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Housing prices, buses and trams in Medellín (Colombia)

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Abstract: This paper aims to establish the impact of two medium-capacity transportation systems (MCTS) on housing prices in Medellín (Colombia): Metroplús, a bus rapid transit (BRT) system, and Tranvía, a tramway system. Using repeated cross-sectional data from the Medellín Quality of Life Survey from 2008 to 2018 and difference-in-differences estimators, we find that Metroplús has a negative impact on the growth of rental prices, whereas Tranvía has a positive impact. We do not find any effect on several other outcomes, such as the perception of quality and coverage of the public transportation in the neighborhoods they serve, and the number of private vehicles in the household.

Keywords: Public transportation, MCTS, real state prices.
JEL CLASSIFICATION: R40, R58

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1. Introduction

Public transportation plays a critical role in the formation, working, and growth of cities. It is central to the decision of localization within urban areas because it provides access to all the benefits they offer, from jobs to physical amenities such as parks, libraries, and schools. As a result, the organization of economic activity and the urban quality of life within a city are crucially dependent on the transportation system. Theoretically, transportation is also associated with a range of externalities that can offset its positive impact: congestion, pollution, noise, and visual disamenities (Blomquist, 2006, Ahfeldt, Nitsch, and Wendland, 2019). Beyond its direct effect on accessibility, urban transport infrastructure is also crucial for public finance. As one of the largest public expenditure projects for local governments, financed to a great extent by the taxes collected if it generates a positive land value uplift (LVU) (Ahfeldt, 2011). Consequently, establishing how transport improvements affect different dimensions of citizens' welfare, like housing prices, is an important public policy issue.

Despite its importance, only half of the urban residents have convenient access to public transport. This, combined with the need to create low-carbon, resilient, and inclusive cities, means that urban transportation will require major investments in the future, especially in cities that do not have rail systems. In such cases, Medium-Capacity Transport-Systems (MCTS) will be fundamental to achieving a sustainable transport pattern (UN-Habitat, 2020). MCTS cover a wide range between low and high-capacity systems. They operate in streets with mixed traffic, using a reserved right-of-way, physically separated by curbs, barriers, or grade separation from other traffic, but with grade crossings for vehicles and pedestrians, including regular street intersections (Novales, Orro, Conles, and Anta, 2011).

This paper aims to study the impact that accessibility to Metroplús and Tranvía de Ayacucho, two MCTS, had on housing prices in Medellín[1]. We measure accessibility as the proximity to the closest station and follow the standard Rosen (1974) theoretical framework that estimates the value consumers attribute to different amenities through their willingness to pay (WTP) for their homes. Our identification strategy uses repeated cross-sectional data from the Medellin Quality of Life Survey (QLS) from 2008 to 2018, the City's Zoning Plans (Planes de Ordenamiento Territorial - POT) 2006 and 2014 (Alcaldía, 2015), and demographic statistics from the National Administrative Department of Statistics (DANE).

To estimate the effect of Metroplús and Tranvía we compare rental prices in treated areas and in control areas in a difference-in-differences setup. We define geographical areas that are treated by each MCTS. Our baseline treatment definition considers all properties located within three buffers of the closest station: 300 m, 600 m, and 900 m. For the control area we consider all properties located beyond 900 m from the closest station. In both cases, we use the year when each system started operating as the moment of treatment, to capture the uncertainty associated with public project completion in the city. The results show a negative effect of the BRT and a positive effect of the Tramway on housing prices.

[1]Metroplús is a Bus Rapid Transit (BRT) and Tranvía is a tramway (also known as a street railway).

In order to understand the mediating mechanisms behind the causal relationship between MCTS and housing prices, we also explore their effect on ownership of private vehicles and the perception of coverage and quality of public transportation as well as safety and noise, air, and visual pollution in the area that capitalize on housing prices (Ahfeldt *et al.*, 2019). To do so, we use information from the perception section in the QLS. We find that neither of the systems had an effect on the ownership of cars and motorcycles or the perception of the quality and coverage of public transportation in their neighborhood. Additionally, we analize the Origin-Destination Survey of Medellín (2017) and find that while there has been a lot of investment in public transportation in the city, people still prefer walking, using regular buses, and private vehicles.

Our research has policy implications. Among MCTS, BRTs are the most widely spread. Over the last two decades, BRTs have gained popularity worldwide as an effective alternative for sustainable urban transportation due to their lower cost, flexible implementation, and ability to transport big masses of people in similar times compared to rail systems[2]. Empirical literature in the field of engineering suggests that while the construction of railway infrastructure is generally more expensive, experts differ concerning operational costs. Brunn (2005) finds that although BRT systems have lower per-mile expenses to build, their annual operating costs are about 24% higher than any type of rail transport, making it less cost-efficient in the long run. As Yang, Chu, Gou, Yang, Lu, and Huang (2019), Zhang, Yen, Mulley, and Sipe (2020) point out, this calls for new research to determine the real effects of BRTs on different dimensions of social welfare compared to other types of transportation systems, allowing planners to make more informed decisions.

We contribute to the existing literature by comparing the effects of a BRT system with a tramway, similar in capacity, speed, and the communities they serve inside the same city. To our knowledge, this is the first paper to carry out a comparison of MCTSs. Medellín, a city famous for proving the power of public investment to remake the fortune of a city, is a good field of research for our purpose. The evidence we find for this densely populated, highly polluted city with a fast-growing population[3], and significant congestion problems (characteristics of other cities in the Global South) can be useful for urban planners.

The literature on the effects of BRT systems on housing prices focuses on case studies of different cities in China (Deng and Nelson, 2013, Zhang and Wang, 2013, Zhang, Meng, Wang, and Xu, 2014, Ma, Ye, and Titheridge, 2014, Salon, Wu, and Shewmake, 2014, Pang and Jiao, 2011, Deng, Ma, and Nelson, 2013, Yang *et al.*, 2019) and the Transmilenio System in Bogotá, Colombia (Targa, 2003, Rodríguez and Targa, 2004, Perdomo, Mendoza-Álvarez, Mendieta-López, and Baquero-Ruiz, 2007, Rodríguez and Mojica, 2009, Munoz-Raskin, 2010, Perdomo, 2015, 2017). The rest of the studies were carried out in Australia (Mulley and Tsai, 2016, Mulley, Ma, Clifton, Yen, and Burke, 2016, Zhang *et al.*, 2020), the United States ((Cervero and Duncan, 2002, Perk and Catalá, 2009, Curley, 2012), South Corea (Cervero and Kang, 2011), Canada (Dubé, Des Rosiers, Thériault, and Dib, 2011) and Argentina (D'Elia, Grand, and León, 2020). The evidence in Latin

[2]According to GlobalBRTData, as of August 2022, there are 182 cities in the world with a BRT system in operation, 21 of which are expanding, and 51 cities that are constructing or planning one for the coming years.

