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The external effects of public housing developments on informal housing: The case of Medellín, Colombia☆

Héctor M. Posada[a,1], Andres García-Suaza[b,1], David Londoño[a,1]

[a] Universidad de Antioquia, Colombia
[b] School of Economics, Universidad del Rosario, Colombia

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ABSTRACT

The provision of new subsidized housing projects presents an effective solution for alleviating the significant housing deficit in developing countries. However, limited knowledge exists regarding how these housing projects impact the quality of the surrounding environment, particularly when situated near informal settlements. By using highly detailed data from Medellin, Colombia, and employing an instrumental variables strategy, we estimate the external effects of social housing programs on the neighboring communities. Our results demonstrate that these projects contribute to a reduction in informal housing, poverty levels, and crime within the surrounding neighborhood. This external effect is significant and often overlooked when assessing the overall returns of social housing programs.

1. Introduction

One in three households in Colombian and Latin-American cities live in a precarious dwelling, defined by tenure insecurity, poor-quality materials, low access to public services or overcrowding (Daude et al., 2017). Faced with this situation, the governments of the region have promoted different policies to mitigate this housing deficit. In Colombia, an important share of the resources for housing and habitat improvement programs is channelled through the development of real estate projects known as Social Interest Housing or Priority Interest Housing programs (VIS and VIP, for its Spanish acronyms). Under these programs, beneficiary households buy new homes with subsidized prices and interest rates. For example, Mi Casa Ya program (see Minvivienda, 2015) has subsidized 162,000 households to purchase their own homes since 2015. Recent evidence revealed that this program has generated significant reductions in poverty and improvements in employment in directly benefited households (Lopez, 2021).

The impacts of public housing projects go beyond their directly benefited households. They can significantly affect their surrounding habitat, particularly because public housing in Colombia is often found on the peripheries, close to large informal urban settlements due to space restrictions and high land prices in the city center. We highlight the potential ambiguous effect of public housing projects on the quality of housing in their areas of influence. For example, projects could stimulate precarious housing by inducing migration of low-income households, seeking to take advantage of improved urban infrastructure. At the same time, the quality of VIS housing may not represent an improvement over current conditions and replicate the same social problems of the settlements, further depressing the area where they are located. These projects could also generate positive externalities in the neighborhood. For example, they could build trust in the private sector and incentivize housing construction through a demonstration effect (see Schwartz et al., 2006, for a detailed discussion). At the same time, expansions to public infrastructure like roads and utilities could improve the quality of the habitat.

Verifying the effect is important from an academic point of view, especially in a developing country. There is abundant evidence of the positive impacts of social housing projects in the North American case. Consistently, previous studies have shown that the provision of public housing in New York led to renovation processes in their areas of

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E-mail addresses: hector.posada@udea.edu.co (H.M. Posada), andres.garcia@urosario.edu.co (A. García-Suaza), david.londonoa@udea.edu.co (D. Londoño).

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influence(see Ellen et al., 2001; Schwartz et al., 2006; Baum-Snow and Marion, 2009), increasing economic activity, reducing poverty and crime rates (see Freeman, 2003; Freedman and Owens, 2011; Diamond and McQuade, 2019; González-Pampillón, 2022). In comparison, little is known about the impacts of social housing projects when these projects are built in cities with large housing deficits, informal settlements and a high potential for rural-urban migration. From a public policy point of view, it is important to judge the effectiveness of housing provision, particularly considering that this policy competes with other alternatives, such as habitat improvements and rental subsidies, that have proven to be superior in the North American case (see Olsen et al., 2005, for a discussion of alternative policy instruments). Using highly granular public information from Medellin, Colombia and an Instrumental Variables identification strategy, in this paper we estimate the external effects of new social housing projects (VIS) on housing quality indicators of their neighborhood, characterized by high levels of informal housing. Our basic measure of housing quality is built as the proportion of households in the neighborhood that lives in an informal housing according to the definition of UN-Habitat (2003). Specifically, a household lives in an informal house when it exhibits at least one of the following: overcrowding, inadequate connection to water and sewage and low quality walls or flooring. To explore the potential mechanisms that explain our main results, we also estimate the external effects of VIS on each one of the mentioned individual components of the informal housing indicator. Additionally, we estimate the effects of VIS on crime incidence, multidimensional poverty, unemployment rate and migration in order to fully understand the spatial spillovers of VIS projects.

We instrument the indirect exposition of a neighborhood to public housing projects with the surrounding geological suitability. We show that worse surrounding suitability leads to lower public housing, supporting the relevance condition required for an instrument to be valid. At the same time, we argue that the instrument is not affected by non-observable characteristics that also affect informal housing, given the nature of our instrument, a structural feature of the land not easily affected by human activity. In particular, conditional on predetermined land values and geological suitability inside the neighborhood, surrounding suitability does not affect informal housing inside except through its influence on VIS projects around. We provide some evidence of the exclusion restriction by running a placebo test as proposed by Van Kippersluis and Rietveld (2018). Results from this test support the idea behind exclusion restriction.

Our main results suggest that greater indirect exposure of the neighborhood to public housing projects leads to a significant drop in informal housing. Specifically, a 10% increase in exposure to VIS projects reduces informal housing by 4%. These results are robust to different treatment and instrument definitions, as well as geographic units of analysis. We also observed that new VIS projects reduce poverty and crime and increase land values in the neighborhood. These results reveal that VIS projects are not only important for their direct effects on reducing the quantitative housing deficit but also for indirectly helping to reduce the qualitative housing deficit in their areas of influence.

We organized the rest of the paper as follows. Section 2 summarizes the literature that studies the indirect impacts of public housing. Section 3 describes the housing sector and the socioeconomic conditions of Medellín. Section 4 describes the data, the construction of the indicators and the empirical strategy, including the instrumental variable. Section 5 shows descriptive statistics. Section 6 presents the main findings and Section 7 the robustness checks. Finally, Section 8 presents the main conclusions.

2. Related literature

Our study contributes to the growing literature on the effects of public housing projects in developing countries. Previous studies have focused on analyzing the effects of this policy on the benefited households. Franklin (2020) reveals how the national public housing program in South Africa improved employment in women. In this work, the distance between the city centers and the projects is used to control for the effects of location. Then, the results are interpreted as the effects for households of moving to formal housing. However, Picarelli (2019) shows for this same program that new projects located in disconnected areas of the cities, generated worse results in the labor market for the families. Based on experimental evidence Alzúa and J.Cruces (2016) and Chagas and Rocha (2019) indicate that households benefiting from public housing projects exhibit worse outcomes because the projects were far from the main urban employment centers in Argentina and Brazil. In Colombia, the work of Camacho-González et al. (2022) exploits that 38% of the beneficiaries were selected through a lottery to show that beneficiary households exhibit better employment indicators, explained by the proximity of housing to the opportunities offered by the cities. Similar results were found for VIS housing by Lopez, 2021. In summary, the evidence shows that public housing projects generate positive effects on household employment indicators when they are close to job opportunities and have good construction quality.

There is abundant evidence of the spillover effects of public housing projects in developed countries, especially the US. For New York, Ellen et al. (2001) and Schwartz et al. (2006) indicate how public housing projects in New York positively affect housing prices in surrounding areas. These authors explain that these projects make neighborhoods more attractive to investors and families alike, increasing demand in these zones. Nonetheless, the effects of new housing projects on prices may differ depending on the timing and the context in which they are analyzed. For example, Santiago et al. (2001) show that the effects of subsidized housing on property prices in Denver disappear over time, and become negative when neighborhoods are primarily Afro-descendant. Similarly, Asquith et al. (2021) and Daminger (2021) report negative effects on rental value, accompanied by increased immigration in low-income neighborhoods, while Diamond and McQuade (2019) document heterogeneous effects as a function of neighborhood income conditions, finding negative impacts on property values in high-income neighborhoods.

