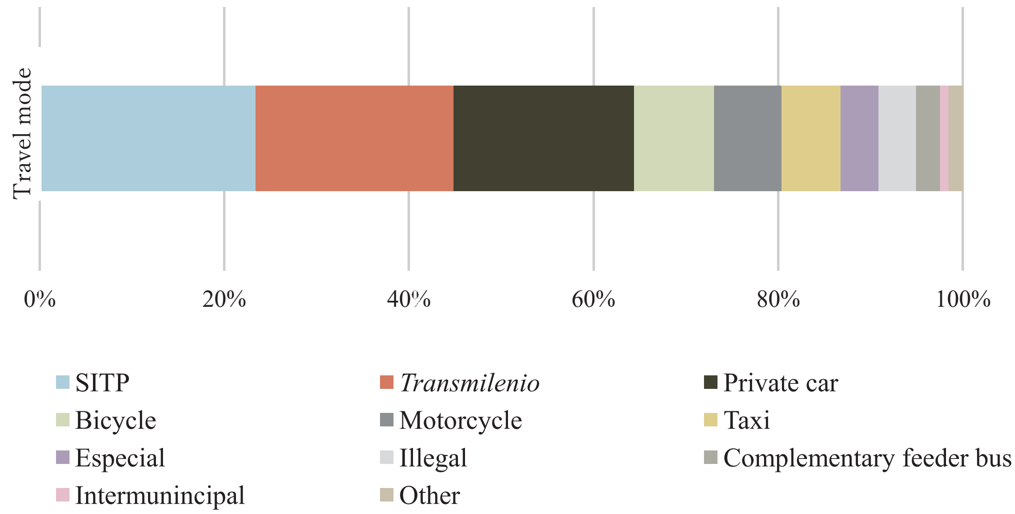

Fig. 5 Modal share of trips in vehicle.

Source: Mobility Secretary of Bogotá, 2019 Household Transportation Survey (Secretaría Distrital de Movilidad, Encuesta de Movilidad de Bogotá 2019)

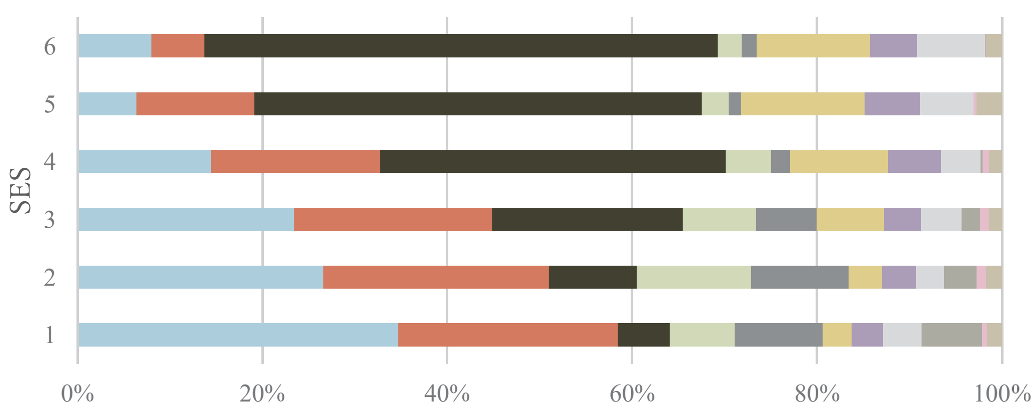

Fig. 6 Modal share of trips in different vehicles by social economic strata (SES).

Source: Mobility Secretary of Bogotá, 2019 Household Transportation Survey.
Note: Legend of this figure is common with Fig. 5.

3.1. Data source

The data used for this analysis were derived from the Bogotá Household Survey 2019 (Secretaría de Movilidad de Bogotá, 2019)[3]. The survey questionnaire includes population characteristics, trip characteristics and origin and destination of each trip. Data were collected from 21,828 households and 142,566 individuals over five years old living in Bogotá and 18 neighboring municipalities (Bojacá, Cajicá, Chía, Cota, El Rosal, Facatativá, Funza, Gachancipá, La Calera, Madrid, Mosquera, Sibaté, Soacha, Sopó, Tabio, Tenjo, Tocancipá and Zipaquirá).

3.2. Data selection

Based on reliable previous studies of this field, (Vergel-Tovar and Rodriguez, 2018; Harbering and Schuter, 2020; Guzman and Bocarejo, 2017) the variables used for this analysis were selected as listed in Table 3.

3.2.1. Dependent variable

The dependent variable was travel mode, which consisted of five categories: car, *Transmilenio*, SITP, taxi and bicycle. These categories were selected based on the frequency of use among the target group in the 2019 Household Survey.

3.2.2. Independent variables

The independent variables used in this model were divided into three groups: (1) socio-demographic, (2)

Table 3 Variables for multinomial regression analysis, including description and source.