[3]Medellín adds about 50,000 people per year.

America focuses on capital cities such as Bogotá and Buenos Aires. Most studies find a positive effect, although the zero effect found in Los Angeles (Cervero and Duncan, 2002), as well as the negative effects found in Beijing (Zhang and Wang, 2013, Zhang *et al.*, 2014), and Bogotá (Munoz-Raskin, 2010), suggest that the negative effects of BRTs can be a complex phenomenon and not just a local effect, explained by the dependence to private vehicles as in the case of Cervero and Duncan (2002). Although we find no empirical evidence specific to tramways, there is extensive literature on commuter, heavy rail, and light rail transit. This evidence is mixed. Gupta, Van Nieuwerburgh, and Kontokosta (2022) find price increases of 8% around the Q-Line in New York City while Ransom (2018) finds a positive impact for one station, negative impacts for two stations, and no impact for the rest, when studying a new light rail in Washington. In the latter case, the author argues that the system was not a significant improvement relative to the bus lines that serviced previous to the LRT, and because of it there was not a significant LVU. According to the literature, commuter rail and heavy rail premiums are 9.6% and 4.0% higher than light rail premiums, respectively (for a meta-analysis on the effects of rail transit on housing prices see Rennert (2022)).

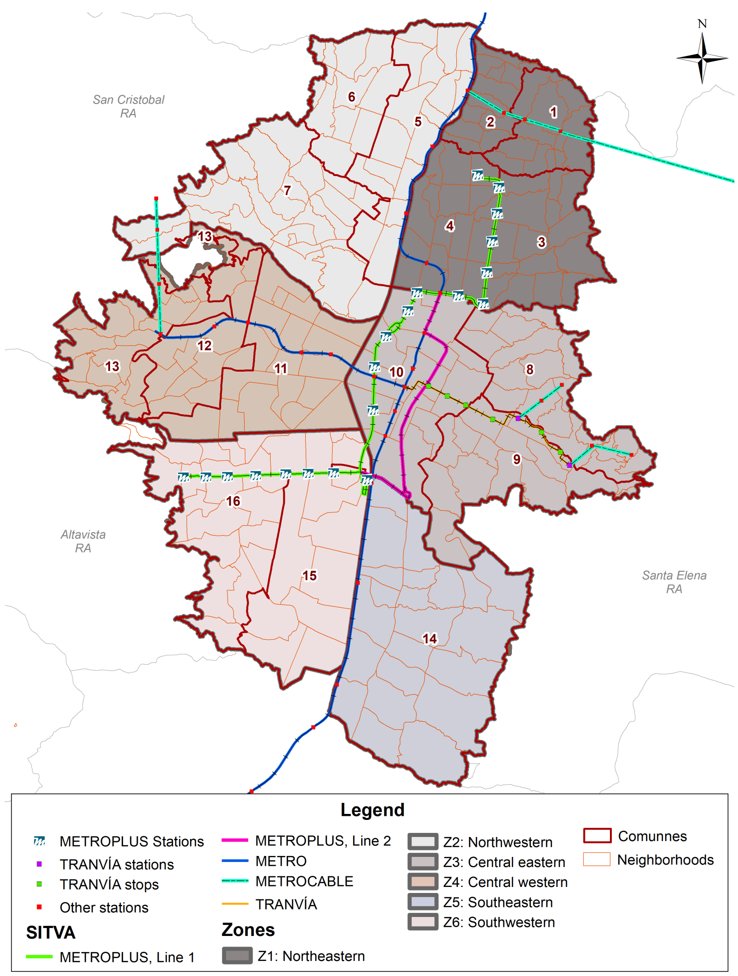
Regarding the overall effects of the systems, recently, Brooks and Denoeux (2022) identify three key conditions under which transit retrofitting could successfully occur, stating that transit needs all three to hold, to stand a fighting chance: (i) the mass transit option must exceed the speed of the private car; (ii) mass transit must serve sufficiently dense areas; and (iii) mass transit must take people where they want to go. To reach this conclusion, the authors compare two BRT systems: Transmilenio in Bogotá and Jarkarta's BRT system. The former is one of the most studied systems in the world, widely cited as a success: Tsivanidis (2022), for example, finds a welfare gain in the city of about 57% only from travel time saved. Jakarta's BRT system has a different story. According to Gaduh, Gračner, and Rothenberg (2022), proximity to the stations neither reduced vehicle ownership nor travel times, and it did not increase commuter flows. We analyze our results in light of these conditions.

The rest of this paper is organized as follows. Section 2 presents background information on public transportation improvements in Medellín. Section 3 focuses on the empirical framework. Section 4 shows the main findings and a discussion on mechanisms, and Section 5 concludes.

2. Public transportation improvements in Medellín

Medellín is in the northwestern part of Colombia, in the Aburra Valley. With a population of around 2.8 million people and a metropolitan area of close to 4 million, it is the country's second-largest city. Its urban area covers 105 km^2, making it the third most densely populated city in the world, according to the World Economic Forum (2017). The city has 6 zones, 16 boroughs, and 249 neighborhoods (Figure 1). One of its most important public policies is the SITVA (Sistema Integrado de Transporte del Valle de Aburra), an integrated system of transportation created to solve the city's mobility problems and achieve sustainable urban transportation. The SITVA began operating with lines A and B of its Metro train system in 1995 and 1996, respectively. In 2000, additional systems were planned to generate massive corridors and connect the suburbs and the hillside neighborhoods to the Metro, in a fishbone design. As part of this initiative, the Metrocable (cable-car system) Line K started operating in the northeastern zone (Z1) of the city in 2004, line J in the central-western zone (Z4) in 2008, and lines H and M in 2016. Lines 1 and 2 of Metroplús (BRT) were implemented in 2011 and 2012, respectively. In March 2016, a tramway called Tranvía de Ayacucho began operating in the central-eastern zone (Z3). Currently, the SITVA serves all boroughs of the city, except two in the northwestern area. Thanks to this system, Medellín has become a flagship in the implementation of an inclusive, sustainable, and clean transportation system[4]. Figure 1 shows the complete system.

Figure 1: SITVA and city zones



Metroplús crosses the city from the northeast (Z1) to the southwest zone (Z6), passing through the central-eastern zone (Z3) where it connects with line A of the Metro that runs north to south. The system has two lines, each with 21 stations, and it is fueled by natural gas. Line 1 started operating in December 2011 and Line 2 in April 2012. Line 2 coincides with line 1 in 13 of its 21 stations, except when it crosses the downtown area (Z3), where its buses share the road and bus

[4]Medellín won the Sustainable Transport Award 2012, and the MobiPrice 2015 and the Lee Kuan Yew World City 2016.

stops with public transportation and private vehicles[5]. Hence, in line with the theoretical and empirical literature (Zhang and Wang, 2013, Hensher and Mulley, 2015, Deng and Nelson, 2013) which highlights that BRT systems only have a significant impact when they have dedicated lanes and stations, making them faster and perceived as permanent and inducing long-term behavior changes among commuters, our case study focuses on line 1 of the Metroplús.