The evidence for developed countries also shows that interventions of larger scales have bigger effects on prices (Ellen et al., 2001; Santiago et al., 2001; Ellen et al., 2007; Voith et al., 2022). Additionally, Funderburg and MacDonald (2010) show that the LIHTC development programs for new housing projects in Iowa have effects that persist in the medium term (5 years or more), while Voith et al. (2022) shows that the effects persist 10 years after the intervention.

The literature for developed countries also studies the effects of public housing on poverty, household income, and crime incidence, showing mixed results (see Varady, 1982; Agnew, 2010, for an extensive discussion). The seminal study by Freeman (2003) shows that in the United States, subsidized housing programs did not concentrate poverty while Olsen et al. (2005), Susin (2005) and Saraswat (2021) reveal that housing projects led to increases in income and improvements in working conditions. In contrast, Baum-Snow and Marion (2009) find that LIHTC developments in Chicago decreased income because the program led to the influx of low-income households.

In contrast, little is known about the effects of these types of projects on developing countries. One exception is González-Pampillón (2022), showing that in Montevideo, Uruguay, a stimulus to housing supply in middle-class neighborhoods generates price increases in surrounding areas. Nonetheless, to the best of our knowledge, the only study that analyzes the effects of new housing projects on informal housing is Gechter and Tsivanidis (2020). Using a differences-in-differences strategy and unexpected changes in regulation as a source of exogenous variation, this study shows that the construction of new buildings in downtown areas of the city of Mumbai leads to reductions in informal housing and informal employment in the surrounding areas.

Our study help to elucidate particular features of the external effects of new public housing projects in developing countries. Social housing projects in Medellín are in most cases located in peripheral zones, far from the industrial and commercial centers and far from large private land developments. Also, these projects are developed into highly crowded zones of the city with high levels of poverty and housing deprivations. As a consequence, compared with the closely related work of Gechter and Tsivanidis (2020) where housing projects are located in the city center of Mumbai, in our study is less likely to see high scale gentrification processes and drastic changes in land use patterns, thus making our design especially helpful to identify how poor households in poor neighborhoods im- prove their dwellings as a result of new nearby large social housing projects. This in turn can help us to better illustrate the full potential of social housing projects in reducing poverty rates. Finally, we highlight two attributes of our exercise which help us to improve the identification of our causal effects of interest. First, we use census data to accurately measure informal housing in small geographic units in order to obtain a high degree of spatial granularity. Second, our instrumental variables identification strategy takes advantage of the geological quality of the land as a source of exogenous variation of the treatment variable, conditional on a rich number of socioeconomic and urban indicators.

3. Socioeconomic context and the social interest housing policy in Colombia

During the second half of the 20th century, Colombia experienced a process of rapid urbanization, industrialization and migration of low-income families from rural areas to cities. This accelerated growth implied challenges to the provision of housing. As a result, in 2020 about 5.1 million households (20.8% of total), experienced some form of housing deficit (DANE, 2021; Departamento Nacional de Planeación, 2021).

In response to these circumstances, different policies have been deployed in Colombia, including providing new social interest housing (VIS, for its Spanish acronym). A VIS is a housing unit whose value does not exceed 135 Colombian Minimum Legal Wages (SMLMV, for its Spanish acronym). Currently, the program finances up to 80% of the property value, subsidizes up to 30 SMLMV of the initial fee, and up to 4 pp of the interest rate for seven years. Subsidies are delivered through financial institutions to households with incomes below 4 SMLMV and do not own their home (Minvivienda, 2015). In 2021, VIS programs benefited nearly 62 thousand households at the national level.

As in the rest of Colombia, Medellín[1] experienced a proliferation of informal settlements with significant housing deprivation. According to the 2020 Quality of Life report by Medellín Cómo Vamos[2] (Medellín Cómo Vamos, 2020), 17.9% of households lived in low quality housing in 2019. The city also exhibited an unemployment rate of 11.9% in 2018, which was higher than the national average rate (9.7%), and poverty and extreme poverty rates of 14.2% and 3.6%, respectively.

The informal urban growth and high poverty rates in Medellín can be seen in the form of stark spatial inequalities. As shown in Fig. 1a, precarious housing is mainly located on the slopes of the periphery to the east and west of the city, where the highest rates of multi-dimensional poverty are also found (see Fig. 1b). These areas are characterized by steep slopes (see Fig. 2a), narrow and unplanned streets and lagging infrastructure, implying low access to jobs (see Fig. 2b) and other opportunities.

One frequently examined feature of VIS projects is their location. It is common for these projects to be developed where land prices are low to minimize construction costs and make housing affordable. However, the location of these projects can force households to move away from the opportunities offered by the city. Fig. 3a shows the location of the VIS projects built in Medellín between 2004 and 2018, along with their size and the average land value per square meter in 2020. Although VIS projects can be found throughout the city, the most extensive projects are concentrated in the center-west in a sector known as Pajarito. There is also an important concentration of projects in the center-east, in the extreme southwest in the district of San Antonio de Prado, and in the south in Belén neighborhood. Another group of small-scale projects can be found in the city center. It is observed then that the VIS projects are concentrated precisely in areas with low land values per square meter, low accessibility, and especially in areas with a high incidence of informal housing.

[2]Medellín Cómo Vamos is a private alliance that examines the evolution of different socioeconomic indicators of the city of Medellín using information from the National Census of the year 2018 and the annual Quality of Life Survey of Medellín.

4. Empirical strategy

4.1. Unit of analysis and sample

The households data is obtained from the Colombian National Census of 2018. The data is georeferenced at census block level, which is the smallest geographical area defined by the census. In our main estimation, the census block will be used as the unit of analysis. In total, there are 11,201 census blocks. This high spatial granularity allows us to minimize measurement errors that arise when larger areas are used.

Considering that new public housing directly changes the housing stock inside the census block, our sample is limited to blocks that do not have any projects. In addition, recognizing that certain zones from the city have no probability of being treated, we also limit our sample to blocks within 400 m of a VIS project, looking to have only blocks that could have been treated but that, for different reasons, have greater or lesser exposure. Consequently, our sample size is reduced to 4,619 blocks. Fig. 5a classifies blocks with VIS projects, blocks that are indirectly exposed to VIS housing (our sample), and blocks far away from any project. Despite the small size of census blocks, their irregular shapes and sizes could improperly influence treatment measurements. To check the robustness of our results, we also use uniform grids of 70 $\times$ 70 m^2, similar in size to the average block, as the geographical unit of analysis. In this case, the sample size is 6,062 units.

4.2. Data and variables

To build our exposure to treatment indicators, this paper uses data generously provided by the Colombian Chamber of Construction of public housing projects built in Medellin between 2004 and 2018. We have information of their precise location as well as the number of blocks, apartments and square meters. Our main treatment variable is based on the accessibility index proposed by Hansen (1959):

$$VIS \quad Exposure_i = \sum_{s=1}^{S} \frac{VIS_s}{d_{is}} \tag{1}$$

where $VIS \quad Exposure_i$ represents the indicator of indirect exposure to VIS housing at census block i, VIS_s is the percentage of VIS housing (as a fraction of the total square meters or housing units built in the city) at location s, and d_{is} is the distance between census block i and location s. Accordingly, location i will experience a greater exposure to VIS when it is closer to areas with larger housing projects. We take the logarithm of this measure to reduce the influence of outliers in the regressions. Fig. 3b shows the spatial distribution of the VIS housing exposure index. As expected, the highest levels of exposure are concentrated in the center-west, the center-east, and the southwest zones of the city.