Variable	Measurement	Mean	Std. Dev.	Descriptions	Source
Dependent variables					
Travel mode	Categorical			(1) Car, (2) BRT, (3) Bus, (4) Taxi, (5) Bicycle	SDM, 2019
Socio-demographic variables					
Age	Discrete	4.100	1.554	(1) 5-18, (2) 19-25, (3) 26-35, (4) 36-45, (5) 46-60, (6) 61+	BHS, 2019
Gender	Categorical	0.499	0.500	1: male, 0: female	BHS, 2019
Income (COP)	Categorical	6.898	2.347	(1) 0-8280.116, (2) 828.117-1.500.000, (3) 1.500.001-2.000.000, (4) 2.000.001-2.500.000, (5) 2.500.001-3.500.000, (6) 3.500.001-4.900.000, (7) 4.900.001-6.800.000, (8) 6.800.001-9.000.000, (9) 9.000.000+, (10) NA	BHS, 2019
Education level	Categorical	2.462	1.266	(0) non, (1) primary and secondary education, (2) technitian, (3) under-graduate, (4) post-graduate	BHS, 2019
Employment status	Categorical	1.866	1.274	(0) unemployed, (1) employed, (2) student, (3) penstioned/incapacitate, (4) housechores, (5) other	SDM, 2019
No. of children	Discrete	0.644	0.931	No. of children under 18	SDM, 2019
Car availability	Ratio	0.515	0.446	Ratio of vehicles to household member over 18 years	SDM, 2019
Bicycle availability	Ratio	0.359	0.484	Ratio of bicycles to household member over 18 years	SDM, 2019
Travel related variables					
Travel time	Continuous	55.552	58.545	Travel time in minutes	SDM, 2019
Travel cost	Continuous	6652.379	30504.409	Travel cost in COP	SDM, 2019
Travel distance	Continuous	27.887	413.830	Travel distance in km	SDM, 2019
Travel purpose	Categorical	3.794	2.333	(1) work, (2) study, (3) go to home, (4) leisure, (5) shopping, (6) administrative pro-cedures, (7) drop someone off, (8) Other	SDM, 2019
Built environment					
Population density	Ratio	22889.074	12934.065	Population per UPZ area in km2	SDP, 2017
Office density	Ratio	0.046	0.0526	Ratio of office-use plot to total ZAT area	UAECD; SDM,2019
Distance to CBD	Continuous	5.853	2.911	Distance from the centroid of ZAT	SDDE; SDM,2019
Distance to primay road	Continuous	0.403	0.277	Distance from the centroid of each ZAT in km	DANE, 2018; SDM,2019
Pedestrian density	Ratio	0.086	0.031	Ratio of pedestrian to total ZAT area	IDU; SDM,2019
Commerce density	Ratio	0.046	0.061	Ratio of commercial use plot to ZAT area	UAECD; SDM,2019
Distance to BRT station	Continuous	1.021	0.846	Distance from the centroid of ZAT in km	Transmilenio S.A.; SDM,2019
No. of BRT stations	Discrete	0.198	0.502	No. of BRT stations in ZAT	Transmilenio S.A.; SDM,2019
Distance to bus stop	Continuous	0.219	0.218	Distance from the centroid of ZAT in km	Transmilenio S.A.; SDM,2019
No. of bus stops	Discrete	9.700	5.473	No. of Sitp stops in ZAT	Transmilenio S.A.; SDM,2019

travel-related, and (3) built environment variables. The socioeconomic variables included age[4)], gender[5)], income[6)], education level[7)], employment status, the number of children[8)], car availability[9)] and bicycle availability[10)]. Travel-related variables include travel time[11)], travel cost[12)], travel distance[13)], and trip purpose.[14)]

Built environment variables included population density[15)], office density[16)], distance to central business district, distance to primary road[17)], pedestrian density[18)], commerce density[19)] , distance to *Transmilenio* station[20)], the number of *Transmilenio* stations, distance to SITP stop, and the number of SITP stops.

3.2.3. Data collection: qualitative approach

The data for the qualitative analysis were gathered from semi-structured interview surveys with eight high-income households in Bogotá. We aimed to choose households with access to cars but located in neighborhoods with different characteristics to understand how the built environment at neighborhood level would affect individual transport choices.

This survey was divided into four sections: (1) household and members, (2) travel frequency by mode, (3) perceptions about each mode, and (4) opinion about possible improvements. For travel frequency in section 2, we asked about travel behaviors before the COVID-19 pandemic, because many people changed their behaviors as a result. For the same reason, we did not ask for more detailed information about daily and weekly travel behaviors. We interviewed eight people in three households. Interviews lasted from 20 to 30 minutes each. Information was noted during the interviews.

4. Results

4.1. Descriptive analysis

Table 4 shows the sample size and modal split for Bogotá. It shows that car is the dominant mode of travel among wealthy households in Bogotá. Of 15,442 trips included in the analysis, 49.3% were by private car. In total, 30.8% of trips were by public transport, including 19.0% by *Transmilenio* and 11.8% by SITP. In total, 13.0% of trips involved taxi, and only 6.9% were by bicycle despite government initiatives.

Fig. 7 compares modal share by age group. Younger people (19–25 years) reported greater use of public transport, with 33% of trips by *Transmilenio* and 17% by SITP, compared with 31% by car. However, up to age 46–60 years, car use increased with age. Children aged 5–18 probably travel with their parents, because their modal distribution is like those aged 26–35 and 36–45 years, the most likely ages for their parents. The proportion of car trips was slightly lower among those aged 61 years and over, compared with that of those aged 46–60 years, but the percentage of taxi trips was the highest in this age group.

Fig. 8 shows that the choice of car or public transport

Table 4 Modal split among high-income households in Bogotá.