The Tranvía or Line T of the SITVA serves boroughs 8, 9, and 10, in the central-eastern zone (Z3) of the city, and it has 6 stops and 3 stations. It connects with the Metro Line A, enabling passengers to access the rest of the SITVA, and two lines of cable cars (lines M and H). The system made its first commercial trip on March 31st, 2016. In addition, the project included green areas, new public spaces, and 2,241 trees, shrubs, and palms. Tranvía goes on the same road as the historic electric streetcar – initially mule-drawn – that operated in the city from 1887 to 1951.

These MCTS are comparable due to their capacity, speed, and the characteristics of the citizens they serve. Metroplús has a total capacity of 3,270 passengers per hour (p/h), while Tranvía can transport 3,807 p/h. Both systems travel at a speed of 16 km/h. The age, socioeconomic strata[6], and reasons for travelling are similar in both cases: over 50% of passengers use these transportation systems to commute to work, and 19% use them to go shopping. Residents in strata 2 and 3 are the most common passengers, ranging from 37% to 43% of the total (Metro de Medellín, 2020).

3. Empirical Framework

To study the effects of Medium-Capacity Transportation Systems on housing prices, we estimate the following equation:

$$lnP_{ijt} = \lambda_t + \alpha_j + \beta D_{1it} + \rho_{jt} S_{ijt} + \gamma N_{jt} + \mu_{ij} \quad (1)$$

where factors vary by i households, j neighborhoods and time t. λ_t and α_j are time and neighborhood effects that capture unobservables and reduce the omitted-variable biases. lnP_{ijt} is the log of rental housing prices, S_{ijt} represents the structural characteristics of housing units, N_{jt} is a vector of neighborhood characteristics, and μ_{ij} is an error term with the usual properties.

To estimate the effect of interest, we use a canonical DiD estimator. If the moment of intervention is defined as $\tau_t = 1$ and if $t = \tau_t$, then $D_{1it} = \tau_t M_i$ (or $\tau_t T_i$) is the policy variable of interest, in which M and T represent accessibility to Metroplús and Tranvía and take values of 1 for units defined as treated, and 0 for control units. In other words, M and T capture the capitalization or economic gain of the homeowner for their accessibility to Metroplús and Tranvía services. In Section 4, this interacted variable will be called *Metroplús* and *Tranvía*, respectively.

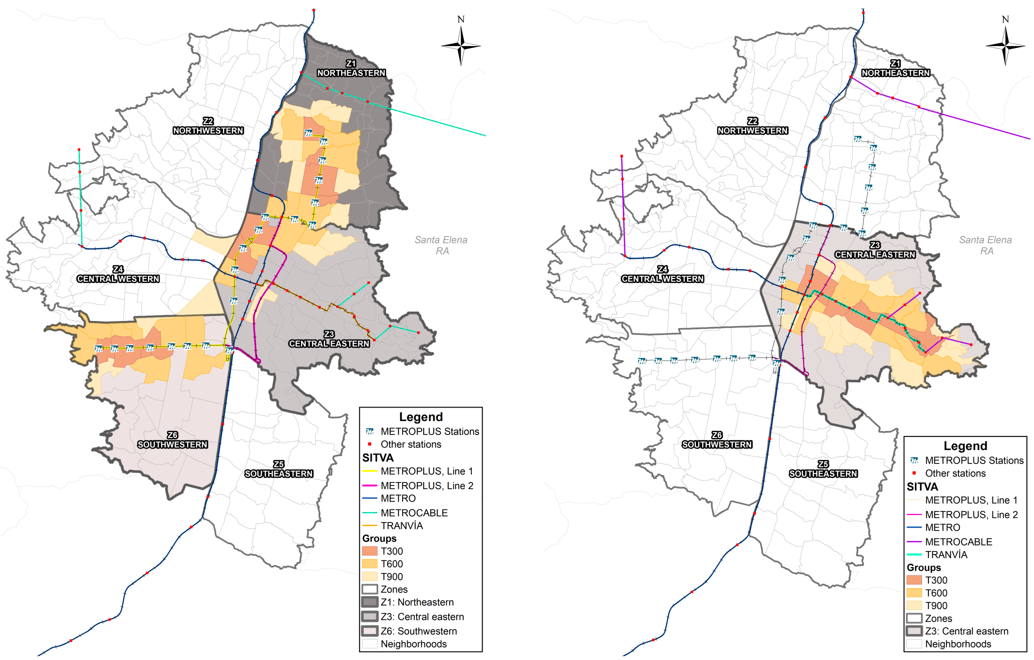
In our baseline analysis, we identify neighborhoods whose centroids fall within a buffer zone of 300 m, 600 m, or 900 m to the nearest station of each system (M300, M600, and M900 for

[5] As of March 2023, the remaining stations of Line 2 are under construction.

[6] Socioeconomic strata in Colombia was conceived as an instrument that allows a municipality or district to classify its population in distinct groups or strata with similar social and economic characteristics. It has six levels: level one is lower-low, two is low, three is upper-low, four is medium, five is medium-high, and six is high. One is associated with the lowest income and six with the highest income groups, respectively.

Metroplús and T300, T600, T900 for Tranvía). This is based on what we consider to be the maximum feasible walking time to a station (20-30 minutes) considering the altitude range in the city. After this, we conduct an analysis dividing the treatment areas into three rings: 0 to 300 m, 300 to 600 m, and 600 to 900 m from the closest station to each system, in order to determine the differential effect at each distance. The control group is given by observations beyond 900 m of distance to the closest station. Figure 2 shows the different treatment and control groups, as well as the SITVA stations and the zones of the city where the systems were implemented. To account for differences in the number of observations across neighborhoods, we weigh each specification by the number of observations in each neighborhood.