Using the National Census of Colombia for 2018, we compute the informal housing indicator following the recommendations by UN-Habitat (2003). A house is considered to be precarious or informal

[1] With a population of approximately 2.4 million inhabitants and a 7% share of the national GDP, Medellin is the second most important city in Colombia. Medellín is located in the northwest of the country, in the middle of a narrow valley between the central and western Andes mountain ranges and is crossed from north to south by a river that bears the same name.

[2] 2Medellín Cómo Vamos is a private alliance that examines the evolution of different socioeconomic indicators of the city of Medellín using information from the National Census of the year 2018 and the annual Quality of Life Survey of Medellín.

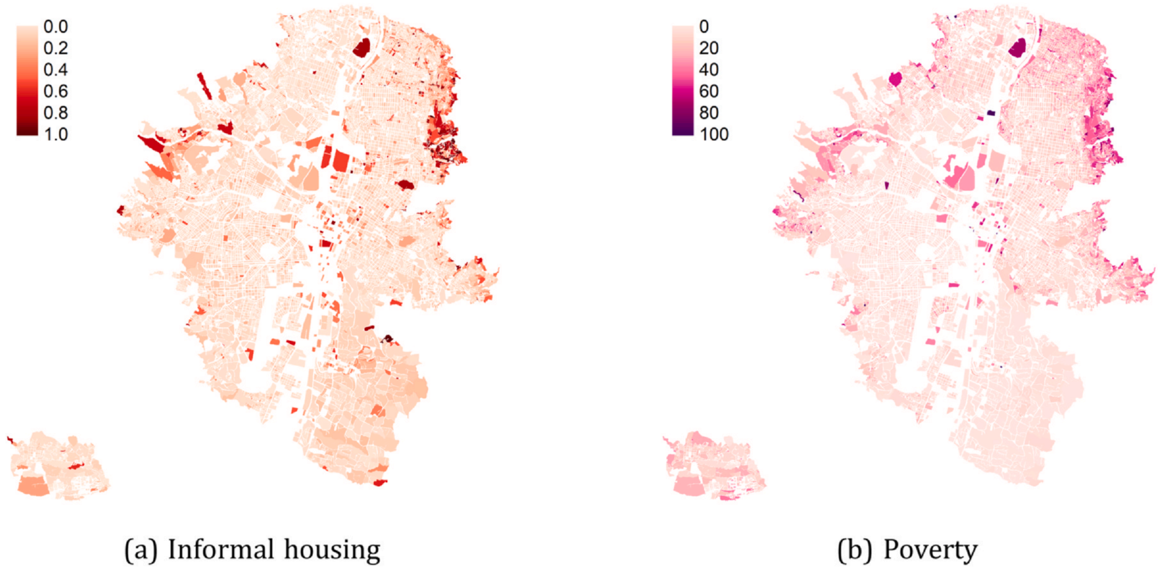


Fig. 1. Informal housing and Poverty. Panel a shows Informal housing rates, and panel b shows Poverty rates. Author's calculations. Colombian Census, 2018.

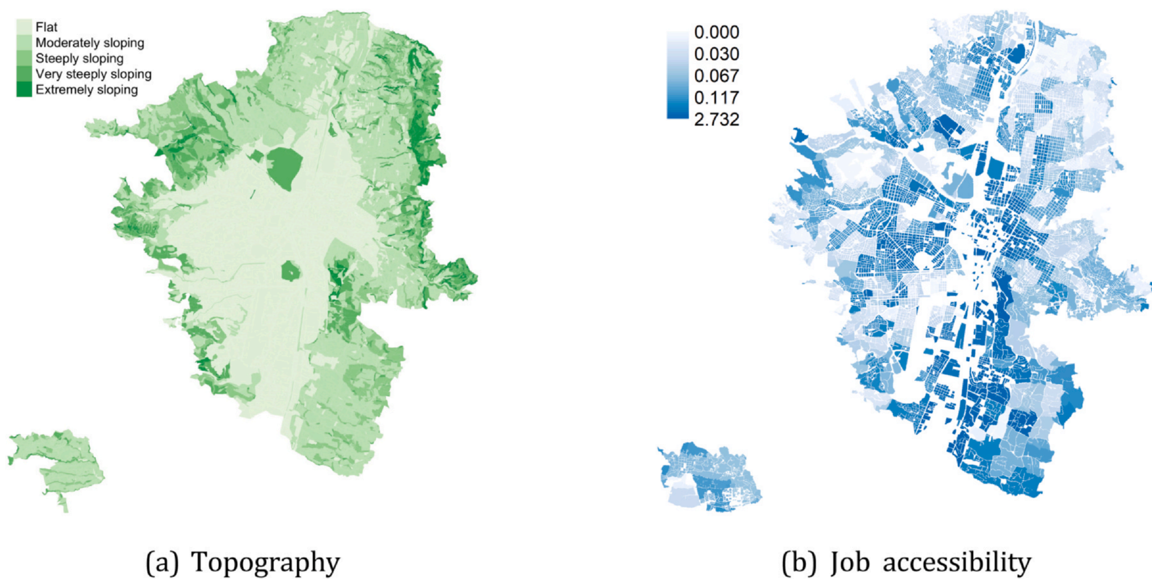


Fig. 2. Job accesibility and Slopes. Panel a presents land classification according to its slope level, and panel b presents the Hansen's job accesibility index. Author's calculations. POT, 2014; OD, 2017.

when it exhibits at least one of the following: overcrowding, inadequate connection to water and sewage and low quality walls or flooring. From census data, we determine if a person migrated in the previous five years, as well as employment status. Crime data was obtained from the open data repository of the local government of Medellin (MedData). This data describes the coordinates and time of robberies reported to the police. The multidimensional poverty index[3] was obtained from the public repository of the Departamento Administrativo Nacional de Estadísticas (DANE, for its Spanish acronym).

Our instrumental variable is a binary variable that indicates if the land around the block is geologically unsuitable for construction. This variable is made using data from the 2006 Medellin's Zoning Plan (POT, for its Spanish acronym). In our exercise, we control for an extensive group of confounder variables which include the dependency rate, the average years of education, accessibility to employment, education and health opportunities, the slope of the terrain, the quality of the roads, the distances to the stations of the mass transportation system, the distance to the main roads. Crucially, we also control for the geological suitability inside the block, as well as its land values to close any undesired influence our instrument may have on outcome variables (we discuss the instrument and its validity in detail in the next Section). The distances to the transportation stations and main roads, the quality of the streets and average land rents were obtained from the 2014 POT. Finally, accessibility to opportunities was calculated from the 2017 Origin and Destination survey of the Aburra Valley Metropolitan Area.

4.3. Identification strategy

The purpose of this exercise is to estimate the effect of new public housing projects on housing quality, crime, migration, and poverty in

[3] The multidimensional poverty index is made up of 15 indicators organized into 5 dimensions that seek to capture the welfare conditions of households: education, childhood and youth, health, work, and access to public services and housing conditions. A household is considered poor when they have a level of deprivation in 33% of the 15 weighted indicators.