Travel mode	Number	%
Car	7,615	49.3
Transmilenio	2,934	19.0
SITP	1,817	11.8
Taxi	2,006	13.0
Bicycle	1,070	6.9
Total	15,442	100.0

Source: Secretaría Distrital de Movilidad, 2020

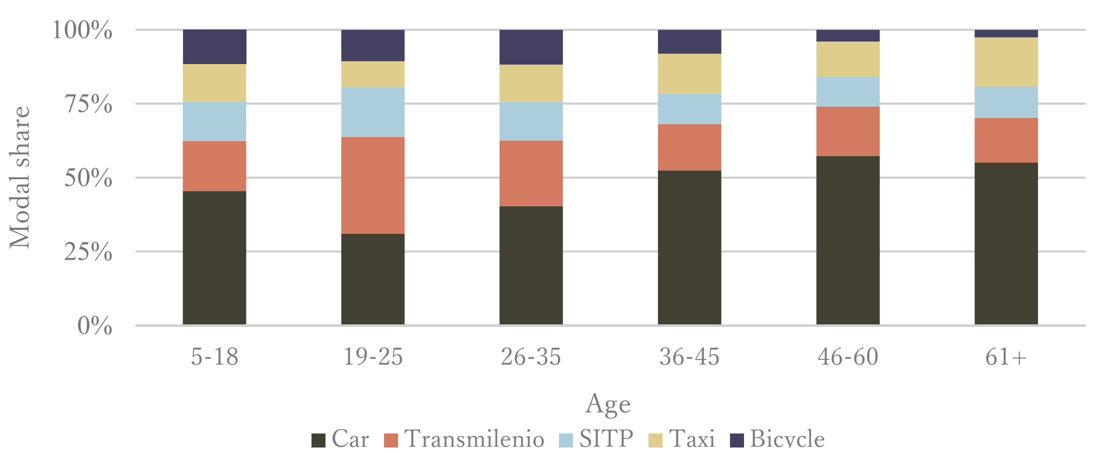

Fig. 7 Distribution of modal share by age among high-income households in Bogotá

Source: Developed from information provided by Secretaría Distrital de Movilidad, 2020

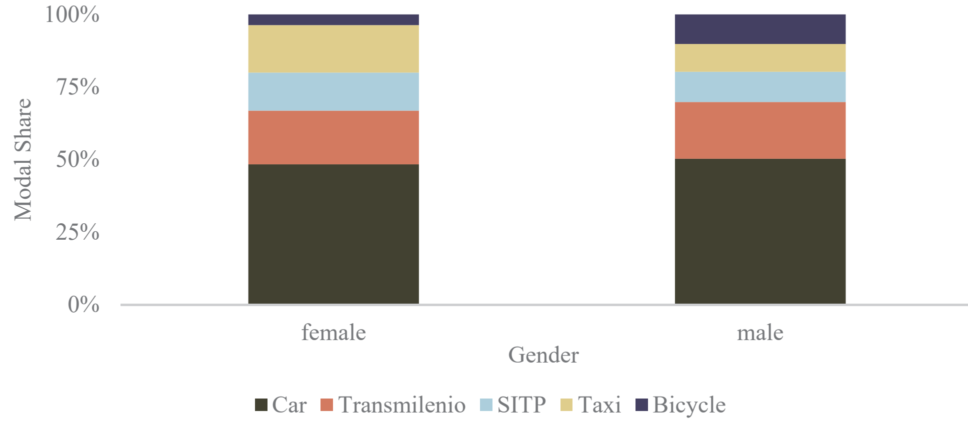

Fig. 8 Distribution of modal share by gender among high-income households in Bogotá.

Source: Developed from information provided by Secretaría Distrital de Movilidad, 2020

did not vary significantly between men and women. However, men were more likely to use bicycles, and women were more likely to use taxis. Women are also less likely to travel by bicycle because they tend to be more concerned about personal security. The conservative culture of Latin America may also discourage women from travelling by bicycle (Harbering and Schuter 2020).

Fig. 9 describes modal share by travel purpose. It shows that people tend to commute to study by public transport. The percentage of public transport use in trips between work and home are slightly lower, but still relatively high compared with that in trips for other purposes. People therefore tend to use public transport more for daily commuting, but cars for weekend activities such as shopping trips.

4.2. Regression analysis

Table 5 shows the odds ratios of the regression model. The chi square test confirmed that the model was appropriate. The coefficients of all variables in the final model were all significant except the number of bus stops, and therefore this was omitted from the regression analysis. The reference for travel mode was car.

