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Abstract

Transportation policies have an important incidence on the allocation of resources within cities. Therefore, investigating the impacts of transit investment is relevant especially in developing countries where informal housing is highly prevalent and spatial disparities are remarkable. We study the impact of a transit expansion of the Metrocable system in Medellín (Colombia) as a natural scenario to understand the causal links between lowering access cost and informal housing. Using a difference-in-difference identification strategy, we estimate that the expasion of Line H of Metrocable reduces informal housing up to 15 percentage points. We also show that the magnitude of the effect depends on the distance to the intervention. When exploring potential mechanisms mediating the analyzed causal relation we find that the labor market plays a crucial role.

Keywords: Informal housing, Transportation cost, Land value, Informal labor market, Colombia.

JEL codes: R41, R42, R31, J46

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1 Introduction

Transportation infrastructure shapes the urban structure through its influence on the organization of economic and social activities (Baum-Snow & Turner 2017, Glaeser 2020, Redding & Turner 2015, Weisbrod 2008). Specifically, transit infrastructure investment generates that firms and households reallocate production and consumption resources, changing decisions related to residence, working place, schooling, among others. The impact of these investments might be more critical in developing countries where lack of job opportunities, informal labor, spatial segregation and Informal Housing (IH) are highly prevalent (Boisjoly et al. 2017, Glaeser et al. 2008, Mahabir et al. 2016). Therefore, disentangling how transit interventions affect IH is essential to understand the wider economic benefits of transportation policies in the developing world.

According to UN-Habitat, IH is a dwelling solution characterized by one or more of the following: low quality of building materials, overcrowding, tenure insecurity and lack of connection to sanitation and water infrastructure (see UN-Habitat 2003, and Gechter & Tsivanidis 2020). IH is usually present in the urban periphery in settlements with poor social and spatial connection to the rest of the city, inadequate public infrastructure provision, and high environmental and geological risks. The sum of factors such as migration, urban poverty, illegal land occupation, the absence of compliance with planning regulations, and the lack of affordable formal housing has boosted the proliferation of IH and Informal Settlements (IS) (see Fekade 2000, Gaisie 2015, UN-Habitat 2003, and Durand-Lasserve 2006).

To improve living conditions in IH and IS, governments have implemented different policies including slum upgrading programs (Cattaneo et al. 2009, Galiani et al. 2017); provision of utility infrastructure (Gonzalez-Navarro & Quintana-Domeque 2014); and provision of transit infrastructure (Ordóñez-Barba et al. 2013, Soares & Soares 2005). Knowing that a reduction in transportation costs improves accessibility and has positive impacts on productivity, markets access, job opportunities, among others, a complete assessment of transport policies requires quantifying its impact on different dimensions of housing in the context of IH.

There is extensive literature assessing the impact of transit infrastructure on productivity and socioeconomic outcomes (Berg et al. 2017, see c.f. Rietveld & Bruinsma 1998, World Bank 2012, and Roberts et al. 2020 for an extended discussion). This evidence has consistently shown that investing in transport infrastructure increases housing and land rents (Arnott & Stiglitz 1981, Billings 2011, Dorantes et al. 2011, Gibbons & Machin 2005, Glaeser et al. 2008, Hongbo & Mulley 2006, Wheaton 1977, and Efthymiou & Antoniou 2013). For instance, Cohen & Paul (2007) found that public highways and airport investments increased manufacturing firms property values in the U.S, while Dorantes et al. (2011) showed that the construction of Madrid Metro line 12 increased housing rents and benefited business activities in the proximity of the new stations. There is also evidence showing that transit interventions could negatively affect housing rents, e.g. through an agglomeration cost channel that depends on the type of transit infrastructure (i.e., metro, railway, bus, airport and others) and the distance to the stations (Glaeser et al. 2008, Hongbo & Mulley 2006, and Efthymiou & Antoniou 2013).

Another strand of literature has studied how transit infrastructure affects labor misallocation in the light of the Spatial Mismatch Theory (see Kain 1968, and Gobillon et al. 2007 for a review). This theory states that living in a disconnected location raises the probability of having poorer labor market outcomes. A large number of theoretical models have exploited this idea to quantify the relation between commuting time, job acceptance and informality (Moreno-Monroy & Posada 2018, Tsivanidis 2019, Zárate 2019, see Zenou 2009, and Flemming 2020). There is also empirical research focused on the developing world, which reports that transport infrastructure improvements reduce travel time, allowing workers to reach a higher number of job opportunities and affecting the levels of labor informality[1]. (see Moreno-Monroy & Roman 2015, Suárez et al. 2016, and Oviedo et al. 2019).

Despite all of this research, less is known about how transit infrastructure improvements impact IH. In this paper, we study the causal impact of an expansion of the Metrocable, the cable car transport system in Medellín, on IH and other relevant outcomes using data from the Encuesta de Calidad de Vida (Survey of Living Conditions, ECV for its acronym in Spanish). We also explore whether changes in land value, job opportunities and migration patterns might be acting as mediating mechanisms behind the causal

[1]Recent studies have also explored the effects of transport infrastructure on dimensions like crime (see c.f. Bocarejo & Oviedo 2012, Canavire-Bacarreza et al. 2016, and Khanna et al. 2020), and schooling decisions (Dustan & Ngo 2018, Müller et al. 2008)

relationship of interest. For instance, if a transit infrastructure investment increases housing and land rents, households could have higher incentives for dwelling ownership or tenure regularization as well as for investing in housing quality improvement. This leads to a reduction in IH. Also, if transit infrastructure improvement facilitates the access to job opportunities raising household's income, one might expect to observe higher housing quality.

Finally, transit infrastructure improvements can increase migration, which in turn affect IH in two directions. On the one hand, new transit infrastructure might attract skilled workers close to the stations, increasing housing quality. In this line, Warnes (2020) presents evidence that supports the fact that transit infrastructure might increase spatial segregation between high-skilled and low-skilled residents within the city. On the other hand, new transit investments could attract low-income migrants increasing the incidence of slums and IH close to the stations. The latter is related to the Harris-Todaro mechanism (Brueckner & Lall 2015, for further discussion, see Harris & Todaro 1970, and Cavalcanti et al. 2019).

To identify the causal effect of the Metrocable expansion on IH we use a difference-in-difference (DiD) strategy that exploits the spatial and temporal variations in transit infrastructure provision. Specifically, we study the impacts of Metrocable's Line H, which started commercial operations in 2017. This line serves the comuna[2] 8 in Medellin, a steeped zone with high IH incidence. To do so, the treatment zone is defined by the neighborhoods close to Line H. In turn, to have a proper counterfactual comparison, the control zone is defined taking advantage of the sequentially in the expansion of the Metrocable network. In particular, we use as a control zone neighborhoods in comuna 6 which will be served by Line P, and have informal origin over a steeped territory.

Our results indicate that the Metrocable's expansion leads to a significant decrease in IH. Specifically, IH experienced a decrease between 14.9 percentage points (p.p.) and 11.5 p.p., for buffers around Line H of 500 meters and 1,500 meters, respectively. This result is robust to different samples, specifications, buffer sizes, and control zones definitions. We also provide evidence of the causal effect of Line H on different dimensions of IH, i.e., tenure status, crowding and quality of building materials. In all cases, the transit infrastructure intervention tends to improve housing quality conditions.