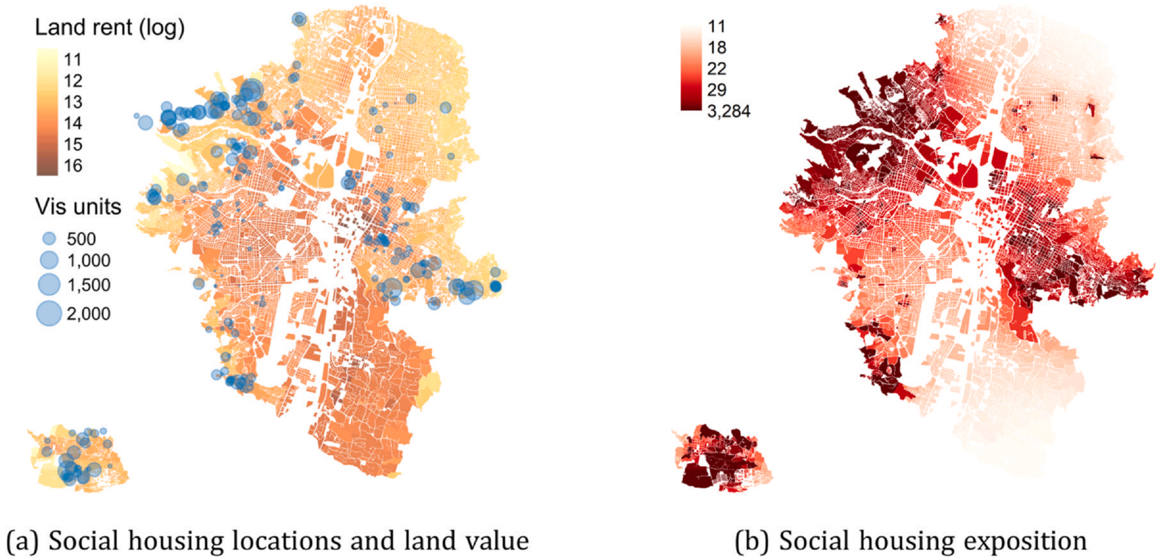


Fig. 3. Spatial distribution of VIS projects. Panel a shows the locations and sizes of VIS projects, together with land values per square meter in 2020. Panel b presents the indirect exposure to VIS defined in Eqn 1. Author's calculations. Camacol, 2020.

the neighborhood. To do this, the first approach is to estimate the parameter β in the following equation:

$$y_i = \beta\ VIS\ Exposure_i + \delta' \boldsymbol{X}_i + \varepsilon_i \tag{2}$$

where y_i is the outcome variable and $\boldsymbol{X}_i$ is the vector of control variables. However, the estimation of β in Eq. 2 through ordinary least squares is expected to produce a biased and inconsistent estimator. The location of VIS projects is non-random and probably depends on non-observable characteristics that simultaneously affect housing quality, like community organization, neighborhood and family support networks, future infrastructure and investment projects to be built in the area, causing an omitted variable bias. For example, neighborhoods with organized and proactive communities can generate collective actions to improve facades, legalize tenure, and incentivize public housing.

Therefore, the treatment variable $VIS\ Exposure_i$ and the error term ε_i are correlated and $\hat{\beta}$ does not reflect the causal effect of interest. To overcome the identification problems arising from the endogeneity of $VIS\ Exposure_i$, we use an instrumental variables identification strategy. The equations for the first stage and the reduced form are given by:

$$VIS\ Exposure_i = \rho_1 IV_i + \gamma_1' \boldsymbol{X}_i + v_{1i} \tag{3}$$

$$y_i = \rho_2 IV_i + \gamma_2' \boldsymbol{X}_i + v_{2i} \tag{4}$$

where IV_i is an instrumental variable. The causal effect of $VIS\ Exposure_i$ on y_i can be identified from the following expression:

$$\beta = \frac{\rho_1}{\rho_2} = \text{cov}(y_i, \widetilde{IV}_i)/\text{cov}(VIS\ Exposure_i, \widetilde{IV}_i) \tag{5}$$

where $\widetilde{IV}_i$ is the residual obtained from the regression of IV_i on the vector of covariates $\boldsymbol{X}_i$. The sample analog of the right-hand side of 5 is the instrumental variables estimator.

The instrument must meet two identification conditions. First, the instrument must have a high explanatory power over the treatment variable to meet the relevance assumption. Second, the instrument must not be correlated with ε_i. This is known as the exclusion restriction and it implies that the instrument is not affected by the same factors that affect the outcome and that the instrument only affects the outcomes through the treatment variable. For our estimation, we use the surrounding geological suitability of the census block as an instrumental variable for the indirect exposition of that particular census block to new public housing projects. Geological variables such as access to bedrock, seismic risk, landslide hazard or soil quality are popular instruments as they relate to construction cost and lower density and are not affected by potential causes of socioeconomic outcomes (Rosenthal and Strange, 2008; Combes et al., 2010; Rosenthal and Strange, 2020). Other examples that use geological variables as an instrument include Di Addario (2011); Hawley (2012); Curci, 2015; Liu (2017) and Duranton and Turner (2018). We further discuss the instrument and its validity in the next subsection.

4.4. Instrument construction

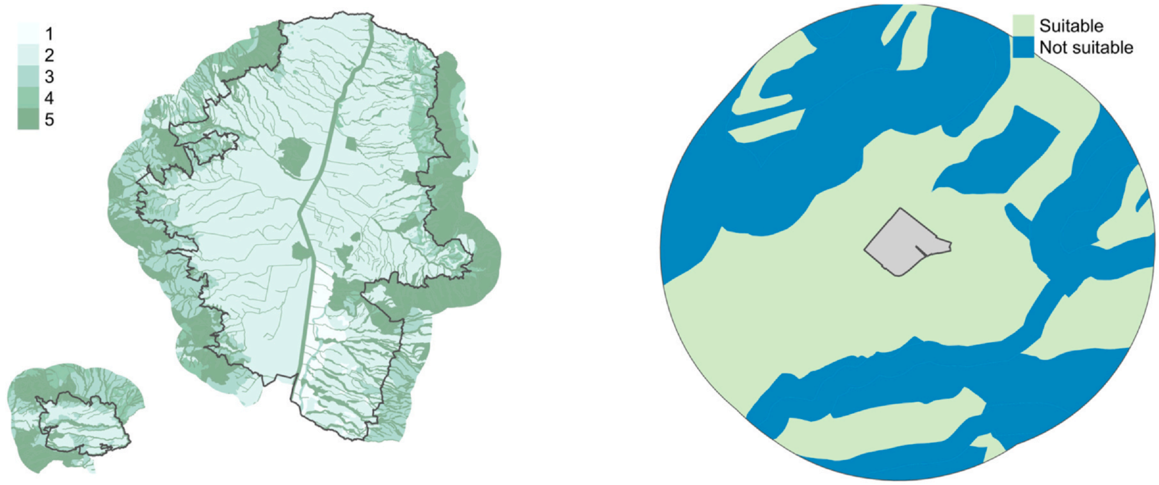
Geological data of Medellin was obtained from the 2006 POT. The POT in its 30th article classifies land zones into 5 categories according to the level of geological suitability. In zones 1, 2 and 3 the geologic, geomorphology, and topology conditions favor land occupation with little or no interventions. On the contrary, zones 4 and 5, geologic, geomorphology, and topology conditions make landslides, floods and other natural disasters highly probable, restricting land development. As we can see from Fig. 4a, land without favorable conditions for construction is concentrated in the periphery around hillside areas of the city, whereas land with favorable conditions for construction is concentrated in the middle of the valley.

We group zones 1, 2 and 3 into a new category called geologically suitable and 4 and 5 zones into a new category called geologically unsuitable. Then, we define our instrument IV_i as a binary variable which takes the value of one if unsuitable land is more prevalent around the census block and takes the value of 0 otherwise. Fig. 4b illustrates the construction of the instrument. The census block is represented by the grey polygon, the land around the block is defined by the buffer, and the areas of the two land categories are represented in different colors. The category that occupies the largest area defines the prevailing geological suitability and therefore the value of our instrument.