Figure 2: Baseline scenario. Treated and control groups BRT System (left) and Tranvía (Right), SITVA stations, and Zones of the city



To understand the mechanisms mediating the causal relationship, we estimate Equation (2) using the answers of the heads of households in the QLS. Y_{ijt} represents either the number of private vehicles (motorcycles and cars) or the perception of the public transportation's quality and coverage, as well as safety, noise, air, and visual pollution in the neighborhood. Our policy variable of interest is D_{1it} and we focus on observations in the 300 m buffer. We include the socioeconomic strata of the housing unit, represented by $Strata$, and the same vector of neighborhood-level covariates in N_{jt}.

$$Y_{ijt} = \lambda_t + \alpha_j + \beta D_{1it} + \rho_{jt} * Strata + \gamma N_{jt} + \mu_{ij} \tag{2}$$

3.1 Time frame

We use the year when each system started operating as the moment of treatment, to capture the uncertainty associated with public project completion in Medellín. For the BRT system, we define the period before treatment as the years from 2008 to 2011 and the after-treatment as all years from 2012 to 2018, considering Metroplús started operating in December 2011. This also follows the literature that suggests a lag in the LVU after the implementation of a new BRT, which is more easily observable for relatively mature systems, i.e., at least three years old (Zhang and Yen, 2020). In the case of Tranvía, we define the period before treatment as 2008–2015 and the period after treatment as 2016–2018. We set 2016 as a period after treatment because the QLS was carried out in October and Tranvía started operating in March.

3.2 Data

To estimate the effect of accessibility to the Metroplús and Tranvía on housing prices, this research uses repeated cross-sections from the QLS from 2008 to 2018. Explicitly, the data from this source includes rental prices reported by the heads of households, the usual structural characteristics of dwellings S_{ijt} suggested by the literature, and several neighborhood-level variables. The first variable in N_{jt} taken from the QLS is *Security* which captures the interviewees' perception of security in their neighborhood. We take this instead of a crime rate because, in a city with a violent past like Medellín, the influence of security on the willingness to pay for housing may be more connected to the inhabitants' perception than the police statistics. The second one is *Minority* which shows whether the interviewee identifies as part of an ethnic minority.

Vector N_{jt} also includes transportation (SITVA stations), education, culture and worship, health, and recreation amenities. These variables are determined based on their exact latitude and longitude available from the geodatabase of the POT 2006 and 2014. This allow us to control for the differences in amenities and access to transportation infrastructure across the city, a weakness of other studies identified by Ahlfeldt, Redding, and Sturm (2016). Moreover, accounting for the whole public transportation system helps minimize the risk that access to other types of mass public transportation confounds the estimates. We calculate population density per neighborhood using data on population from DANE. Finally, to study the causal mechanisms we believe can drive the results, we use the questions about the number of private vehicles (cars and motorcycles) in the household and the perception section from the QLS. Many households did not participate in this section of the survey and for this reason, there is a different number of observations when estimating the effect of the MCTS on other outcomes.

3.3 On the parallel trends assumption

The basic identification condition of the DiD strategy is the parallel trends assumption (PTA). The PTA establishes that if in the absence of treatment, the average outcomes for treated and control groups follow parallel paths over time, one can estimate the average treatment effect for the treated sub-population (ATT) by comparing the average change in outcomes experienced by the treated group and the average change in outcomes obtained by the control group (Callaway and Sant'Anna, 2020). In our study, the intuition is that housing prices trends would be the same in treatment and control zones in the absence of the interventions.

Given the critical importance of the PTA in identifying causal effects with the DiD design, authors tend to see it by looking at the raw data. The current way in which authors evaluate the pre-treatment dynamics between a treatment and control group with differential timing is to estimate a regression model that includes treatment leads and lags. Including leads and lags into the DiD model allows to check whether the two groups are comparable on outcome dynamics pre-treatment. Such event studies are not a direct test of the parallel trends assumption but they show that the two groups of units are comparable on dynamics in the pre-treatment period (Cunningham, 2021). The model takes the form:

$$lnP_{ijt} = \lambda_t + \alpha_j + \sum_{\tau=-q}^{-1} \gamma_\tau D_{i\tau} + + \sum_{\tau=0}^{m} \delta_\tau D_{i\tau} + \rho_{jt} S_{ijt} + \gamma N_{jt} + \mu_{ij} \tag{3}$$

Treatment occurs in year 0, and the equation includes q anticipatory effects and m lags or post-treatment effects. Under this specification, if the estimated γ_τ is simultaneously not significant for $\tau \leq 2011$ for the Metroplús specification and $\tau \leq 2015$ for Tranvía, we have evidence that differences between treatment and control are constant in the pre-intervention period, suggesting that the parallel trend assumption holds. All specifications include the covariate vectors S_{ijt} and N_{jt} as well as the neighborhood and year fixed-effects.

The event study results use the log of rental prices as the dependent variable and 2012 and 2016 as the years of reference for all buffers and rings in the estimation. This specification includes the mentioned control variables and neighborhood and year-fixed effects. Regarding Metroplús, results in Table 1 show no significant estimated coefficients between 2008 and 2011, suggesting that the parallel trends assumption holds. Furthermore, they also show some (negative) significant estimated coefficients in 2014 (300 m buffer) and from 2016 to 2018, suggesting the presence of the causal impact of interest. For the case of Tranvía, results in Table 2 show only some pre-trends several years before its implementation (in Column 1 for 300 m buffer), but they vanish beyond the 600 m buffer. Overall, we believe that results for both MCTS show that the PTA holds for Metroplús and Tranvía, supporting the internal validity of our estimates.

However, further discussion can take place. As pointed out by Roth (2022), context related information can help when the PTA do not seem plausible *"(...) to use context-specific economic knowledge to inform the discussion and analysis of possible violations of parallel trends. Bringing economic knowledge to bear on how parallel trends might plausibly be violated in a given context will yield stronger, more credible inferences than relying on the statistical significance of pre-trends tests alone (...)"* (Roth, 2022, p. 319). In this case, we believe that the control group for Tranvía can have some potential confounder variables, particularly close to the downtown area. According to Proantioquia (2017), the downtown area congregates several transport modes: Metro, Metroplús, Tranvía, and public buses operated by private companies. 76% of bus routes in the city circulate in the downtown area, which coincides perfectly with our control group because it is located beyond 900 m. Furthermore, the downtown area has the least public space in the city, and during the past decade, its transformation has been a priority for the local government.