[2] A comuna is an administrative division of the city that groups neighborhoods and has a local government that provides some services

To explore the potential mediating mechanisms behind the relation between transit infrastructure and IH, we estimate the effects of Line H on: household migration indicators, individual labor outcomes, and the values that owners are willing to receive to rent their houses (apparent rent). Our estimates indicate that labor market and land value might be the main drivers of the impact on IH. In particular, we found positive effect of transit infrastructure on apparent rent and labor income, and negative in the case of labor informality. Our results support the idea that transit infrastructure provision impacts household wellbeing beyond accessibility to better job opportunities. Besides, we provide complementary insights to the literature devoted to studying the impact of the cable car system in the context of IS, which has reported positive impacts in terms of the reduction of both commuting time and crime rates (see Blanco & Kobayashi 2009, Bocarejo et al. 2016, Canavire-Bacarreza et al. 2016, Garsous et al. 2019, Heinrichs & Bernet 2014, and Khanna et al. 2020).

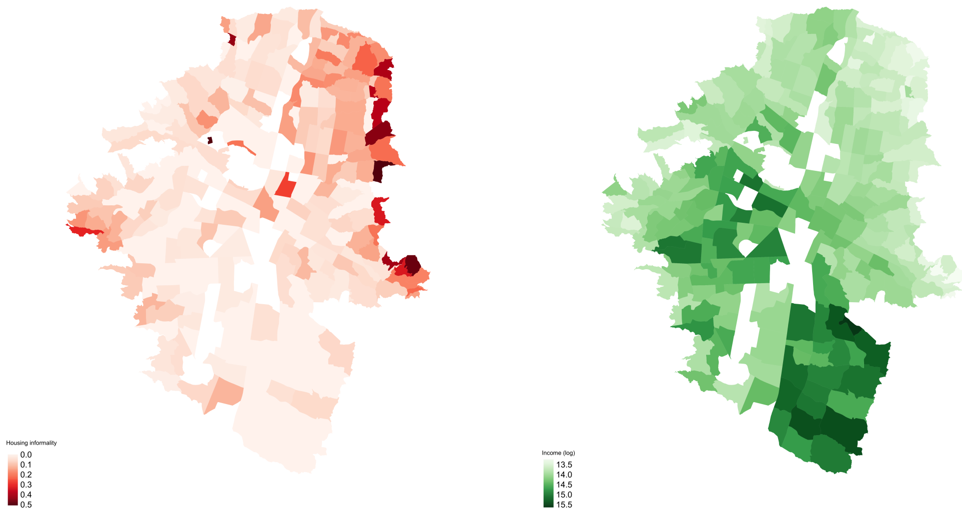
The rest of the paper is organized as follows. The second section briefly describes some facts related to IH in Medellin. The third section presents the empirical strategy and data, and the fourth discusses the results. Finally, the fifth presents some concluding remarks.

2 Informal housing and spatial disparities in Medellin

Latin America and the Caribbean is nowadays one of the most urbanized regions in the world (UN-Habitat 2012). This is partly the consequence of the large rural-urban migration flows of poor households in the mid-20th century. This urban growth surpassed the governments and markets capacity to provide adequate formal housing, and as a result, IH and IS have proliferated in the region (Daude et al. 2017). In Colombia, and its cities, the informal urban growth has been accentuated by the massive internal forced displacement originated by the civil conflict. This growth was particularly dramatic in Medellín because of the intense violence generated by the emergence of drug cartels during the 1990s.

According to the Colombian National Census 2018, Medellín is the second Colombian largest city, with a population of 2.3 million approximately. Together to other nine municipalities, Medellin form the Metropolitan Area of the Valle de Aburra (AMVA), a urban agglomeration with an estimated population of 3.8 million. The urban zone of Medellín is divided into 16 comunas, and the comunas are divided into 249 neighborhoods. According to Medellín Cómo Vamos[3] Report 2018, the city exhibited an unemployment rate of 11.9% in 2018, which was significantly higher than the average of the country (9.7%). In Medellín, poverty and extreme poverty rates are also high, 14.2% and 3.6%, respectively. Inner spatial disparities are also remarkable in terms of several socioeconomic outcomes. For example, Figure 1 shows that IH and low household's expenditure (measured in logs) at the neighborhood level are concentrated in the northeastern zone of the city.

Figure 1: Spatial distribution of IH and household expenditure



(a) IH indicator (b) Expenditure (in logs)

Source: Author's calculations. ECV, 2016. IH refers to Informal housing.

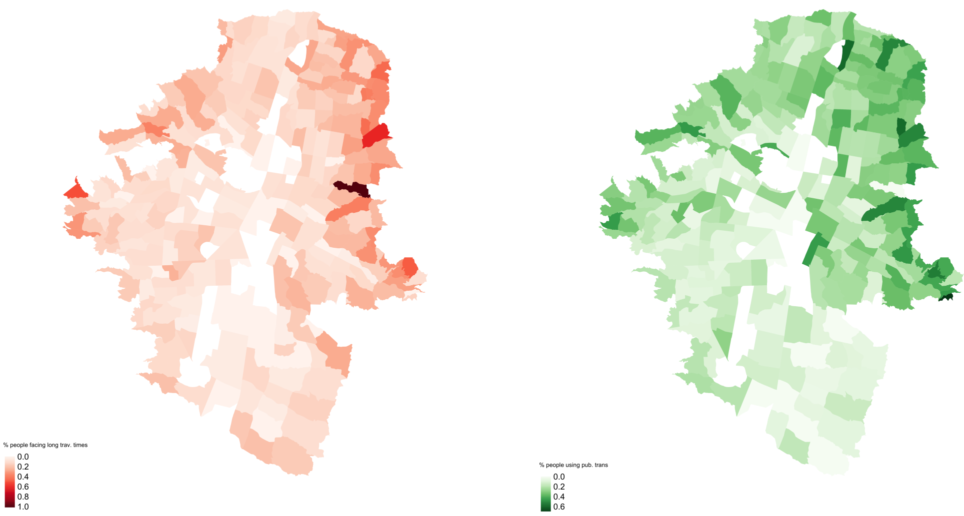
In this study, the IH indicator is defined as a simplified version of the slum indicator proposed by UN-Habitat (2003). Specifically, a dwelling is considered IH when it exhibits one o more of the following: non-durable walls materials (zinc, clothe, cans,

[3]Medellín Cómo Vamos is a private alliance that annually produces the Informe de Calidad de Vida report with a series of socioeconomic statistics about Medellín using the primary information provided by the National Department of Statistics (DANE), and using the information of metropolitan surveys like the Gran Encuesta Integrada de Hogares (GEIH) and the Encuesta de Calidad de Vida (ECV)

waste, plastic, wood and similar materials), overcrowding (ratio between household size and the number of bedrooms equal or higher than 3), and insecure land tenure[4] (unauthorized occupants).

Medellín is located in a narrow valley crossed north to south by the Medellín River. The city initially grew around the plain areas of the valley, but since the 1950s experienced fast growth across the steeped zones of the east and west mountains. As reflected above in Figure 1.a, this growth left a high incidence of IH over the northeastern zone of the city and in some neighborhoods in the west side. It also can be observed a strong correlation between mobility and IH. Figure 2 shows the spatial distribution of the percentage of workers that spend 40 minutes or more traveling to their workplace and the percentage of workers that use public transportation. It can be seen that people living in neighborhoods with a higher incidence of IH also face long travel times to the workplace and use more intensively public transportation.