Using a buffer size of 400 m, Fig. 5b shows the spatial distribution of the instrument. As expected, the map indicates a concentration of unsuitable land for construction around the urban fringes in the steepest areas of the city (see Fig. 2a). We also use buffers of different sizes, to capture impact heterogeneity based on distance and check for spatial decay in the effect.

4.5. Instrument validity

As previously mentioned, our instrument must be strongly correlated with our treatment variable (exposure to VIS housing) to be valid.



(a) Geology (b) Surrounding area

Fig. 4. Geology and surrounding area definition. Panel a classifies land zones according to their level of geological suitability. In zones 1,2, and 3 conditions favor land development, whereas in zones 4 and 5 conditions restrict land development. Panel b illustrates how the instrument was built.

We argue that low geologic suitability implies lower available land and higher costs on social housing developments, therefore, limiting the amount of construction that actually takes place in a given zone. One major concern originates from the fact that, in certain zones in the city, our instrument may not be relevant at all, as the probability of VIS construction is close to zero, independent of the geological suitability of the land. For example, we don't expect any project to be developed in El Poblado, a high income neighborhood of the city. To address this issue, we limit our sample to blocks inside 400 mts buffers around any VIS Project, to somewhat control for this probability and fulfill the relevance assumption. It is also important to clarify that the presence of VIS projects in areas classified as unsuitable not necessarily means the absence of relevance. Our measure of exposure to VIS captures small local changes in housing units or floor space. This means that surrounding unsuitability leads to a smaller housing units or less square meters built, instead of explaining the absence or not of VIS projects. This assumption can be checked through a weak instrument test, as proposed by Stock and Yogo, (2005).

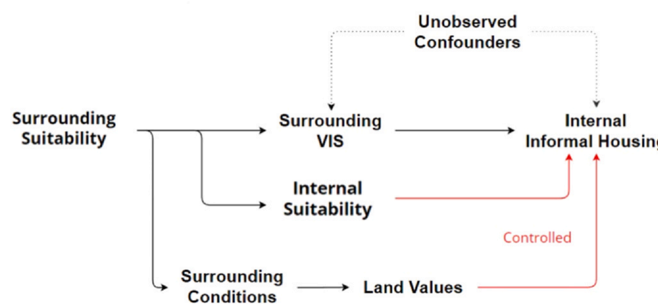
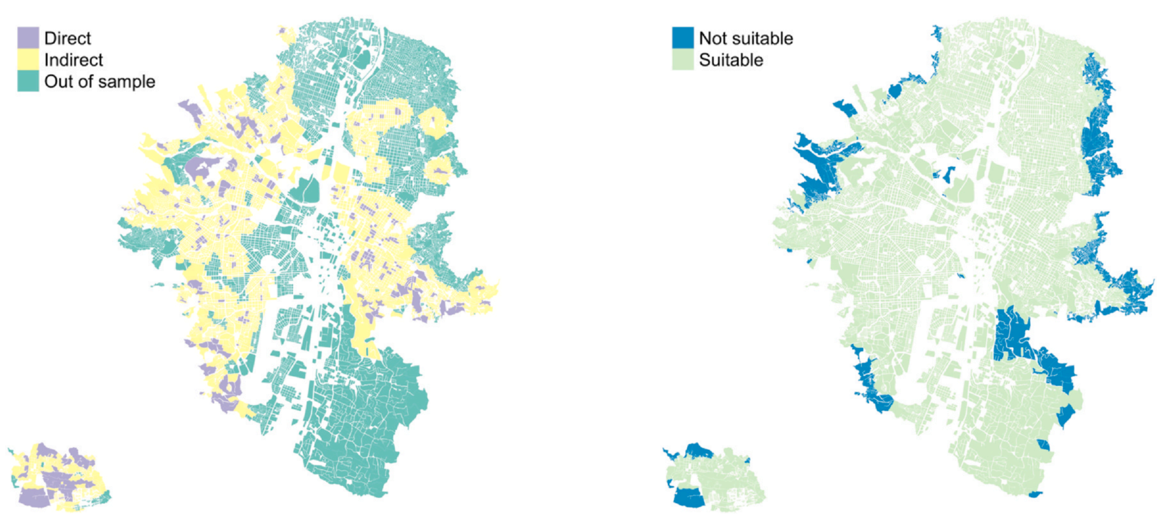


Fig. 6. Causal Diagram.

Our instrument must also meet the exclusion restriction. This restriction is composed of two different assumptions. First, our instrument must not share a common cause (or confounder) with the dependent variable. In other words, the instrument must be assigned as "good as



(a) Sample definition (b) Instrument distribution

Fig. 5. Sample and instrument. Panel a represents locations with VIS projects (Direct), locations with an indirect exposition to VIS projects (Indirect), and locations out of sample. Panel b presents the spatial distribution of the intrumental variable. Author's calculations. POT, 2014; Camacol, 2020.