Table 1: Event study for housing prices. Metroplús

Dependent variable:	ln(Rent Prices)				
	[1] 0-300 m	[2] 300-600 m	[3] 0-600 m	[4] 600-900 m	[5] 0-900 m
D2008	0.047	-0.028	0.001	0.061	0.018
	(0.052)	(0.047)	(0.039)	(0.046)	(0.033)
D2009	-0.036	0.002	-0.013	0.031	-0.001
	(0.047)	(0.045)	(0.035)	(0.024)	(0.028)
D2010	0.032	-0.040	-0.012	0.033	-0.000
	(0.034)	(0.060)	(0.041)	(0.029)	(0.032)
D2011	-0.095	-0.025	-0.052	-0.011	-0.041
	(0.058)	(0.059)	(0.046)	(0.032)	(0.035)
D2013	-0.044	-0.146	-0.109	0.021	-0.071
	(0.044)	(0.105)	(0.069)	(0.037)	(0.051)
D2014	-0.109^{c}	-0.026	-0.062	0.030	-0.035
	(0.064)	(0.054)	(0.045)	(0.034)	(0.036)
D2015	-0.026	-0.079	-0.060	0.035	-0.032
	(0.061)	(0.056)	(0.044)	(0.042)	(0.036)
D2016	-0.188^{a}	-0.069	-0.113^{b}	-0.015	-0.085^{b}
	(0.046)	(0.066)	(0.049)	(0.059)	(0.042)
D2017	-0.146^{b}	-0.063	-0.096^{b}	-0.018	-0.073^{c}
	(0.059)	(0.061)	(0.047)	(0.054)	(0.039)
D2018	-0.110^{a}	-0.080	-0.091^{b}	0.027	-0.057^{c}
	(0.040)	(0.052)	(0.037)	(0.043)	(0.032)
Observations	60,924	64,758	68,746	62,498	74,308
R-squared	0.618	0.612	0.604	0.624	0.602
Time-variant neighborhood characteristics	Yes	Yes	Yes	Yes	Yes
Housing characteristics	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Standard errors clustered at the neighborhood level are in parentheses.
^{a} p<0.01, ^{b} p<0.05, ^{c} p<0.1

As stated by O'Neill, Kreif, Grieve, Sutton, and Sekhon (2011), when the parallel trends assumption seems implausible, methods that rely on alternative assumptions warrant consideration. One of the alternatives is to use a matching technique to balance the treatment and control groups according to pre-treatment outcomes and covariates, and then apply DiD to the matched data to address residual imbalances in time-varying observed confounders or in time-invariant unobserved confounders, and to estimate the ATT. Therefore, creating a matched control pool similar to the treated group can help control for time-invariant residual biases (Abadie, 2005).

For this reason, to make estimates more robust to functional form misspecification and problems in the selection of the control groups, we carried out a robustness test using what we name the Geographical Approach (GA) and focus on specific zones considering that in these areas, locations may only differ in the treatment. For Metroplús, we carry out the estimations considering only the Northeastern zone (Z1), and for Tranvía we only take the central-eastern zone (Z3). Moreover, we combine DID and propensity Score Matching (PSM), using the single nearest neighbor on all explanatory variables to select our control group. PSM is expected to discard units that are not sufficiently similar to the treated units and to reduce bias from

Table 2: Event study for housing prices. Tranvía

Dependent variable:	ln(Rent Prices)				
	[1] 0-300 m	[2] 300-600 m	[3] 0-600 m	[4] 600-900 m	[5] 0-900 m
D2008	-0.111[b]	0.006	-0.042	0.045	-0.006
	(0.052)	(0.054)	(0.046)	(0.048)	(0.038)
D2009	-0.047	0.087	0.032	0.008	0.024
	(0.061)	(0.077)	(0.058)	(0.036)	(0.041)
D2010	-0.147[a]	0.001	-0.060	0.050	-0.016
	(0.031)	(0.064)	(0.048)	(0.033)	(0.035)
D2011	-0.049	0.077	0.025	0.027	0.027
	(0.066)	(0.069)	(0.055)	(0.036)	(0.038)
D2012	-0.075	0.115[b]	0.036	0.043	0.039
	(0.076)	(0.048)	(0.052)	(0.032)	(0.036)
D2013	-0.056	0.084	0.026	0.009	0.019
	(0.051)	(0.058)	(0.048)	(0.036)	(0.035)
D2014	-0.074	0.091[c]	0.021	-0.008	0.010
	(0.059)	(0.053)	(0.049)	(0.033)	(0.035)
D2015	-0.095	0.027	-0.025	-0.014	-0.020
	(0.096)	(0.057)	(0.058)	(0.043)	(0.040)
D2017	-0.068	0.035	-0.008	0.037	0.010
	(0.073)	(0.083)	(0.061)	(0.047)	(0.043)
D2018	-0.039	0.085[c]	0.032	0.032	0.032
	(0.061)	(0.051)	(0.044)	(0.023)	(0.029)
Observations	67,579	68,654	70,578	69,378	74,301
R-squared	0.707	0.707	0.703	0.710	0.702
Time-variant neighborhood characteristics	Yes	Yes	Yes	Yes	Yes
Housing characteristics	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Standard errors clustered at the neighborhood level are in parentheses.
[a] $p<0.01$, [b] $p<0.05$, [c] $p<0.1$

the potential misspecification of the subsequent regression model (Austin, 2011). In our final estimation, we combine GA and PSM.

4. Results

In Section 4.1 we present estimations of the effect of both MCTS on housing prices using the specification given by Equation (1) and including the set of control variables defined in Section 3.2. Later, in Section 4.2 we study the impact of Metroplús and Tranvía on other outcomes related to transportation and transit-related externalities. This allows us to explore the potential mechanisms mediating the causal relationship.

4.1 Main findings

Table 3 presents the estimates of the DiD strategy when we regress the log of housing prices on the interacted Metroplús variable for the three treatment groups that we established. In Column 1 we estimate Equation (1) for the 300 m buffer and find a negative significant effect on housing prices. The effect decreases when we include more distant treated observations (Columns 2 and 3), suggesting that the impact depends on the treatment intensity, i.e., the closer to the Metroplús station, the higher the reduction of housing prices after treatment. In Column 4 we show the results when jointly including all three rings (0 to 300 m, 300 to 600 m, and 600 m to 900 m) in the estimation. We confirm the negative effect on housing prices for the first ring (300 m) and no effect in the other two rings. These results confirm that the effect is concentrated closer to the stations. In particular, in the post-period housing prices were 5.7 p.p. $= (e^{0.055} - 1)$ lower in treated areas (properties) located up to 300 m of the BRT stations.