Figure 2: Spatial distribution of travel time and public transport use



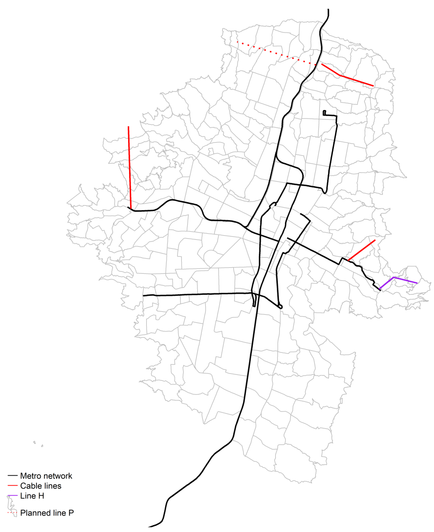
(a) Transportation time (b) Public transportation use

Source: Author's calculations. ECV 2016.

[4] We do not consider the lack of connection to water and sanitation as indicators of informality. While households can directly modify building materials, overcrowding and tenure security through housing investment, expansions of public services infrastructure depend on other factors, including public investments.

Recognizing the poor living conditions and the low accessibility of households located in the steeped zones of the city, local authorities planned and implemented an innovative medium capacity transit system consisting of cable cars. This system, the Metrocable, is connected with the rest of the massive transport system (see Figure 3). These cable car lines allowed access to the top zones in the urban periphery solving mobility needs. The first cable car line (Line K) began operating in 2004 in comuna 2, one of the most convulsed and violent areas of the city during the 1990s and 2000s. Motivated by the success of the first cable car line, a second one was built in 2008 in comuna 13.

Figure 3: Metro and Metrocable transportation system in Medellin



Source: Medellìn's Mobility Plan 2006-2030. Black line corresponds to Metro and Bus Rapid Transit System, and red line are Metrocable lines.

More recently, Lines H and M began operations in years 2016 and 2019, respectively. As a result of these expansions, Medellin hosts one of the most extensive cable cars networks in the world. Previous studies have shown that the Metrocable has had positive impacts on many socioeconomic outcomes (see Blanco & Kobayashi 2009, Bocarejo et al. 2016, Canavire-Bacarreza et al. 2016, Heinrichs & Bernet 2014, and Garsous et al. 2019). Given the large amount of resources invested in this transport system, there is still, from the public policy perspective, the interest of understanding the impact of the Metrocable on different dimensions of living conditions. As we will argue later, we believe that the expansion of the Metrocable through Line H provides an ideal natural experiment scenario to assess the impact of reducing access cost on relevant social outcomes such as IH. Line H directly impacts a zone with a high incidence of informality, which makes a case of particular interest to study.

3 Identification strategy and data

Our study focuses on estimating the causal impacts of the Metrocable's Line H on IH and other relevant socioeconomic outcomes. Line H serves neighborhoods located in the east-center of the city. These neighborhoods were occupied during the 1950s and 1980s by waves of migrants due to rapid industrialization and rural violence. Low-skilled workers and low-income households were located across the periphery and the steeped side of the mountain[5] in a spontaneous way looking for job opportunities.

The most recent urban expansion in the zone is characterized by self-building of housing and the lack of urban planning (e.g., tight streets). Beyond the narrow roads and steeped terrain, mobility is also limited by geographic accidents. Comuna 8 is delimited by the Santa Elena water stream in the south, and the Pan de Azucar hill in the north[6]. The mobility restrictions originated by these geographical and topological conditions has been accentuated by the historical low public transport infrastructure investments.

In response to the accessibility restrictions in comuna 8, in 2006, local authorities planned Lines H and M of the Metrocable system as part of the Mobility Plan 2006-2030 (Plan Maestro de Movilidad del Área Metropolitana 2006-2030 in Spanish). This project was approved in 2008 and obtained the national government support in 2011. Line H consists of three stations over a corridor of 1.4 kilometers. It was built between 2015 and 2016 and started operations at December 17th 2016. Currently, Line H benefits around 280 thousand inhabitants.

Because of the size of the intervention, significant impacts on economic activities and wellbeing are expected in the treatment zone. Therefore, this intervention is an interesting quasi-experimental scenario to studying the causal relationship between transport infrastructure and IH. To this end, we estimate the actual levels of IH in the treatment

[5]Altitude in these neighborhoods is around 700 mts higher than in the city center.

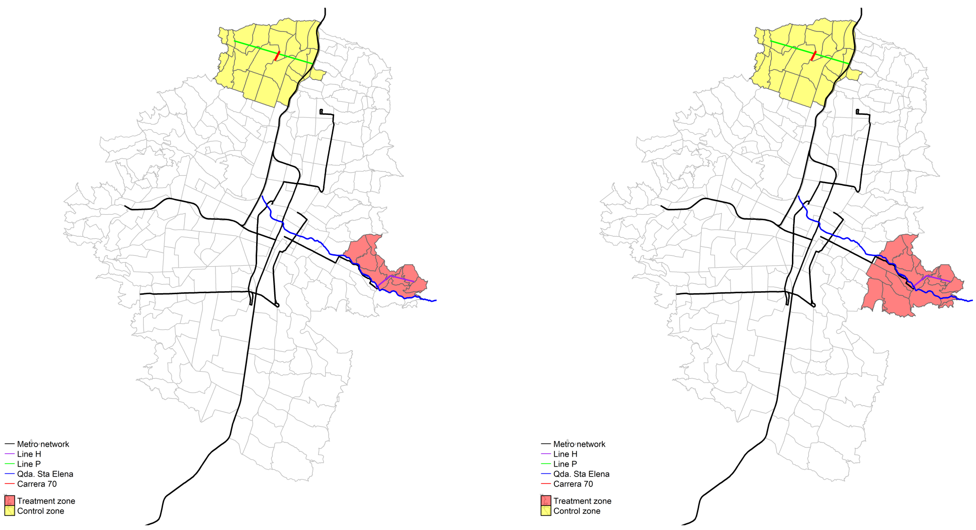
[6]Pan de Azucar hill has an altitude of 2,138 mts, whereas the average altitude of the city is of 1,495 mts

zone and the corresponding counterfactual, i.e., the level of IH that would observe in the absence of the Line H, which is estimated using a control zone. The control zone can be defined using the planned Metrocable's lines that will be built in locations with similar characteristics to the zone of intervention. Specifically, taking advantage of the sequentiality in the expansion plans of the Metrocable system, we defined the comuna 6 as control zone. This comuna will be served in the future by Metrocable Line P benefiting around 350 thousand inhabitants. Similar identification strategy has been implemented by Moreno-Monroy & Roman (2015), Dustan & Ngo (2018), Billings (2011), Zárate (2019). Similarly to comuna 8, the neighborhoods in comuna 6 experienced a fast growth during the second half of the 20th century. In comuna 6 the accessibility also has been difficult for a long time because of the geography and poor transport infrastructure. This makes it reasonable to use comuna 6 as a counterfactual zone.

In our baseline analysis, the treatment zone is given by neighborhoods whose centroids are within buffers of 500, 1,000 and 1,500 meters around Line H, and that simultaneously do not lie to the south of Santa Elena water stream. This is because that neighborhoods can not easily reach the cable line through walking. In addition, we control for the possibility of simultaneous interventions as the Light Rail that connects Line H with the rest of the system. In fact, the closest station to Line H corresponds to the final station of the Light Rail previously built. In such case, these neighborhoods are not directly impacted by the construction of Line H.

In turn, the control zone is defined using neighborhoods whose centroids are within buffers of 500, 1,000 and 1,500 meters around a western segment of future Line P which has the same length than Line H. We proceed in this way to guarantee similar extensions for treatment and control areas and avoid to include neighborhoods with higher access, e.g., to the Metro stations. Figure 4 shows the benchmark treatment and control zones. To validate our results we also consider as a treatment zone those neighborhoods into de buffers around Line H but including the neighborhoods to the south of Santa Elena water stream.