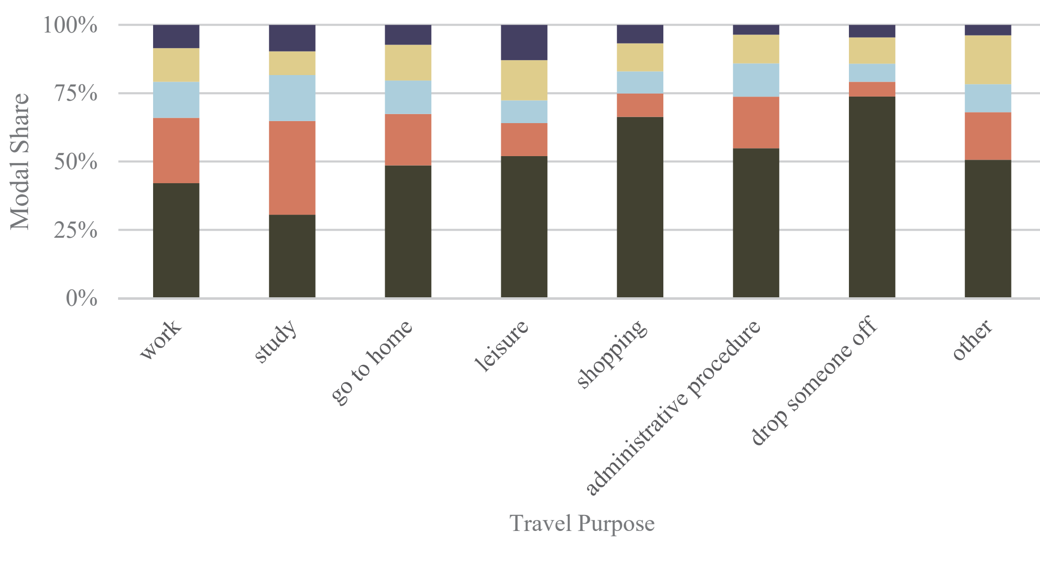

Fig. 9 Distribution of modal share by travel purpose among high-income households in Bogotá.

Source: Developed from information provided by Secretaría Distrital de Movilidad, 2020

Table 5 Multinomial regression results for mode choice for trips (odds ratios).

	Dependent variable: Car (1)											
	(2) *Transmilenio*			(3) *Bus*			(4) *Taxi*			(5) *Bicycle*		
	Exp (B)	SE		*Exp (B)*	SE		*Exp (B)*	SE		*Exp (B)*	SE	
Socio-demographic variables												
Age group												
5–18 years	1.146	0.379		1.482	0.023	**	1.325	0.100		3.703	0.000	***
19–25 years	2.368	0.000	***	2.033	0.000	***	0.957	0.735		5.096	0.000	***
26–35 years	1.471	0.000	***	1.493	0.000	***	0.948	0.584		4.814	0.000	***
36–45 years	0.973	0.779		1.133	0.262		0.906	0.314		3.167	0.000	***
46–60 years	0.969	0.703		0.909	0.315		0.727	0.000	***	1.467	0.016	**
Gender (female)	0.995	0.926		1.291	0.000	***	1.650	0.000	***	0.370	0.000	***
Income range												
0–8,280,116)	3.035	0.000	***	2.746	0.000	***	1.836	0.005	***	1.890	0.018	**
828,117–1,500,000	2.425	0.000	***	2.416	0.000	***	2.152	0.000	***	2.227	0.000	***
1,500,001–2,000,000	1.874	0.000	***	1.479	0.015	**	1.641	0.001	***	2.802	0.000	***
2,000,001–2,500,000	1.339	0.017	**	1.562	0.001	***	1.236	0.113		1.427	0.047	**
2,500,001–3.500.000	1.318	0.005	***	1.222	0.071	*	1.039	0.727		1.120	0.432	
3,500,001–4,900,000	1.450	0.000	***	1.413	0.001	***	1.167	0.143		0.919	0.565	
4,900,001–6,800,000	1.044	0.635		1.009	0.932		0.905	0.313		0.756	0.043	**
6,800,001–9,000,000	0.908	0.340		0.841	0.136		1.079	0.460		0.674	0.008	***
9,000,000+	0.768	0.005	***	0.621	0.000	***	1.014	0.882		0.765	0.047	**
Education												
None	0.653	0.008	***	1.129	0.466		0.711	0.032	**	2.409	0.000	***
Primary and secondary education	1.038	0.637		1.314	0.003	***	0.843	0.044	**	3.141	0.000	***
Technician	1.222	0.054	*	1.263	0.060	*	1.055	0.638		3.391	0.000	***
Undergraduate	0.942	0.382		1.004	0.961		0.853	0.024	**	1.759	0.000	***
Employment status												
Unemployed	0.600	0.043	**	0.658	0.110		1.409	0.123		0.434	0.023	**
Employed	1.032	0.785		0.868	0.261		1.050	0.700		1.202	0.297	
Student	1.196	0.210		0.894	0.476		0.991	0.958		0.822	0.334	
Pensioner/unable to work	0.777	0.082	*	0.662	0.010	**	0.892	0.443		0.848	0.517	
Stay at home parent	0.742	0.033	**	0.698	0.016	**	1.152	0.317		0.977	0.919	
No. of children	0.958	0.135		0.955	0.170		0.892	0.001	***	1.018	0.659	

Table 5 Multinomial regression results for mode choice for trips (odds ratios) (Cont.)