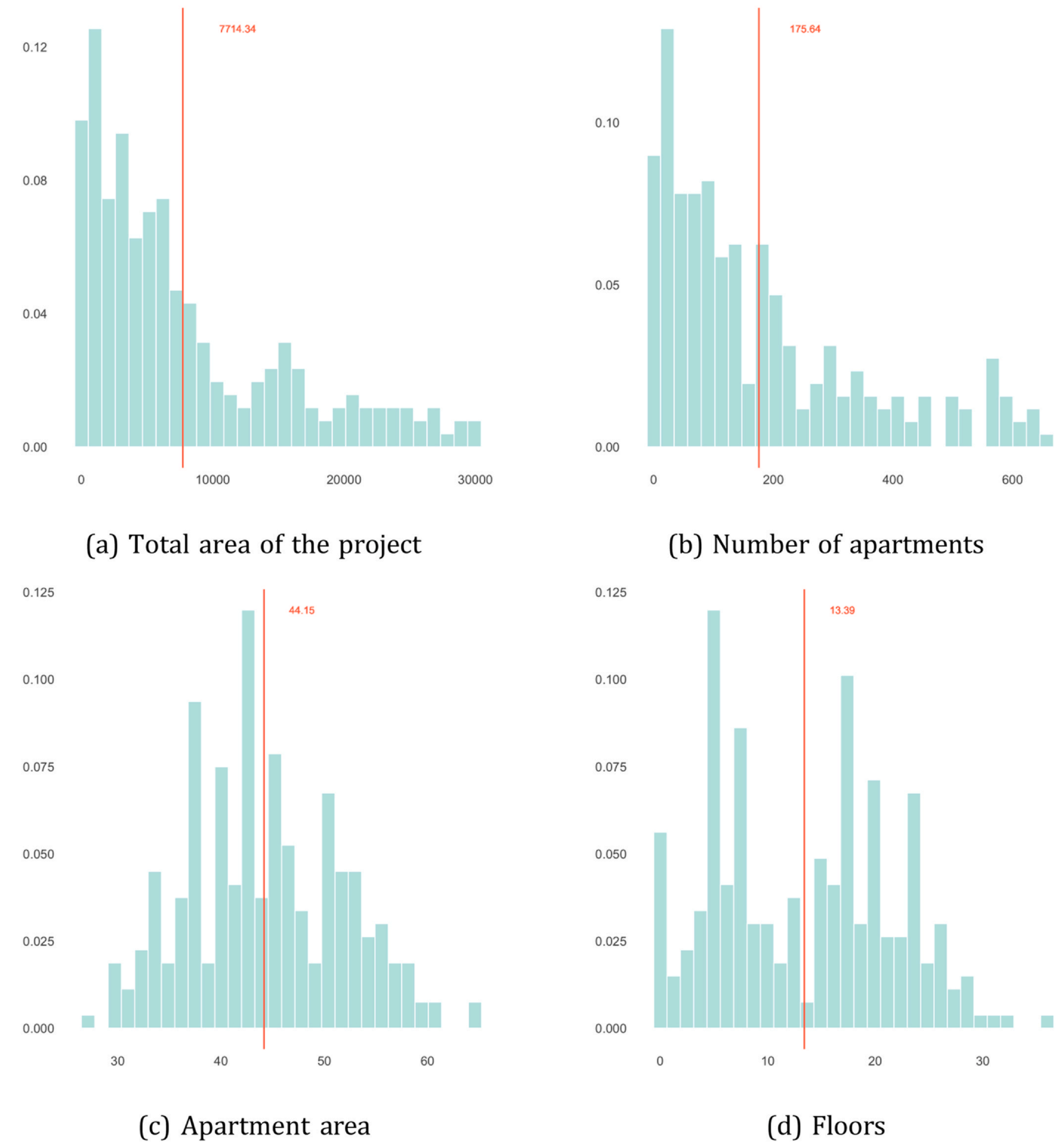


Fig. 7. VIS housing characteristics.

random" after conditioning on control variables. Fortunately, geologic variables have the advantage of being structural features of the land, with little to no change over small periods of time. Consequently, they rarely share a common cause with socioeconomic variables.

The second assumption requires that, the instrument only affects the dependent variable through the treatment variable. As we mentioned before, geological unsuitability around a block implies a lower indirect exposition of that block to social housing developments. Nonetheless, geological unsuitability around could also affect private development, and therefore, informal housing inside a given block. We argue that any improper effect this geological suitability around a block may have on land development inside the block is probably through two main channels: first, by affecting the geological suitability inside the block, as they could be similar given proximity, and second, by affecting surrounding conditions, such as access to amenities. We block these effects using as controls, the geological suitability inside the block and land values that reflect the overall surrounding conditions. In this manner, we avoid any undesirable direct effect our instrument has on outcomes. Our causal structure can be summarised as shown in Fig 6.

Now, to provide some evidence of the exclusion restriction, we run a placebo test as proposed by Van Kippersluis and Rietveld (2018). The idea is to use a subsample of blocks where the treatment cannot happen

Table 1
Descriptive Statistics

Variable	Mean	SD	Min	Max
Informal Housing (% Total)	0.05	0.08	0.00	1.00
VIS m2 (log)	3.37	0.32	2.73	5.28
Unsuitable (400 m)	0.11	0.31	0.00	1.00
Unsuitable	0.11	0.31	0.00	1.00
Land value	13.41	0.63	10.08	15.99
Job Access	0.11	0.17	0.00	2.73
Education Access	0.19	0.21	0.00	1.96
Health Access	0.15	0.39	0.00	4.85
Slopes	0.28	0.42	0.00	1.00
Bad Roads	0.35	0.41	0.00	1.00
Dist. Pub. Transport	7.01	1.02	0.00	8.98
Dist. Main Road	4.90	1.00	0.58	6.99
Dependency Rate	0.44	0.08	0.00	0.92
Education Years	12.08	1.69	2.10	18.00

regardless of the instrument. In the absence of treatment, the IV should have no correlation with the outcome variable, to prove, that the instrument only affects the outcome through the treatment, at least for this sample. Particularly, we use the wealthy neighborhoods of El Poblado for this test, as VIS projects cannot be built in them. We present the results from the weak instrument test as well as the placebo test in Section 6.

5. Descriptive statistics

Between 2004 and 2018, 268 VIS housing projects were developed in Medellín containing 57,185 homes and 2,501,730 square meters. According to Fig. 7a and 7b, the average project contains 175 apartments, equivalent to a private habitable area of 7,714 square meters. There is also a high level of dispersion manifested in the coexistence of projects of a single housing unit with mega projects with 600 apartments and built areas above 30,000 square meters.

The average housing unit is 44.15 m^2, and the average building height is 13.30 floors, reflecting the high structural and residential densities of the projects. It is also can be seen that there are two groups of projects in terms of structural density: one group is characterized by buildings with an average height of 5 floors, and the other is characterized by buildings with an average height of 20 floors (see Fig. 7c and 7d).

As previously highlighted, the projects are located on the city's outskirts, in areas with low land values and low accessibility to labor markets. The average distance of the projects to the city center is 4,419.04 m, which given the city's high population density and limited territorial extension, implies a relative disconnection from the rest of the city. It also should be noted from Figs. 3b and 4a, that in areas of high exposure to VIS housing, there are also important variations in the geological suitability of the land with a concentration of non-suitable land in the urban edges towards the center-west, central east, and north-east, the steepest areas of the city (see Fig. 2a).

Table 1 provides summary statistics of key variables in the main sample. Notably, the percentage of informal housing in census blocks exhibits considerable variation, with informality ranging from a mean value of 5% to instances where it comprises 100% of the housing stock. In contrast, the treatment variable, VIS exposure, displays a more symmetric distribution, characterized by a minimum value of 2.73 and a maximum value of 5.28, with an average of 3.37. This symmetry is to be expected given our deliberate sample

restriction to census blocks in proximity to projects, coupled with a log transformation. Of particular interest is the similarity in the distributions of our instrumental variable (unsuitable land 400 m around) and the key control variable (Unsuitable land inside the block). At first glance, this might suggest a strong correlation between the two but the Pearson's coefficient reveals a correlation of only 0.34. This observation holds significance as it implies that the instrumental variable, when conditioned on this control, possesses sufficient variability to explain the treatment variable while also effectively mitigating any spurious correlation between the treatment and dependent variable. Turning our attention to the average values of other variables, the blocks within our sample are characterized by populations that largely have secondary education, families with a high rate of economic dependency, approximately one-third of roads in poor condition, and a sloped topography.