Figure 4: Definition of the treatment and control zones



(a) Baseline scenario (b) Alternative treatment

Source: Authors' calculations. Medellin's Mobility Plan 2006-2030.

In this scenario, the causal impact of Line H on IH can be captured using a DiD identification strategy. Hence, we consider the estimating equation given by:

$$y_{it}^{d} = \alpha^{d} + \gamma^{d} D_{i}^{d} + \lambda^{d} T_{t} + \delta^{d} D_{i}^{d} T_{t} + \boldsymbol{\theta^{d}}' \boldsymbol{X_{it}^{d}} + \epsilon_{it}^{d} \tag{1}$$

where y_{it} is the dwelling status which takes the value of one when the housing is informal and the value of zero when the housing is formal. D_i is a treatment indicator that takes the value of one when the household i is located in the treatment zone and the value of zero when the household i is located in the control zone, and T is a time indicator that takes the value of one for the period after the intervention. d refers to the buffer size uses for the estimation. Parameters λ and γ account by time and group systematic differences, respectively, while δ is the parameter that measures the average impact of the transit infrastructure intervention.

One might expect that δ is negative, however the impact can be also ambiguous. On the one hand, new transit infrastructure improves access to city amenities including to the formal job centers. As a result, housing demand rises in the benefited zone, leading to a rise in housing rents, and thus, in housing quality. Additionally, the higher access improves labor market indicators which in turn could increase housing quality. On the other hand, the new transit infrastructure might increase low-income migration and squatting in the periphery, which in turn could increases IH. Our analysis will account by the aggregate effect, however we will explore the possible mechanisms mediating this causal relation.

Although comunas 8 and 6 share a common historical origin and similar topographical and geographical conditions, systematic pre-treatment differences in terms of socioeconomic and labor outcomes might be found. Controlling by these differences will be crucial for the identification of the causal impact. Therefore, our specification also includes a set of control variables, $\mathbf{X}$, that account for potentially confounding effects. Socioeconomic information about households and their members is obtained from the ECV. This survey is carried out on annual basis since 2004 and is statistically representative at comuna level. Tables 1 and 2 present the average of a set of socioeconomic characteristics at the household and at the individual level for year 2016 using the buffer of 1,500 meters. We also present p-values associated to the hypothesis test of equal means between treatment and control zones.

For the comparison, we use the following household characteristics: IH indicator and its three components (wall materials, crowding and tenure status), property rent values (in logs), migration status (whether a household was living in a different city or neighborhood two years ago), household expenditure (in logs), dependency rate (ratio non-employed to employed members), and household size. Also, we consider household head socioeconomic variables such as education, age, sex, marital status (married or with a permanent partner). In this regards, it is noticeable that control zone is characterized by lower IH rates, higher housing rents, higher incidence of migration, and in general, better socioeconomic conditions.

In the case of individual characteristics, we consider employment status (including whether an individual is a formal or informal worker which proxy using social security payments), age, sex, marital status and education, as well as whether the time to workplace and ue of public transportation. Accordingly, p-values indicate that mean differences are statistically significant for all variables but for being unemployed, sex and marital status. Remarkably and consistent with previous discussion, workers in treatment zone experience longer travel times and higher use of public transportation.

Table 1: Descriptive statistics at the household level. 2016 and buffer of 1500 meters.

Variable	Treatment	Control	p-value
Informal housing	0.184	0.054	0.000
Housing crowding	0.132	0.032	0.000
Wall materials	0.059	0.011	0.000
Tenure status	0.021	0.014	0.382
Rent value (in logs)	12.505	12.758	0.000
Migration status (city)	0.007	0.024	0.075
Migration status (neighborhood)	0.035	0.071	0.026
Household expenditure (in logs)	13.588	13.834	0.000
Dependency rate	0.954	0.694	0.000
Household size	3.882	3.578	0.005
HH education	8.583	10.702	0.000
HH age	49.809	53.208	0.001
HH sex (male)	0.528	0.537	0.780
HH marital status (with partner)	0.604	0.560	0.187

Source: Author's calculations. ECV 2016. HH refers to head of household

The basic identification condition of the DiD strategy is the parallel trends assumption which in this context states that IH trends would be the same in both zones in the absence of treatment. In order to provide some evidence on the parallel trends assumption, we run an event study analysis for the period 2013-2018 using the following specification[7]:

$$y_{it}^{d} = \alpha^{d} + \gamma D_{i}^{d} + \lambda_{t} + \sum_{\tau=2013}^{2018} \beta_{\tau}^{d} D_{i\tau}^{d} + \boldsymbol{\theta^{d}}' \boldsymbol{X_{it}^{d}} + \epsilon_{it}^{d} \tag{2}$$

where $D_{i\tau}$ is a treatment indicator that takes the value one when an individual is treated

[7]This exercise excludes 2015 as the operation of the survey changed and data obtained might be no comparable.

and $\tau = t$, and λ_t is the time trend shared by both groups. If β_τ is not significant for $\tau <= 2016$ indicates that differences between treatment and control are constant in the pre-intervention period, and hence, the parallel trend assumption holds. Moreover, β_τ for $\tau > 2016$ shows a first estimate of the causal impact of interest.

Table 2: Descriptive statistics at the individual level. 2016 and buffer of 1500 meters.

Variable	Treatment	Control	p-value
Employed	0.419	0.464	0.012
Informal worker	0.534	0.390	0.000
Unemployed	0.057	0.045	0.107
Age	32.624	36.655	0.000
Sex	0.475	0.467	0.629
Marital status(with partner)	0.343	0.347	0.774
Education (years)	8.359	9.996	0.000
Travel times (+40 min)	0.396	0.265	0.000
Public transport use	0.070	0.140	0.000

Source: Author's calculations. ECV 2016.

Table 3 shows the results of the event study using the IH indicator as dependent variable and 2017 as year of reference. This specification includes the following controls: household head's characteristics (age, education, sex, and marital status), dependency rate, household expenditure (in logs), household size and neighborhood fixed effects. Results suggest that the parallel trends assumption holds which supports the internal validity of our estimates. Furthermore, these results show significant coefficient in 2018, which is a suggestive evidence of the impact of transit infrastructure on IH. These results are robust for the different buffer's sizes. Using the same specification, we also perform the event study analysis for the three components of the IH indicator. Results in Appendix show that parallel trend assumption holds for all outcomes, except for the case of walls materials, for which significant differences are estimated in 2014.

Table 3: Event study for Informal housing

	500	**1000**	**1500**
D_{2013}	−0.013	−0.037	−0.030
	(0.045)	(0.040)	(0.031)
D_{2014}	−0.027	−0.032	−0.004
	(0.044)	(0.040)	(0.031)
D_{2016}	0.009	−0.009	0.024
	(0.047)	(0.042)	(0.033)
D_{2018}	-0.132^{***}	-0.149^{***}	-0.089^{***}
	(0.044)	(0.039)	(0.030)
N	2880	3914	6811
Adj. R-squared	0.112	0.109	0.082
F Statistic	13.968^{***}	15.135^{***}	14.542^{***}

$^{***}p < .01$; $^{**}p < .05$; $^{*}p < .1$
Source: Author's calculations

4 Metrocable infraestructure and informal housing

We estimate Equation 1 for different buffer sizes around Lines H and P, and focus the analysis on the impact on IH and its three components (wall materials, tenure status, and crowding conditions). We also study the impact on additional outcomes related to housing, labor market and migration conditions. This will allow us to explore the potential mechanism mediating the causal relationship between transit infrastructure and IH. The specification considers the same control than in the event study, i.e., household head's characteristics (age, education, sex, and marital status), dependency rate, household expenditure (in logs), household size and neighborhood fixed effects. Table **??** presents the estimation results for different buffer's sizes.