	Dependent variable: Car (1)											
	(2) *Transmilenio*			(3) *Bus*			(4) *Taxi*			(5) *Bicycle*		
	Exp (B)	SE		*Exp (B)*	SE		*Exp (B)*	SE		*Exp (B)*	SE	
Socio-demographic variables												
Car availability	0.124	0.000	***	0.113	0.000	***	0.149	0.000	***	0.070	0.000	***
Bicycle availability	0.968	0.604		0.870	0.066	*	0.984	0.813		2.459	0.000	***
Travel-related variables												
Travel time	1.008	0.000	***	1.007	0.000	***	0.995	0.000	***	0.991	0.000	***
Travel cost	1.000	0.000	***	1.000	0.000	***	1.000	0.001	***	1.000	0.000	***
Travel distance	1.000	0.006	***	1.000	0.059	*	1.000	0.592		0.957	0.000	***
<u>Travel purpose</u>												
Work	1.672	0.000	***	1.749	0.000	***	0.927	0.403		2.407	0.000	***
Study	2.310	0.000	***	1.985	0.000	***	0.775	0.127		2.031	0.000	***
Going home	1.036	0.633		1.199	0.040	**	0.767	0.000	***	1.512	0.002	***
Leisure	0.657	0.015	**	0.787	0.223		0.874	0.386		2.755	0.000	***
Shopping	0.420	0.000	***	0.673	0.020	**	0.425	0.000	***	1.191	0.414	
Administrative purposes	0.951	0.664		1.080	0.572		0.519	0.000	***	0.840	0.445	
Drop someone off	0.222	0.000	***	0.501	0.000	***	0.387	0.000	***	0.657	0.052	*
Built environment variables												
Population density	1.000	0.044	**	1.000	0.000	***	1.000	0.433		1.000	0.334	
Office density	0.907	0.871		6.013	0.007	***	3.845	0.026	**	3.916	0.104	
Distance to central business district	1.087	0.000	***	1.013	0.351		0.954	0.000	***	0.961	0.028	**
Distance to primary road	0.854	0.267		0.933	0.648		0.715	0.031	**	2.159	0.000	***
Pedestrian density	0.632	0.681		51.091	0.002	***	1.020	0.987		17273.021	0.000	***
Commerce density	0.301	0.021	**	1.087	0.868		0.622	0.305		0.333	0.123	
Distance to BRT station	0.567	0.000	***	1.361	0.000	***	0.947	0.247		0.989	0.878	
No. of BRT stations	1.136	0.013	**	1.050	0.449		1.063	0.269		1.149	0.057	*
Distance to bus stop	0.842	0.405		0.522	0.002	***	0.763	0.248		0.662	0.150	
N	15442											
Prob > chi2	0.000											
Nagelkerke R2	0.382											

Note:*p<0.1; **p<0.05; ***p<0.01

4.2.1. Socio-economic variables

The socio-economic variables suggest an intuitive pattern. Younger people and lower income groups were more likely to use public transport or bicycles than cars. Groups with higher income and higher car availability were more likely to use cars.

We found that younger groups (those aged 19–35 years), particularly student age (19–25 years), were significantly more likely to use public transport, including both *Transmilenio* and SITP. This group tends to have lower access to cars, and public transport is attractive because of its low cost. They are also more likely to commute by bicycle, bicycle-use decreases as age increases.

Many studies (Guerra 2014; Harbering and Schuter, 2020; Zegras, 2010) have found that people with access to cars are strongly attached to their use. Car availability is highly and positively correlated with both car use and low likelihood of use of alternative means of transport. Higher income groups were also positively associated with car use, and lower income groups were more likely to use alternatives.

4.2.2. Trip-related variables

The results suggest that travel cost, and distance do not play important roles in choosing travel mode. Guzman and Bocarejo (2017) also found that there were no significant differences in travel time and cost between car and other transport means in Bogotá, because of the heavy traffic in the city. Access to a car therefore does not necessarily reduce travel time.

We found that public transport was more likely to be used for commuting, and cars for weekend activities. Commuting was positively correlated with the use of public transport, especially for students, but also more generally. Cars may also be preferred for shopping because Bogotá has several big shopping malls in wealthy parts in the city.

4.2.3. Built environment variables

Many studies across Latin America have shown a negative relationship between car use and access to public transport (Guerra, 2014; Harbering and Schuter, 2020; Zegras, 2010). However, we found no consistent correlation among the variables related to access to public transportation. Distance to both BRT and standard buses were negatively associated with their use. This may be due to distribution of car availability (Fig. 10). Sectors with higher car availability tend to be located along *Transmilenio* corridors. Guzman and Bocarejo (2017) assessed accessibility per capita by different means of transport in Bogotá and found that there were similar geographical patterns for access to cars and *Transmilenio*. That means that people living close to stations also have access to cars and prefer to use their cars.

Trips by SITP and bicycle were strongly correlated with pedestrian density. People feel safer cycling, or walking to bus stops, in areas with large numbers of pedestrians (Vergal-Tovar and Rodriguez 2018)[21]. Pedestrian access is an important factor in stimulating the use of public transport.

Office density (Fig. 11) was positively associated with SITP use. Many people living in sectors with many offices work locally, therefore they prefer the SITP to *Transmilenio*. This suggests that SITP and *Transmilenio* are used for different purposes.[22]

5. Discussion and Conclusions

This research examined two questions with the case of Bogotá:

- How much impact does a BRT scheme have on car use? and
- How can a BRT scheme have a greater impact on car use?

We discuss the results of this research to suggest possible solutions for improvements.

5.1. Effect of the BRT on car use

In the global South, BRT schemes are a popular solution to improve public transport. However, when these schemes are not efficient, their effect is also limited. In Bogotá, the *Transmilenio* has had limited effect on car use among high income households. In line with previous research, both quantitative and qualitative results showed the strong relationship between car availability and use. The qualitative analysis showed that people value security and comfort most highly when choosing travel mode, which leads them towards car use. Both the *Transmilenio* and SITP were perceived as insecure, uncomfortable and unpunctual. This explains the inconsistent relationship between proximity to public transport and its use.