Table 3: Effect of Metroplús on housing prices

Dependent variable:	ln(Rent Prices)						
	[1] 0-300 m	[2] 0-600 m	[3] 0-900 m	[4] Rings	[5] Robust GA	[6] Robust PSM	[7] Robust GA+PSM
Metroplús	-0.057[a] (0.017)	-0.034[b] (0.016)	-0.027[c] (0.014)	-0.055[a] (0.016)	-0.084[a] (0.028)	-0.053[a] (0.017)	-0.070[b] (0.032)
Metroplús | 300 m to 600 m				-0.020 (0.022)			
Metroplús | 600 m to 900 m				-0.011 (0.023)			
Observations	60,917	68,739	74,301	74,301	11,701	38,627	7,545
R-squared	0.716	0.704	0.702	0.702	0.513	0.728	0.529
Time-variant NC	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Housing characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors clustered at the neighborhood level are in parentheses.
[a] $p<0.01$, [b] $p<0.05$, [c] $p<0.1$

Considering our discussion of the PTA in Section 3.3, we carry out some robustness checks. Notably, we contrast whether the estimation results are sensitive to the definition of the control by considering three more estimations with alternative methods that aim to redefine our control group and compare it with the buffer in 300 m. We present our results for the Geographical Approach (GA) in Column 5, the Propensity Score Matching (PSM) in Column 6, and the combination of both in Column 7. The estimates confirm that the effect of Metroplús on rental prices is negative and significant. The negative effect is puzzling because the BRT serves a zone with limited access to public transportation before it started operating, and it is a mature transportation system implemented in the densest zone of the city, one of the success conditions pointed out by Brooks and Denoeux (2022). These results can be related to increased traffic and congestion in the streets where one of the lanes was devoted exclusively to Metroplús and also the negative externalities associated with the system such as noise, and visual and air pollution for households located closer to the system that may have surpassed the positive effects of improved accessibility. These findings can also show the emergence of disamenities closer to the system with no positive effect to offset them.

We know turn our attention to study the effect of Tranvía on housing prices. Column 1 in

Table 4 shows a positive significant effect in the first buffer (300 m). This effect does not hold for the 600 m and 900 m buffers in Columns 2 and 3 or the rings beyond 300 m as shown in Column 4. The positive effect is robust to the definition of the control group in Columns 5 to 7: in all cases, the effect of the Tramway system is positive. In particular, housing prices increased by 4.4 p.p. ($= e^{0.043} - 1$) more in treated areas (properties) located up to 300 m from the BRT stations, showing that the effect of Tranvía is very localized. Our intuition is that this can be related to the fast connection to downtown that the Tranvía offers. As pointed out by Kahn (2007), public transportation systems in urban areas tend to have a higher impact when they are connected to a vibrant downtown. Other factors such as the convenience of closer stations, and the heavy investment in amenities closer to the tramway, could make the areas in the 300 m buffer more attractive.

Table 4: Effect of Tranvía on housing prices

Dependent variable:	ln(Rent Prices)						
	[1] 0-300 m	[2] 0-600 m	[3] 0-900 m	[4] Rings	[5] Robust GA	[6] Robust PSM	[7] Robust GA+PSM
Tranvía	0.043[b]	0.004	0.007	0.042[b]	0.112[a]	0.045[b]	0.113[a]
	(0.019)	(0.013)	(0.010)	(0.019)	(0.025)	(0.019)	(0.025)
Tranvía | 300 m to 600 m				-0.023			
				(0.016)			
Tranvía | 600 m to 900 m				0.010			
				(0.014)			
Observations	67,579	70,578	74,301	74,301	7,838	61,536	7,565
R-squared	0.707	0.703	0.702	0.702	0.637	0.696	0.610
Time-variant NC	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Housing characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors clustered at the neighborhood level are in parentheses.
[a] $p<0.01$, [b] $p<0.05$, [c] $p<0.1$

4.2 Mediating mechanisms

Understanding the mechanisms through which the impacts of transportation occur is a complex matter. In this section, we estimate Equation (2) to study the effect of each MCTS on other outcomes, such as the ownership of private vehicles and citizens' perception of several transport-related outcomes and disamenities. By doing so, we aim to capture the mechanisms mediating the causal relationship. Additionally, we document information on the challenges of public transportation in Medellín identified by AMVA (2020), as well as considering information from the Origin-Destination survey from 2017. This helps contextualize our results and sheds light on the broader implications of our findings.

4.2.1 Transport-related

We explore the effect that both MCTS had on the number of cars and motorcycles in the household, as well as their perception of the coverage and quality of the public transportation in their neighborhood[7]. Table 5 shows the results for Metroplús and Tranvía. For Metroplús we find no impact on the ownership of any type of private vehicle nor in the perception of coverage and quality of public transportation in their neighborhood. These results are in line with Gaduh *et al.* (2022) who find that the proximity to a BRT station in Jakarta neither reduce vehicle ownership nor travel times, and it does not increase commuter flows. We find no significant effect of Tranvía in any of these outcomes either.

Table 5: Transport related mechanisms

	Private vehicle		**Perception**		**Private vehicle**		**Perception**	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Dependent variable:	Car	Motorcycle	Coverage	Quality	Car	Motorcycle	Coverage	Quality
Metroplús	0.002	-0.019	-0.043	0.002				
	(0.018)	(0.020)	(0.076)	(0.072)				
Tranvía					-0.009	-0.043	-0.015	0.062
					(0.022)	(0.045)	(0.066)	(0.045)
Observations	62,071	62,071	51,182	51,182	62,071	62,071	51,182	51,182
R-squared	0.290	0.036	0.113	0.083	0.290	0.036	0.113	0.083
Time-variant NC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Strata	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors clustered at the neighborhood level are in parentheses.
[a] p<0.01, [b] p<0.05, [c] p<0.1

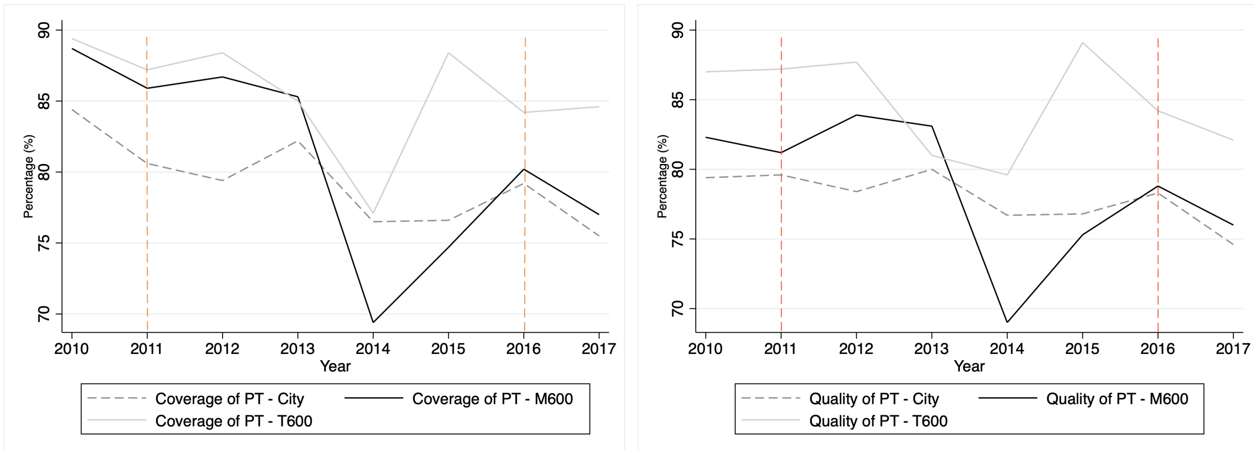
We delve further into the perception of transportation because is the public who knows their specific transport needs and the main element of any transport system is its users. Therefore, involving the public in transportation planning processes is crucial, as it enhances the likelihood that the actions and services provided by public agencies better align with the needs of the community (UNESCAP, 2012). As shown in Figure 3a and Figure 3b, the general perception of public transportation is higher in the zones where Tranvía operates. Although it seems that the percentage of people with a positive perception of public transportation in the city is decreasing. This is one of the key areas where transportation in Medellín needs to improve.