It can be seen that the provision of new transport infrastructure significantly reduces IH. Interestingly, our estimates are decreasing with the distance to Line H, indicating that the impact depends on the treatment intensity, i.e., the higher the access, the higher the reduction in IH. In particular, for households located up to 500 meters, IH dropped in 15 p.p., whereas for households located up to 1,500 meters IH dropped in 11.6 p.p.. Results suggest that the transit infrastructure not only improves access to city amenities and job opportunities, but also improves housing physical conditions. It is important to note that these results also hold for the model without controls (see Table 4).

Table 4: Impact of transit infrastructure on Informal housing

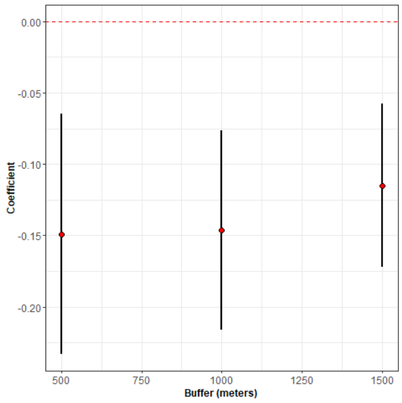
	500	**1000**	**1500**	**500**	**1000**	**1500**
Time × Treatment	−0.149***	−0.146***	−0.115***	−0.152***	−0.158***	−0.118***
	(0.043)	(0.036)	(0.029)	(0.045)	(0.037)	(0.030)
Time dummy	0.021	0.017	0.009	0.021	0.023	0.012
	(0.020)	(0.016)	(0.011)	(0.021)	(0.016)	(0.011)
Treatment	0.186***	0.188***	0.133*	0.152***	0.147***	0.130***
	(0.068)	(0.066)	(0.080)	(0.035)	(0.030)	(0.024)
Constant	1.216***	1.035***	0.963***	0.066***	0.055***	0.054***
	(0.297)	(0.232)	(0.179)	(0.014)	(0.010)	(0.008)
Controls	Yes	Yes	Yes	No	No	No
Neighborhood FE	Yes	Yes	Yes	Yes	Yes	Yes
N	966	1312	2281	980	1330	2316
Adj. R-squared	0.119	0.112	0.079	0.027	0.028	0.021
F Statistic	6.909***	6.901***	6.021***	9.904***	13.660***	17.853***

***p < .01; **p < .05; *p < .1
Source: Author's calculations

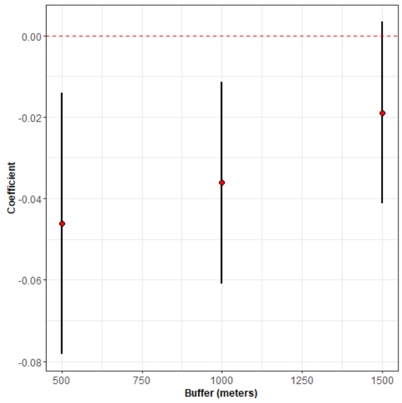
Figure 5 presents the estimated effects of Line H on the three components of IH, showing that tenure insecurity and crowding decrease for all buffer's sizes. Improvements in tenure status can be related to the higher incentives to invest in housing as land rents are expected to rise (see c.f. McIntosh et al. 2018). In contrast, reductions in crowding levels might be the combined effect of better job opportunities and housing supply, and the reduction of household size[8].

[8]Family groups low-income neighborhoods are usually composed by more than two generations, i.e., parents, sons and grandchildren. This is consequence of high incidence of early pregnancy, high housing cost and economic restrictions for afford housing investment. Once economic conditions improve households tend to either reallocate family groups by emancipation, or build new rooms or floors on the original family house. In fact, using ECV 2018, we find that average household size in treatment zone (using the 1,500 meters buffer) reduces to 3.57, almost 10%

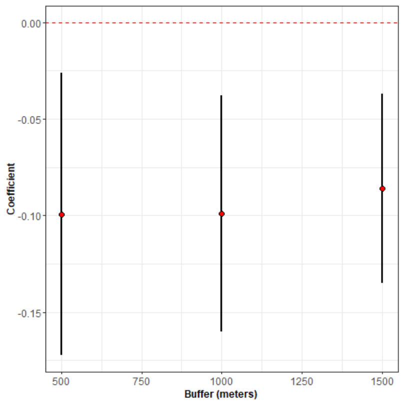
Figure 5: Impact of transit infrastructure on housing informality outcomes



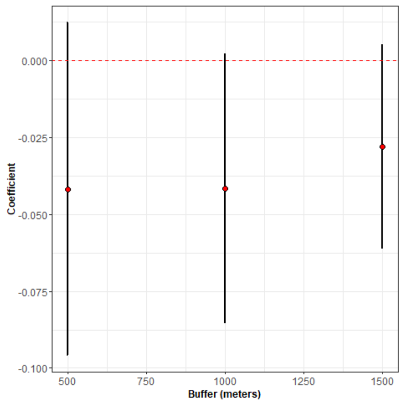
(a) Housing informality



(b) Tenure status



(c) House crowding



(d) Walls material

Source: Authors' calculations.

Finally, our estimates provide evidence that Line H positively impacts the walls quality, although these results are not significant. A possible explanation for this result is that, unlike the other two components of the IH indicator, walls quality is a structural feature of the dwelling that might require a higher amount of investment and time to be changed. Summing up, all previous results reveal the existence of a strong link between transport infrastructure improvements and housing conditions in low-income neighborhoods.

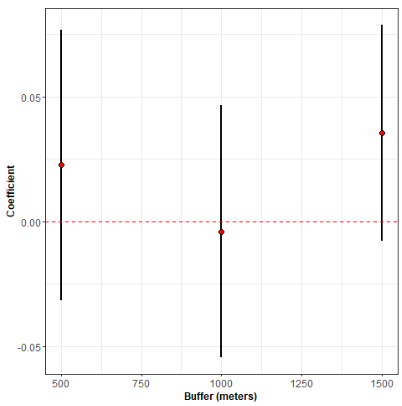
To provide additional evidence supporting these findings, we study whether transit intervention changes housing supply and transportation conditions. Considering the available information in ECV, we first estimate the effect of Line H on household's perception about the housing supply in the neighborhood, which is captured in the survey using a scale that allows to discriminate whether a household head thinks that housing supply has increased in the neighborhood. The coefficients plotted in Figure 8 suggests that the transit infrastructure provision increases the perception of that housing supply improved up to 14.4 p.p., at the 1,500 meters buffer. Similarly, as expected, using the perception of households on how transportation service has changed in the neighborhood, we observed an increase in more than 10 p.p. (see Figure 8). This is validated by the fact that travel times to workplace is significantly reduced as shown in Figure 8.

To explore the mediating mechanisms behind the causal relation of interest, we study the impact of Line H on variables related to land rents, migration decisions, and labor market. Regarding land values, it is well known that individuals value time, and hence, if accessibility increases, land competition is stronger and housing rents tend to increase. As a result, households has stronger incentives to invest in housing, which is expected to reduce IH. Regarding migration, on the one hand, given that the Metrocable connects remote locations, migration and squatting of low-income households could increase, thus raising urban sprawl and IH. On the other hand, because Metrocable makes more attractive the neighborhoods near the stations, high income households could be more willing to compete for housing in these locations, which in turn can decrease IH throught housing quality improvements.