We found several factors that stimulate use of public transport: (1) older people were more likely to use cars, and those of student age (19–25 years) were more likely to use public transport due to economic constraints although they consider the *Transmilenio* to be insecure and uncomfortable: (2) higher office density was positively associated with greater SITP use; (3) pedestrian density was positively correlated with both SITP and bicycle use because it can increase security for bikers.

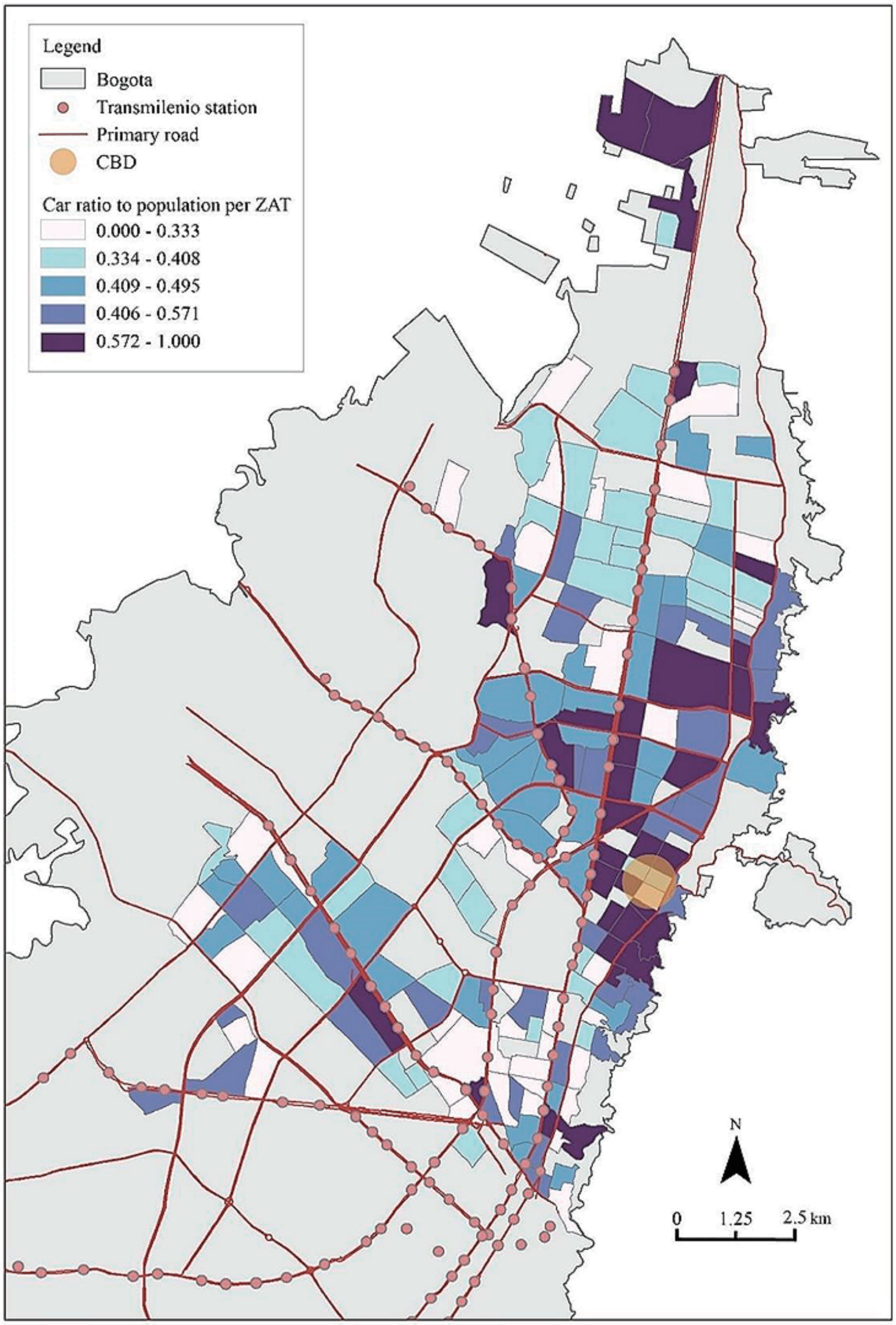

Fig. 10 Car availability per ZAT in high-income sectors in Bogotá.

Source: Developed from information provided by Secretaría Distrital de Movilidad, 2020

5.2. Improvement of public transport: implications for policy

The results suggest several possible improvements for public transport in Bogotá: (1) To focus on younger and middle-income people to increase future and longterm use of public transport, (2) to increase security and comfort of public transport to satisfy needs of users, (3) to increase punctuality of public transport by introducing fixed timetables, (4) to reorganize SITP routs to utilize blank areas of *Trasnmilenio*, and (5) to improve bicycle lanes both in quality and quantity.