It seems that the perception of the public transportation coverage in the areas with accessibility to Metroplús decreased after the implementation of Line 1 in 2011, suggesting that people did not perceive Metroplús as a way of improving public transportation but rather that its operation was detrimental to its good image in the areas. As reported by the interviewees in the Metroplús perception survey (2015), some areas are more difficult to reach after the implementation of Metroplús, creating transportation gaps that impact the most vulnerable population at the top of the hillside that Metroplús serves in Z1. This perception might affect the willingness to pay for

[7]These questions were included in the QLSM in 2010 and there are many heads of household that did not provide an answer.

Figure 3: Perception of public transportation in the neighborhood in the last year: Percentage of people that considered it was Good and Very Good

(a) Coverage of public transportation (b) Quality of public transportation



housing in the closer areas and explain the negative estimated coefficient of Metroplús. In the areas with accessibility to Tranvía, the perception of the quality of public transportation is higher than the average for the city and higher than in the areas close to Metroplús for the whole period, though it is also decreasing. In both cases, in 2014, there was a drop in the number of people that considered the coverage and quality of public transportation as good and very good.

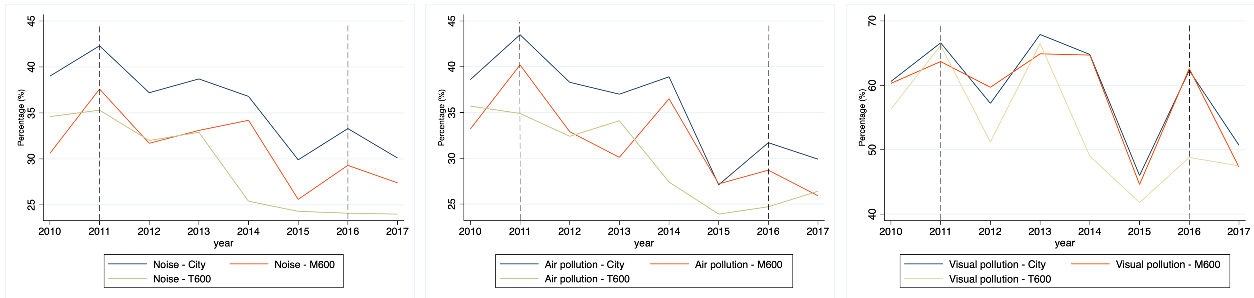
4.2.2 *Safety and environmental disamenities*

Visual, air, and noise pollution are disamenities that can affect housing prices (Ahfeldt *et al.*, 2019). For this reason, we analyze people's perceptions of these aspects (See Figure 4). Less than 50% of the interviewees considered the level of air pollution and noise in their neighborhood to be good and very good, which reveals a generalized problem in the city. However, the perception of the level of air pollution and noise is, in general, lower for the areas served by Tranvía and Metroplús. In both cases, the neighborhoods around Tranvía reported lower perception of these aspects. With respect to visual pollution, between 40% and 70% of interviewees reported a good and very good perception of this aspect, with Tranvía lower and Metroplús close to the city average. The perception of air pollution and noise is lower in the areas with access to Metroplús, which serves less congested areas of the city. Figure 4 shows that in general, the perception of environmental disamenities worsened over the period and suggests that the implementation of the systems did not change the patterns in the perception of the surrounding environmental disamenities. The estimates in Table 6 show that neither Tranvía nor Metroplús had a significant effect on the perception of visual, air, and noise pollution.

The quality of service and user perception depend on essential aspects such as occupancy frequency, reliability, and, in particular, personal safety. Safety is a crucial factor in choosing a mode of transport (Hidalgo, Pereira, Estupiñán, and Jiménez, 2013). Empirical evidence shows that the effect of MCTS on housing prices is closely related to its effect on personal safety (Rodríguez and Targa, 2004). We estimate the effect of MCTS on the perception of safety in

Figure 4: Perception of externalities in the neighborhood in the last year: Percentage of people that considered it was Good and Very Good

(a) Noise (b) Air pollution (c) Visual Pollution



the neighborhood using data from the QLS, and the results are presented in Table 6. Columns 1 and 5 show the effect of Metroplús and Tranvía, respectively. The estimates are not statistically significant.

Table 6: Externalities mechanisms

	Perception							
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Dependent variable:	Safety	Noise	Visual	Air	Safety	Noise	Visual	Air
Metroplús	0.036	0.069	-0.105	-0.048				
	(0.029)	(0.066)	(0.086)	(0.134)				
Tranvía					0.030	0.093	0.021	0.081
					(0.029)	(0.128)	(0.104)	(0.128)
Observations	62,071	51,182	51,182	51,182	62,071	51,182	51,182	51,182
R-squared	0.630	0.099	0.098	0.078	0.630	0.099	0.097	0.078
Time-variant NC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Strata	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors clustered at the neighborhood level are in parentheses.
^{a} p<0.01, ^{b} p<0.05, ^{c} p<0.1

4.2.3 *The challenges of public transportation in Medellín*

The results of the analyzed outcomes in Tables 5 and 6 provide insight into the causal mechanisms at play. Nevertheless, in order to better understand our main findings, we explore information from other sources. According to Medellín's Origin-Destination Survey (2017), between 2005 and 2017, the average commute time increased by 44% (11 minutes), meaning that the inhabitants of the metropolitan area spent an average of 420 hours a year traveling. In the same period, the ownership of motorcycles increased by 207%, while private car ownership increased by 46%, despite the investment in public transportation (SITVA) intended to discourage the use of private modes of transport. During this period, Metroplús, Tranvía, several feeder buses routes, bicycle routes, a public bicycle system (ENCICLA), and electronic platforms that provide information for users, were implemented. Particularly, the motorcycle tenancy grew and, by 2019, motorcycles made up to 59% of the total private vehicles in Medellín. Motorcycles in the city are attractive because they are less expensive. According to Medellín's Secretary of Mobility, in 2019 a person could spend 18% of the minimum wage using a motorcycle as a primary commuting mode and 35% using public transportation.