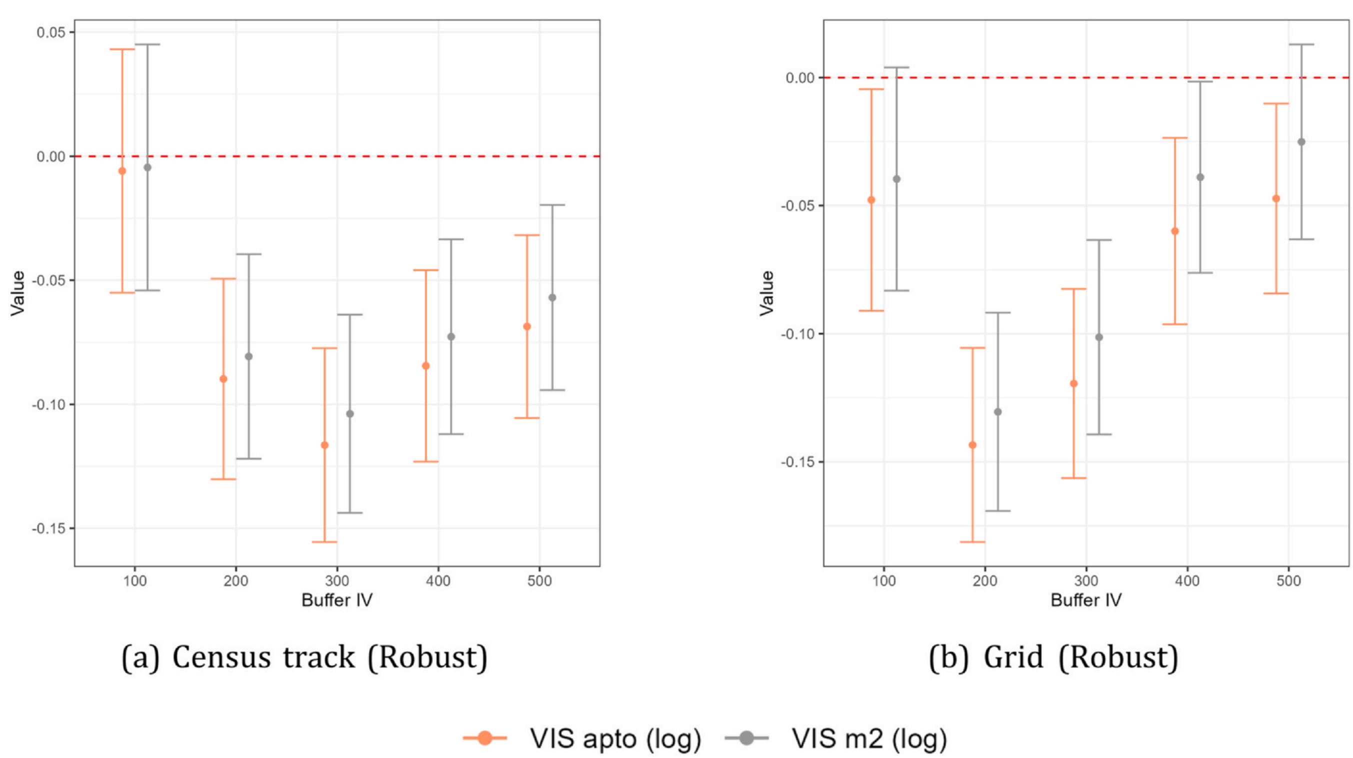


Fig. 8. Instrument Relevance.

Table 2
Main results

Dependent variable	Informal Housing (OLS)	Informal Housing (Reduced Form)	log(VIS m2) (First Stage)	Informal Housing (IV)
Vis exp (m2)	−0.022***			−0.420***
	(0.005)			(0.128)
IV(400m)		0.031***	−0.073***	
		(0.006)	(0.020)	
Unsuitable	0.041***	0.034***	0.038*	0.050***
	(0.006)	(0.007)	(0.020)	(0.010)
Land value	−0.011**	−0.009*	0.053***	0.014
	(0.005)	(0.005)	(0.015)	(0.011)
Job Access	0.037***	0.031**	0.165***	0.100***
	(0.014)	(0.014)	(0.053)	(0.033)
Education Access	−0.012	−0.011	0.109***	0.035*
	(0.008)	(0.008)	(0.018)	(0.018)
Health Access	0.018***	0.020***	−0.150***	−0.043**
	(0.006)	(0.006)	(0.017)	(0.021)
Slopes	0.002	−0.003	0.065***	0.025***
	(0.004)	(0.003)	(0.016)	(0.009)
Bad Roads	0.009***	0.011***	−0.037***	−0.004
	(0.003)	(0.003)	(0.012)	(0.007)
Dist. Pub. Transport	−0.009***	−0.011***	0.066***	0.017*
	(0.001)	(0.001)	(0.005)	(0.009)
Dist. Main Road	0.003**	0.001	0.036***	0.016***
	(0.001)	(0.001)	(0.006)	(0.005)
Dependency Rate	−0.009	0.001	−0.522***	−0.218***
	(0.024)	(0.024)	(0.060)	(0.071)
Education Years	0.001	0.0002	0.012***	0.005**
	(0.002)	(0.002)	(0.004)	(0.003)
Constant	0.306***	0.223***	2.074***	1.094***
	(0.055)	(0.053)	(0.193)	(0.276)
Weak Inst.				13.184
Weak Inst. PV				0.000
Wu-Hausman				43.407
Wu-Hausman PV				0.000
Observations	4.619	4.619	4.619	4.619

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

6. Results

6.1. Identifying assumptions

Before presenting causal estimates, estimations of the first stage (Eq. 3) are shown to verify the instrument's relevance. In Fig. 8, we present the results for both census blocks and grid, revealing a consistent negative relationship between exposure to VIS housing (both to square meters and apartments) and our instrument (which takes the value of one when geological suitability is less prevalent in the land around the census block). This suggests that a worse geological suitability decreases the construction of VIS housing.

Using census blocks as the unit of analysis, the relationship between the instrument and the treatment variable is statistically significant for different buffer sizes around the block except for the smallest buffer of 100 m (see Fig. 8a). Using a uniform grid as the unit of the analysis, the relationship between the instrument and the treatment variable is also statistically significant for different buffer sizes, except when buffers have a size of 100 or 500 m and the treatment variable is constructed using square meters (see Fig. 8b). We also run weak instrument tests revealing that our instrument has enough predictive power (see Table 2).

Next, to support our claims about the fulfillment of the exclusion restriction, we run a placebo test based on (Van Kippersluis and Rietveld, 2018). This test consists of running a regression on the reduced form for a subsample where the IV does not affect the treatment. If the IV is exogenous, the only relation the IV has with the dependent variable is through the treatment, meaning that, in this subsample we should find no correlation between the IV and the dependent variable. Although this test is not a definitive proof of exogeneity, it provides some evidence towards it.

We argue that certain zones of the city can not be treated by VIS housing, mainly because these projects are aimed to low income families, locating them where the cost of living is high is not possible. From Fig. 3b, the north- and south-eastern zones of the city are possible candidates to run the placebo, as they have the lowest levels of indirect exposure to VIS in the city. Nonetheless, the northern areas have some scattered projects, signalling that a higher exposure is possible but yet to happen. For this reason, we chose only the southern area, namely El Poblado, as the sample for our placebo test. Fig. 9 shows how the coefficient associated with the instrument is not significant in the placebo, supporting that the instrument is exogeneous.

Next, we explore how instrumental variables fix the bias by comparing IV estimates to biased OLS coefficients. Table 2 shows the results of the OLS and IV estimation for informal housing, as well as the estimations of the reduced form and the first stage. We expect the correlation between VIS and informal housing to reflect a positively bias given that public housing is usually located in low cost areas, near the informal settlements of the city. The conditional on covariables OLS estimator corrects this positive bias, showing a negative and significant coefficient. Nonetheless, this estimate sits near zero, a small negligible effect compared to the IV estimate. This means that the positive bias is not fully corrected by the introduction of observed confounders, needing the instrumental variable to account for the unobserved confounders.

6.2. Estimation

Now, we estimate the effects of new VIS housing on different outcomes. In Fig. 10a, we systematically observe that higher exposure to VIS housing leads to lower levels of informal housing. For example, for a buffer of 400 m, it is observed that a 10% increase in exposure (both in square meters built and in the number of apartments) reduces the housing informality rate by approximately 4 pp. This magnitude is significant if we make computations based on an average VIS project. That is, building a VIS project of average size (i.e., 7714 square meters) at 300 m of distance of the block, means a variation in the average exposure of 3.9%, which in turn reduces 1.55 pp the informality rate of housing on the block. These results reveal that new VIS housing projects not only directly reduce the quantitative housing deficit but also indirectly reduce the housing deficit in their areas of influence, adding to the positive effects it has on benefited households.

Our results also show that new VIS housing reduces poverty in the neighborhood, an expected result given that housing conditions are an important component of any multidimensional poverty index. (Fig. 10b). In this case, a 10% increase in exposure to VIS projects reduces the multidimensional poverty index by around 5 pp. Again, public housing besides directly reducing poverty by providing housing solutions to families without their own homes, indirectly reduces poverty through the indirect reduction of the housing deficit.