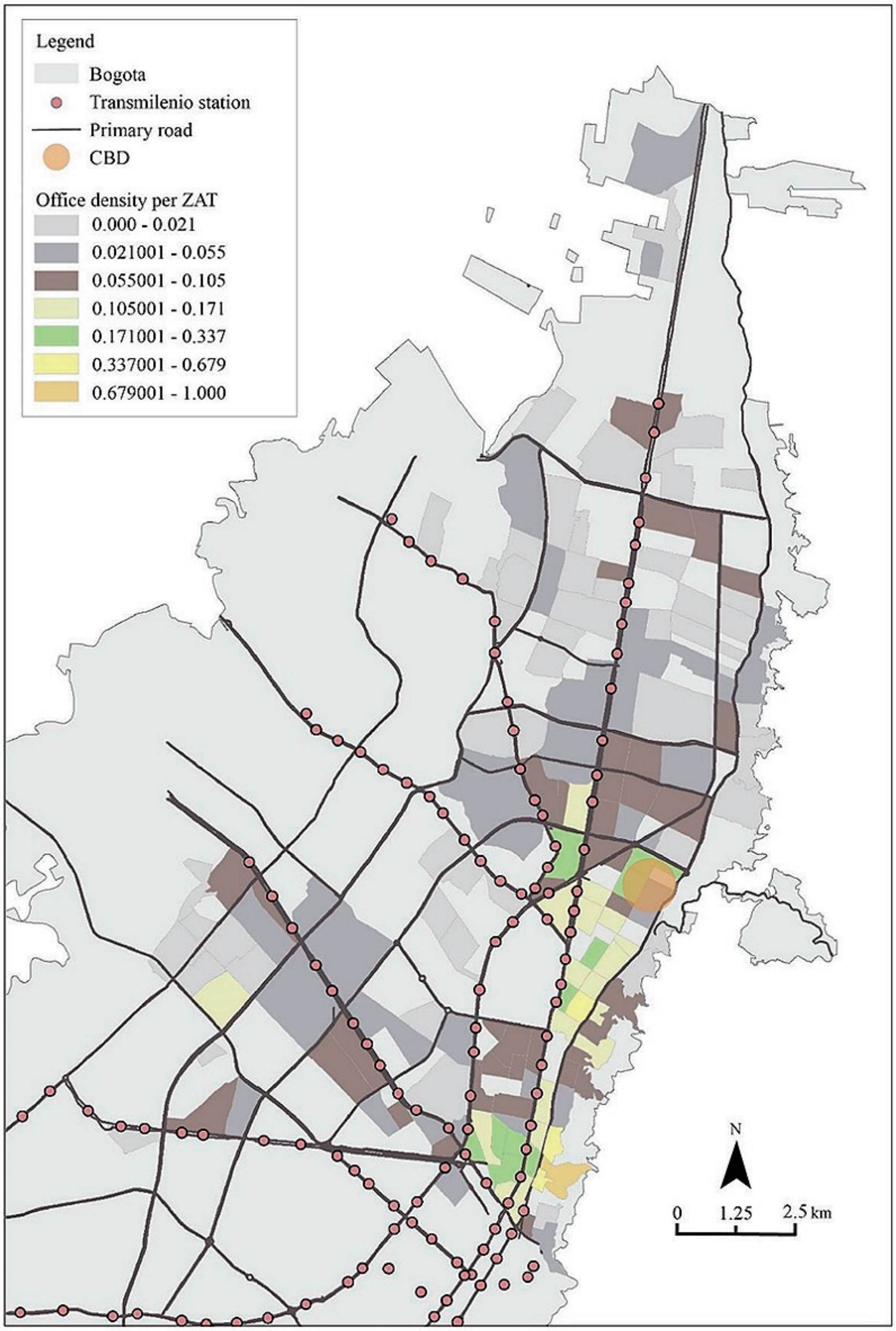

Fig. 11 Office density per ZAT in high income sectors in Bogotá.

Source: Developed from information provided by Unidad Administrativa Especial de Catastro Distrital, 2020

5.2.1. Focus on younger and middle-income people

Adults in high-income households showed solid car use attachment. However, younger people, even in high-income groups, tend to take public transport more often. It is therefore crucial to keep them using public transport, even when their income increases, and cars become more accessible. Similarly, it may be helpful to focus on middle-income groups, as potential high-income earners. This group is expanding with economic growth in developing countries, and therefore increase in car ownership is inevitable. Government should develop transportation policies to make public transport more attractive among potential car users.

5.2.2. Increase security and comfort of public transport

The qualitative analysis showed that commuters valued security and comfort and perceived that public transport in Bogotá lacked these two elements. Both *Transmilenio* and SITP were often described as "crowded and "dangerous". Despite this, the government's recent transportation plan focuses on accessibility rather than security and comfort. This is because the local government is more concerned about emerging low-income groups in the periphery of the city. Improved accessibility may indirectly improve the security and comfort, because more capacity can alleviate overcrowding and therefore improve security. However, we suggest that a more direct approach is needed to security and comfort. For instance, both adults and children require education about public transport etiquette, and pedestrian infrastructure needs to be improved. Recent local government campaigns have focused on sexual harassment of women. That should improve safety, but no action has yet been taken to reduce robberies. Better pedestrian infrastructure may improve security around stations. More research is needed to determine effective ways to improve security, and to change the negative image of public transport.

5.2.3. Fixed timetables

Public transport in Bogotá is generally unpunctual and unreliable. Commuters claimed that there were long waiting times and lack of consistency on travel frequency of buses. However, no effort has been made to change this. The recent transportation plan does not mention improved frequency. We recommend implementing fixed timetables, which would not require much financial investment.