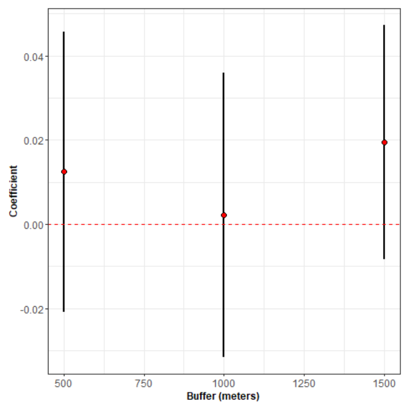
Labor market outcomes can also act as a mediating channel of the causal relation of interest. In particular, according to the spatial mismatch mechanisms, higher urban accessibility is related to better labor market indicators. Specifically, we might expect to observe lower unemployment rates, higher formality rates and higher labor income in locations with higher accessibility. Labor market outcomes are strongly related to household's wellbeing and housing quality so that reduction in IH can be expected after improvements in transport infrastructure provision. Here, it is important to notice that zones around the oldest Metrocable's lines became touristic places. For instance, in comuna 13 served by Line J, inhabitants have developed local services for visitors which provide new opportunities for income generation. However, some of the services are based on small business that are not necessarily formal. This implies that while the expected effect of Line H on labor income is positive, that for informality might be ambiguous.

We explore the relevance of these three channels using information on migration and housing rents at the household level, and information about labor market outcomes at the individual level. To do so, we use dummy variables that identify whether a household has lived in a different neighborhood (within city migration) or in a different city (between city migration) 24 months ago. Results show positive but not significant effects of Line H on migration (see Figure 6). Although coefficients are not statistically significant, it can be noted that the effect on local migration is higher. This can be explained by the lower moving cost and the expected reallocation of economic activities within the city.

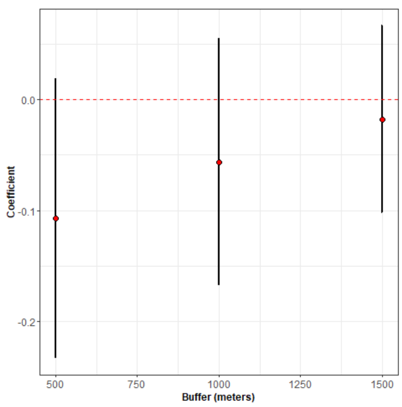
Figure 6: Impact of transit infrastructure on migration and rent values



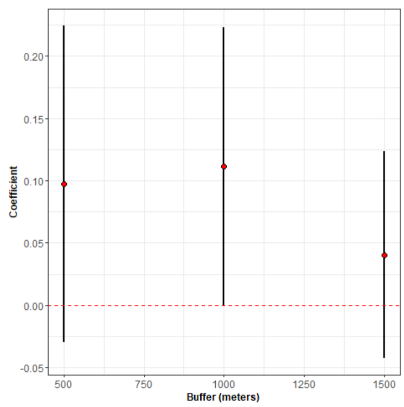
(a) Neighborhood migration



(b) City migration



(c) Rent value (in logs)



(d) Subjective rent (in logs)

Source: Authors' calculations.

To study the impact of Line H on land rents, we use two outcomes: the housing rent paid by tenants and the value that owners are willing to receive if they rent their properties (apparent rent). The evidence suggests that while rents paid by tenants keep unaltered, the apparent rent significantly increase (see Figure 6). This result is consistent with previous literature that document a positive relation between higher access and land rents. Besides, as housing is an important asset for low-income households, if owners expect a higher return of land tenure, it can influence the incentives to have regular tenure.

To study the impact of Line H on labor markets, we consider the following individual outcomes: the unemployment status, the informality status and labor income. In this specification, we use demographic characteristics at the individual level (age, sex, education and marital status) instead than household level. Coefficients in Figure 7 suggest that there is not composition effect within the working age population. That is, changes in unemployment and employment status are not significant and point estimates are close to zero. However, we observe a reallocation effect among employed as informality status seems to be negatively impacted. For all buffers, the point estimates are higher than 5 p.p., although not significant. In sharp contrast, there is a remarkable increase in the labor income (in more than 15 p.p) specially in the neighborhoods closer to the Line H. These results are similar to previous findings by Rotger & Nielsen (2015), Moreno-Monroy & Roman (2015), Hu (2017), Suárez et al. (2016), and Oviedo et al. (2019).

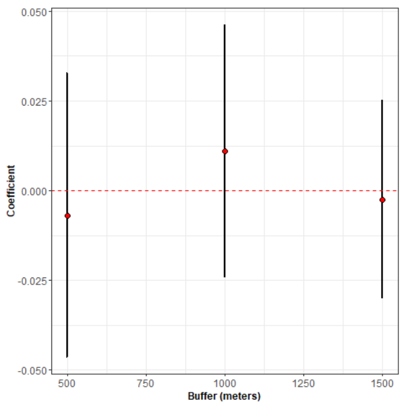
Summing up, all these results imply that reductions in IH can be mediated by the improvements in labor income and job quality. This channel confirms the previous findings by Bonet-Morón et al. (2016) in Colombia on the positive correlation between labor and urban informality.

5 Robustness checks

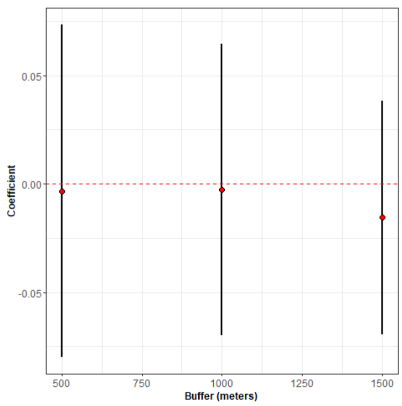
To validate our previous findings, some robustness checks are provided. Particularly, we contrast whether the estimation results are sensitive to the definition of treatment and control zones. Our benchmark estimation assumes that Line H does not influence the south neighborhoods of the Santa Elena water stream. In this way, our first estimation is based on an asymmetrical spatial buffer around to the transport intervention.

Therefore, we define an alternative treatment zone that neglects the presence of the water stream.

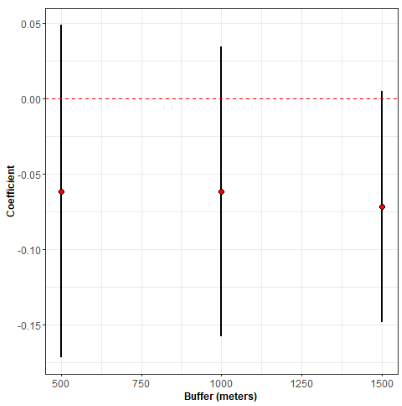
Figure 7: Impact of transit infrastructure on labor market outcomes



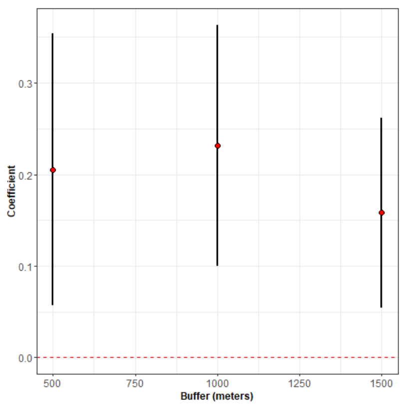
(a) Unemployment status



(b) Employment status



(c) Informality status



(d) Labor income (in logs)

Source: Authors' calculations.