The main mode of transportation in most boroughs is walking, except in Boroughs 2 and 13 where 18% of interviewees reported using the Metro as the main mode, and Boroughs 11 and 14 that use mostly private vehicles. With respect to Metroplús, few people use it as their main mode of transportation in the treated areas. Only in Boroughs 3 and 16, 6% of the people reported using it as their main mode of transport, followed by Borough 4 (3%). It seems like Metroplús is more used in the northeastern and southwestern zones of the city, leaving the central-eastern zone for other modes. Moreover, although it had been operating for over 5 years at the moment of the survey, which makes it a mature transit system, it does not transport a large share of everyday commuters in the city. Tranvía, on the other hand, was reported as the main mode of transport by roughly 1% of people in borough 9. This might not be a true indicator of the passengers in Tranvía because in 2017, when the survey was carried out, it had been in operation for less than 1 year. The people in the central-eastern zone of the city, where the stations are located, reported walking and other public transportation as their main mode of travel.

This is a generalized problem in the city. Based on the information collected in the survey, the Plan Maestro de Movilidad para el Valle de Aburra (Mobility Master Plan for the Aburra Valley, 2019), identified that:

> *"The current mobility model of the Aburra Valley is based on individual and motorized transportation; this makes the system unsustainable, inefficient, inequitable, risky, and unproductive." (AMVA, 2020).*

The document argues that the insufficient use of the public transport system in the city is influenced by inefficient connectivity between some areas of the territory because it is difficult to provide public transportation service regularly, especially in the high hillside area. This is in line with the evidence from the Metroplús Perception Survey (2015) and adds to a lack of reliability in terms of the schedules and frequency of non-segregated modes (such as integrated routes and feeder services), high travel times due to road congestion, and high costs for long journeys involving several transfers, which become barriers to access. Moreover, some conditions encourage the use of private vehicles: a wide range of free and affordable parking spaces and few possibilities for integration between private and public transport. Improving this situation requires a reduction in the incentives for private vehicle usage, as well as creating alternatives, especially achieving a public transportation system that can match the quality of accessibility provided by private motorized transport.

These challenges are closely related to what is known as "transportation gaps", a concept first introduced by (Bouladon, 1968), who compared service capability to demand: there are places that people travel to but are too far to walk, so other types of transportation services should be available, enabling users not to drive. Transportation gaps might be more relevant in cities like Medellín where, due to the socioeconomic characteristics of the residents, the option to drive is limited and may generate opportunity gaps. As a result, there is far less accessibility for lower-income groups and, along with high fares, the negative effects on the poor can be large. Covering transportation gaps can help make the transportation system more balanced and integrated, by meeting the range of travel needs of different groups.

5. Conclusions

This paper aims to estimate the effect that accessibility to Metroplús and Tranvía have on housing prices in Medellín, using a hedonic approach. The results show a significant negative effect of Metroplús and a significant positive effect of Tranvía on rental prices for residents living in neighborhoods located within 300 m of a station. To study the mechanisms mediating the causal effect we estimate the effect of the MCTS on other outcomes. Our findings reveal that the implementation of a BRT system and a tramway in Medellín did not lead to a significant shift from private vehicles to public transportation. Additionally, we do not find any causal effect of these transportation systems on the perception of transit coverage and quality, as well as on visual, air, and noise pollution or safety.

Although we do not find a causal effect, we inspected the changes in the perception variables considering that, as pointed out by Lindau, Hidalgo, and de Almeida Lobo (2014), "There are expectations gaps between the transit user needs and planning". This expectation gap might explain why, while in the treated areas by both MCTS, the perception of public transportation's coverage and quality did not improve after the implementation of the systems, their effect on housing prices differs. The analysis of information from the Origen-Destination Survey (2017) and the Metroplús perception study (2015) reinforces the importance of this link: for this effect to be positive, families must perceive the system as permanent and easily accessible, and as an improving factor for their connectivity.

Our analysis allows us to conclude about the key conditions for transit success identified by Brooks and Denoeux (2022), and it seems that only one of them holds: Metroplús serves Z1, the most densely populated zone of the city followed by Z3, where Tranvía operates. However, by 2018, neither Metroplús nor Tranvía was able to surpass the speed of private cars. During peak hours, the speed of private cars was between 21 and 31 kms/hour, while both Metroplús and Tranvía maintain a speed of 16 kms/hour throughout the day. Due to their design, multiple factors such as road accidents can make them go slower. Finally, the negative change in the percentage of people that perceived the coverage and quality of public transportation as good and very Ggood in the area close to Metroplús and Tranvía may suggest that people do not perceive that the systems are taking them where they want to go. Then, the effect of Tranvía can be related to the positive changes in amenities around the stations and their convenient connection to downtown. However, a further explanation of this link is out of the scope of this paper.

The different effects of the systems can partially be explained because even when presenting equivalent performance, the BRT is still perceived as a lower quality mode than rail systems, but other forces can be influencing the results. Brooks and Denoeux (2022) arrive to their three conditions taking Bogotá's Transmilenio as one of the case studies. This system has a separate right of way for most routes, and some of them have two extra lanes that allow for passing, accidents, and breakdowns. This makes Transmilenio a faster option. The network of free feeder buses improves access for poorer citizens living on the periphery (Tsivanidis, 2022) while feeder routes in Medellín have an extra fee. Considering that Tranvía connects to two different lines of cable cars that transport people to the hillside, while people close to Metroplús, have the option of taking feeder routes paying an extra fee, or walk. As a result, a lot of the citizens use Transmilenio as their main mode of transport, which is not the case of Metroplús. This can be also influenced by the fact that some areas were reportedly more difficult to reach after the implementation of Metroplús because the previous buses were not replaced by feeder routes, creating transportation gaps that impact the most vulnerable population at the top of the hillside that Metroplús serves in Z1.

Our findings bring up some questions, are BRTs better when they are the only massive transit option in the city? Furthermore, if, as Brooks and Denoeux (2022) explain, the success of the systems is correlated with the past, cities in the Global South (with transit-friendly densities) that experience massive inflows of people in short periods of time, might not be able to make big enough streets like Bogotá did. Finally, if MCTS do not become an incentive to switch from a private car to public transit in cities as densely populated as Medellín, it might have adverse effects on congestion, particularly the BRTs for their design, making people worse off than they were in their initial situation, and limiting their ability to access all the benefits that cities can offer. Beyond this, with mass rail systems, congestion tends to make the speed of public and alternative modes of transport much more appealing, however, if public transportation is slower it can create a negative cycle. Despite the popularity of BRT systems, this study shows that when it comes to selecting a MCTS, capacity, speed, and construction costs might not be as important as public opinion because, for the system to contribute to a sustainable transport pattern, it has to be a real incentive at least to decrease the number of private vehicles in the household. In addition, avoiding transportation gaps and ensuring a standard single fare for all trips can contribute to the positive impact of MCTS. All of these become open questions for future research and policy issues going forward.

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