5.2.4. Organize SITP routes

The government's new transport plan provides for increased numbers of SITP buses. However, it may be more efficient to provide more appropriate bus routes. Our results suggest that the SITP is used differently from *Transmilenio*, and the two should therefore be considered as complementary. Better information and reform of SITP routes may therefore be helpful.

5.2.5. Increased numbers of bicycle lanes

More bicycle lanes may increase travel by bicycles. The new transport plan includes increasing the number of bicycle lanes, and creating a 'green road' on Seventh Street. Bicycle parking at stations may also increase *Transmilenio* use by improving access to stations. Bicycles have a better image than public transport, even among high-income households. If better bicycle lanes can achieve a reduction in traffic accidents and robberies, bicycles could become a more popular means of travel.

5.3. Concluding remarks

We identified the extent to which a BRT scheme affects car use, and which aspects determine mode choice between public transport and car. However, more research is required to assess efficient ways to improve security and comfort on public transport to help decision makers in cities in developing countries.

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Notes

1) In Bogota, as well as other cities in Colombia, residential land is classified in six levels named socio-economic strata (SES). It goes from 1 to 6, where 1 is the most vulnerable and 6 is the wealthiest. Total study area of the Bogota Household Survey 2019 is divided in transportation analysis zone (ZAT: zonas de análisis de transporte). Origen-destine matrix is made in this ZAT level.
2) To assess the effects of individual socio-economic status and the quality of the built environment on the choice of travel mode, researches adopted the multinominal logit model, the nested logit model, or the linear regression model (Ao et al., 2020).
3) This was run by the Mobility Secretary of Bogotá (Secretaría de Movilidad de Bogotá) with the help of C & M Consultores S.A. The principal objectives of this survey were to update the transportation model and understand the dynamics of mobility in Bogotá. The 2019 Survey was the fourth Household Survey in Bogotá since 1995.
4) Age was converted into categorical variables and grouped into (1) 5–18 years, (2) 19–25 years, (3) 26–35 years, (4) 36–45 years, (5) 46–60 years and (6) 61 years and over.
5) Gender was a dummy variable of (1) male and (0) female.
6) Income was only available as categorical data in the Household Survey data set: (1) 0–8280,116, (2) 828,117–1,500,000, (3) 1,500,001–2,000,000, (4) 2,000,001–2,500,000, (5) 2,500,001– 3,500,000, (6) 3,500,001–4,900,000, (7) 4,900,001–6,800,000,

(8) 6,800,001–9,000,000, (9) 9,000,000 and over, and (10) not available or no data. The target group was households from SES 4, 5 and 6, but SES is not directly associated with income, and therefore the study included some households from lower income groups. Group (10) was not included in the analysis.

7) Education level was divided into five categories: (0) none, (1) primary and secondary education, (2) technician, (3) undergraduate, and (4) post-graduate.
8) The number of children included all those under 18 years old within a household.
9) Car availability was estimated by dividing the number of cars available in a household by the number of members over 18 years old.
10) Bicycle availability was the ratio of the number of bicycles to household members over six years old.
11) Travel time was calculated from the start and finish time of each trip in minutes.
12) Travel cost included expenses during the trip and any parking fees. It is shown in COP (1 USD = 3,522.44 COP, 2019).
13) Travel distance was measured using GIS, with a centroid of ZAT of origin and the counterpart of destination.
14) Trip purpose was given as categorical variables: (1) work, (2) study, (3) going home, (4) leisure, (5) shopping, (6) administrative purposes, (7) drop someone off, and (8) other.
15) Data for population density were only available at the level of Unidades de Planeamiento Zonal (UPZ), which is a higher level than ZAT. The data were derived from Encuesta Multipropósito 2017 published by the Planning Secretary. The total population of each UPZ was divided by the total area of the UPZ in km^2, obtained from GIS. This was linked to ZAT data.
16) Office density was based on data from the Special Administrative Unit of District Cadaster. Office use plot was identified then divided by the total area of the ZAT in km^2.
17) For the distance to the nearest primary road, we measured distance from the centroid of the ZAT to the closest point on a primary road. The primary road data were taken from the 2018 National Census.
18) Pedestrian density was the ratio of the total area available to pedestrians in km^2 to the total ZAT area in km^2. The Urban Development Institute provided a polygon shapefile of pedestrian areas.
19) Commerce density was captured by identifying the central business district using the Aglomeraciones económicas data set from the Economic Development Secretary (Secretaría Distrital de Desarrollo Económico, 2020). Distance from the centroid of ZAT to central business district centroid was measured in km.
20) Distance to Transmilenio station and distance to SITP stop were measured as the distance from the centroid of the ZAT to the closest Transmilenio station or SITP stop in km. We counted Transmilenio stations and SITP stops within the ZAT, using data from Transmilenio S.A.
21) Vergal-Tovar and Rodriguez (2018) assessed BRT use and the built environment around stations in Latin-American cities and argued that low pedestrian infrastructure led to lower BRT use.
22) Other studies have found significant correlations with other factors. For example, distance to the central business district, job, and population density were all negatively correlated with car use (Zagras, 2010). Proximity to a major highway was positively correlated with both car use (Guerra, 2014) and metro and bus use (Harbering and Schuter, 2020).

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