Figure 9 presents the estimation results of a selected set of outcomes. The effects of Line H on IH and its three components are similar to our benchmark results, although coefficients are slightly lower. For instance, at the 500 meters buffer, Line H reduces IH in 12.6 p.p., 3 p.p. lower compared with the baseline estimation. The effects of Line H on household's perception on housing and transport conditions are also quantitatively the same. Regarding the analysis of potential mediating mechanisms, estimation results are similar but some variations are worthy to remark. The impact of Line H on city migration is higher than in the baseline scenario and it is statistically significant at the

10% significance level. In the case of labor informality, the estimated impact become significant. Finally, results for labor income remain statistically significant. Overall, this confirms that labor market is an important channel to explain the impact of Line H on IH.

As mentioned before, we defined select some neighborhoods in comuna 6 as a control. This type of empirical strategy has been widely used and accepted in previous work. However, it is important to test whether our results hold for a different definition of the control zone. Therefore, we use as an alternative control zone the rest of the neighborhoods of the city except those that are close to a Line H's buffer. In this way, we control for the possible existence of spillover effects. In particular, we consider a control zone integrated by neighborhoods whose centroids are at a distance of of three kilometers or more of the Line H. Similar strategy has been used by Glaeser et al. (2008); Gibbons & Machin (2008); and Dustan & Ngo (2018).

Figure 10 shows that in this case estimation results are similar. Importantly, the estimated effect on the household's perception about transport quality is higher than in the baseline case (15 p.p.). Additionally, the estimated effects on walls quality, city migration and neighborhood migration become statistically significant. This suggests that the reallocation of households can also be a potential channel to explain the total impact of transit infrastructure improvements on IH.

6 Concluding remarks

A high proportion of urban growth in developing countries takes the form of IH, a dwelling solution characterized by the poor quality of building materials, insecure tenure, and overcrowding. IH is usually present in IS, areas with a poor access to the city. This lack of accessibility determines the living conditions and job opportunities of the inhabitants. Providing new transit infrastructure is a crucial policy to generate social and economic inclusion to households living in IH and IS. In Medellin, as well in other cities with a high geographical variability, cable car transport system has been promoted to connect IS to the rest of the city.

On this regard, there is both theoretical and empirical work exploring to what extent transit infrastructure policies affect the living conditions and labor market outcomes. For the case of Medellín, the impact of the Metrocable on crime and rent values has been examined. However, evidence of the impact on housing informality has been less investigated. We study the case of an expansion of the Metrocable in Medellin, using a difference in difference identification strategy. Our results suggest that Line H leads to an important reduction in IH levels, and that labor market is a strong channel driving this relation. Besides, perception on land value and migration are alternative channels that also turn out relevant according to our estimates.

From a public policy perspective, our results contribute to the discussion on the wider economic benefits of transportation policies in the developing world. In particular, we confirm the result in previous literature stating that policies improving access to transit in unserved areas can plausibly expand residential opportunities for the poor and reduce spatial inequities. Moreover, we document that, although the main goal of these policies is provide access to improve economic opportunities of households, additional gains are obtained in term of housing quality.

Besides, we also provide evidence on the spatial heterogeneous impact of the transportation intervention as the distance to the transit infrastructure seems to be crucial. Hence, transport planning might take this factor into consideration to define transportation plans. In the light of these findings, it is relevant to completely assess the impact of transit interventions on different dimensions of social welfare in low-income neighborhood context, and to compare to alternative interventions aiming to reduce the access cost through transportation subsidies (Berg et al. 2017, Börjesson et al. 2020, Gallego et al. 2019, Serebrisky et al. 2009, see c.f. Su & DeSalvo 2008).

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8 Appendix

Table 5: Event study for Tenure

	500	**1000**	**1500**
D_{2013}	0.021	0.008	0.004
	(0.023)	(0.020)	(0.015)
D_{2014}	0.013	0.015	0.014
	(0.021)	(0.018)	(0.013)
D_{2016}	−0.007	−0.004	0.005
	(0.023)	(0.019)	(0.015)
D_{2018}	−0.050**	−0.036**	−0.013
	(0.021)	(0.016)	(0.014)
N	2880	3914	6811
Adj. R-squared	0.018	0.022	0.018
F Statistic	2.858***	3.576***	3.740***

***p < .01; **p < .05; *p < .1
Source: Author's calculations

Table 6: Event study for Crowding

	500	**1000**	**1500**
D_{2013}	−0.035	−0.041	−0.035
	(0.039)	(0.036)	(0.027)
D_{2014}	−0.024	−0.035	−0.013
	(0.039)	(0.036)	(0.028)
D_{2016}	−0.003	−0.026	−0.003
	(0.041)	(0.038)	(0.029)
D_{2018}	−0.097**	−0.122***	−0.088***
	(0.039)	(0.034)	(0.027)
N	2880	3914	6811
Adj. R-squared	0.099	0.096	0.077
F Statistic	12.257***	13.227***	13.657***

***p < .01; **p < .05; *p < .1
Source: Author's calculations

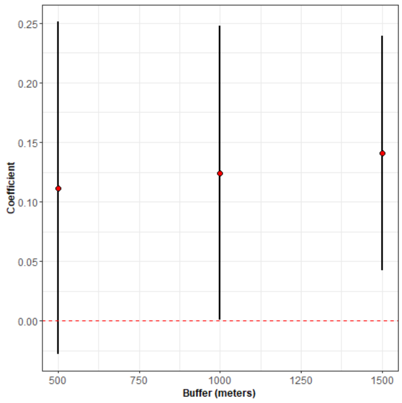
Table 7: Event study for Walls

	500	**1000**	**1500**
D_{2013}	-0.029	-0.023	-0.015
	(0.028)	(0.024)	(0.017)
D_{2014}	-0.061^{*}	-0.050^{**}	-0.030^{*}
	(0.027)	(0.023)	(0.016)
D_{2016}	-0.018	-0.011	0.002
	(0.032)	(0.027)	(0.019)
D_{2018}	-0.057^{**}	-0.051^{**}	-0.025
	(0.028)	(0.023)	(0.016)
N	2880	3914	6811
Adj. R-squared	0.078	0.072	0.050
F Statistic	9.646^{***}	9.887^{***}	8.957^{***}

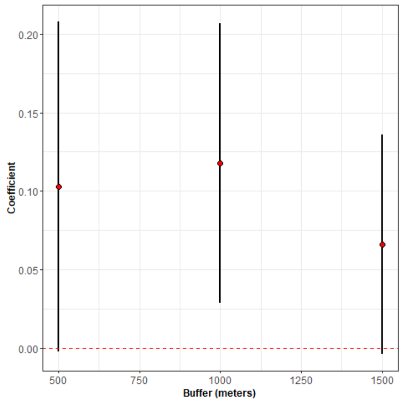
$^{***}p < .01$; $^{**}p < .05$; $^{*}p < .1$

Source: Author's calculations

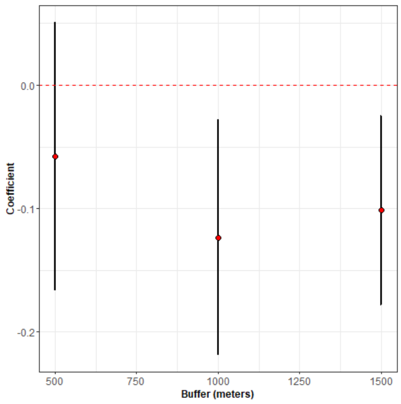
Figure 8: Impact of transit infrastructure on the housing supply, transportation conditions and travel times to workplace



(a) Housing supply



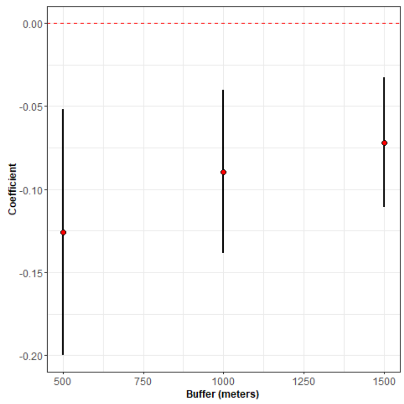
(b) Transportation supply



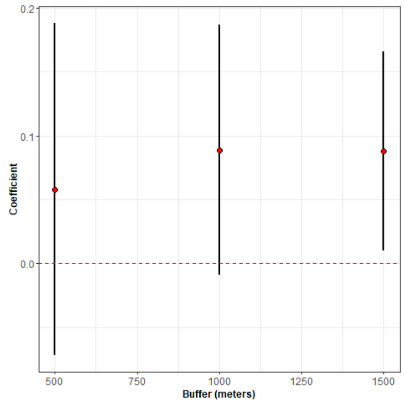
(c) Time to workplace

Source: Authors' calculations.

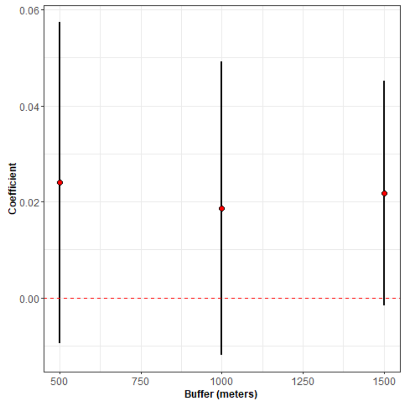
Figure 9: Impact of transit infrastructure on different outcomes: Robustness check of the treatment zone



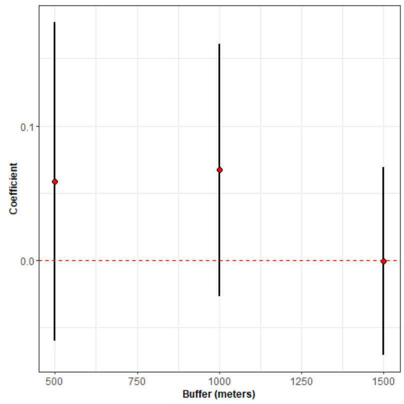
(a) Housing informality



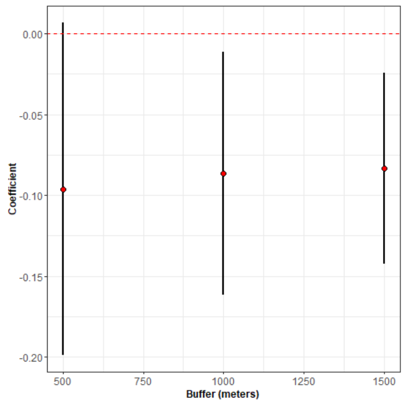
(b) Housing supply



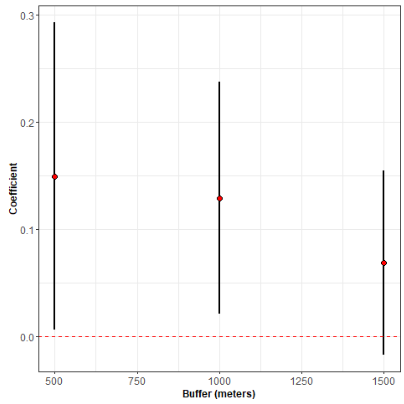
(c) City migration



(d) Subjective rent (in logs)



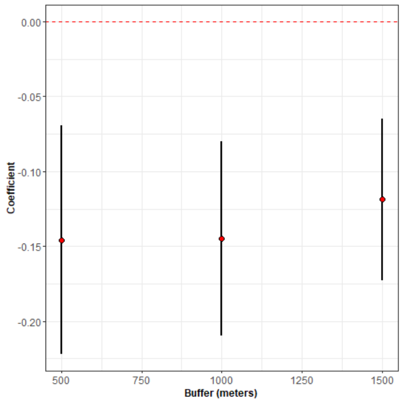
(e) Informality status



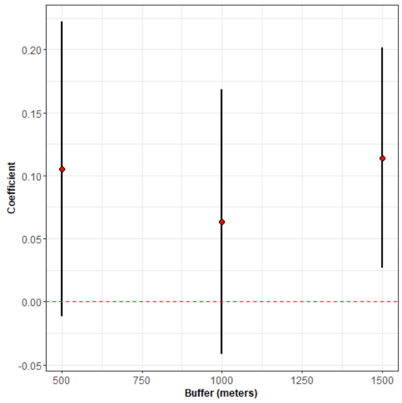
(f) Labor income (in logs)

Source: Authors' calculations.

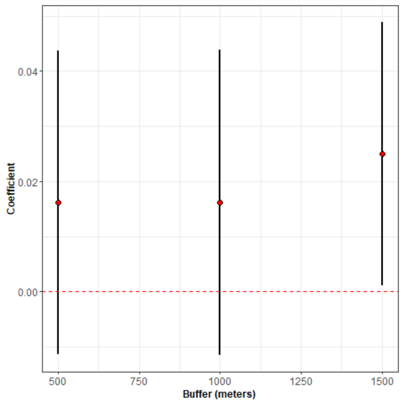
Figure 10: Impact of transit infrastructure on different outcomes: Robustness check of the control zone



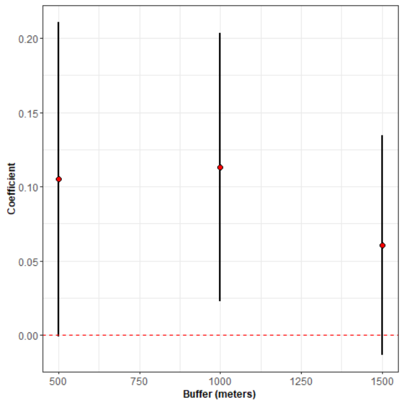
(a) Housing informality



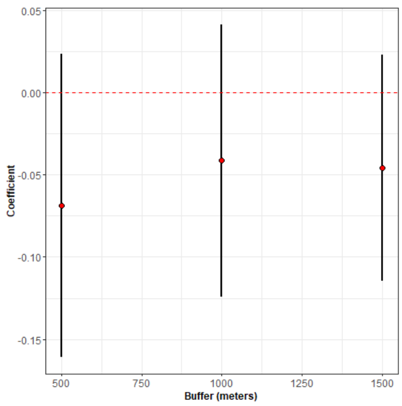
(b) Housing supply



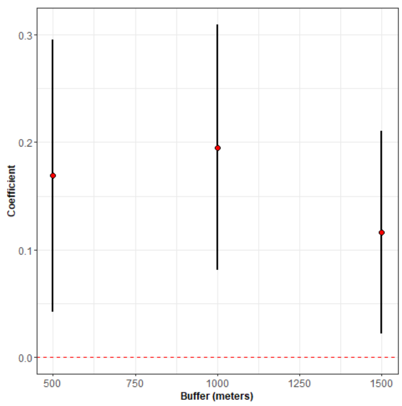
(c) City migration



(d) Subjective rent (in logs)



(e) Informality status



(f) Labor income (in logs)

Source: Authors' calculations.

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