Regarding the components of the informal housing index, Fig. 10c shows that new VIS projects led to an improvement in the quality of housing materials. Now, we cannot differentiate if this effect comes from the construction of new housing by private developers or the improvement of existing housing by the owners. Both imply different mechanisms, as the former is closely related to a demonstration effect which sustains that private developers gain confidence and interest in the sector and thus invest in it. In the latter, keeping up with the Joneses effect (Helms, 2012) would be one possible mechanism, as the social comparison between individuals pressure them to improve their

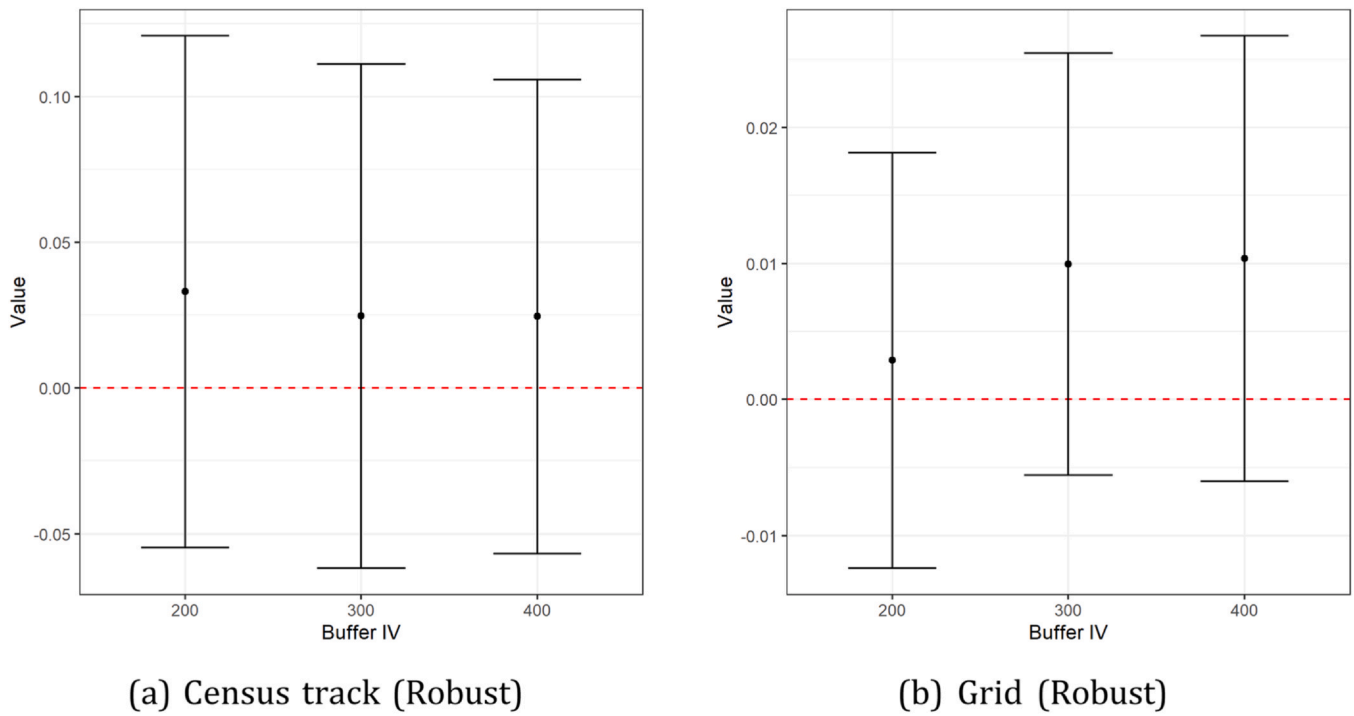


Fig. 9. Instrument Exogeneity.

own conditions to avoid the relatively lower status to their peers. However, if the demonstration effect were prevalent, better housing conditions should coincide with increases in migration which as our results below suggest is not true.

Fig. 10e and 10f show that new VIS projects also led to an increase in the pro- portion of houses connected to water and sewerage infrastructure. This is explained by the urban and habitat standards imposed to VIS housing projects. VIS projects must offer an adequate connection to water, sewage, and electricity infrastructure. To comply with these obligations, developers and urban authorities often have to extend the public utilities network in the territory, thus making cheaper, the connection of existing houses to infrastructure. Finally, Fig. 10d shows that new VIS housing projects did not gen- erate statistically significant changes in overcrowding. In summary, the overall impact on informal housing is likely influenced by both the improvement in the quality of housing materials and the better connection public infrastructure.

Finally, we estimate the effects of a higher exposure to VIS housing on crime rates, land values, migration rate, and unemployment rate. Fig. 11a shows that higher exposure to VIS housing reduces the theft rate. Although there is mixed evidence in the literature about the effects of new housing on crime (Sandler, 2017), our findings are consistent with previous results in contexts with high social and economic segregation (Freedman and Owens, 2011).

Consistent with previous evidence for both developed and developing countries, new VIS housing projects led to an increase in land rents (see Fig. 11c). In turn, Fig. 11d shows that a higher exposure to VIS housing projects is associated with a lower proportion of mi- grants in the neighborhood and Fig. 11b reveals there was no change in unemployment rates. Together, these findings suggest the absence of gentrification.

7. Robustness analysis

As mentioned before, census blocks have different shapes and sizes, which could influence treatment measurement and introduce bias to the estimation. To address the issue, we run causal regressions using a uniform grid as the unit of analysis. Fig. 12 illustrates that, for the most part, our results remain consistent with previous findings, with higher exposure to VIS housing reducing informal housing, multidimensional poverty, and theft rates and increasing land rents.

However, in this case a higher exposure to new VIS housing projects leads to lower unemployment rates (see Fig. 12h). This could suggest that new VIS housing does generate gentrification in their areas of influence by replacing groups of migrants with high unemployment rates for non-migrants with low unemployment rates. In summary, our results are robust for different exposure measures, for different sizes of the areas surrounding the block (i.e. different buffer sizes) and for different definitions of the unit of analysis.

Given the spatial nature of the information, groups of closely related census blocks may be present. To address this issue, we run causal regressions assuming clustered standard errors. We group by geoeconomic zones defined by the POT to guide the calculations of land rents in homogeneous areas.

We have chosen to group errors by geoeconomic zones primarily due to the strong correlation in treatment assignment among neighboring census blocks within the same zone. This approach is grounded in the fact that closely located census blocks tend to exhibit similar treatment levels. However, it is essential to have a large number of clusters and a relatively small number of units within each cluster in order to ensure a meaningful correlation in treatment assignment. In the case of Medellin, which comprises 14 Communes and 332 neighborhoods, these divisions may prove inadequate as clusters, particularly when considering that our observation unit is the census block. In contrast, there are 3,455 geoeconomic zones available, representing a smaller level of clustering compared to the previous two options. What sets geoeconomic zones apart is that they are based on land values and zoning types, ensuring that units within the same zone share a similar probability of treatment assignment, irrespective of their geographic proximity. This makes geoeconomic zones a more robust choice for clustering. Fig 13

As expected, the estimated standard errors are larger under the clustered errors, which makes the instrument lose relevance in the 400 m buffer (see Fig. 14). However, the instrument is still relevant for 200 and 300 m buffers. The appendix (Section 8) shows estimation results under clustered standard errors and for buffers between 200 and 300 m. Figs. 15 and 16 reveal that the main conclusions of our analysis remain unchanged.

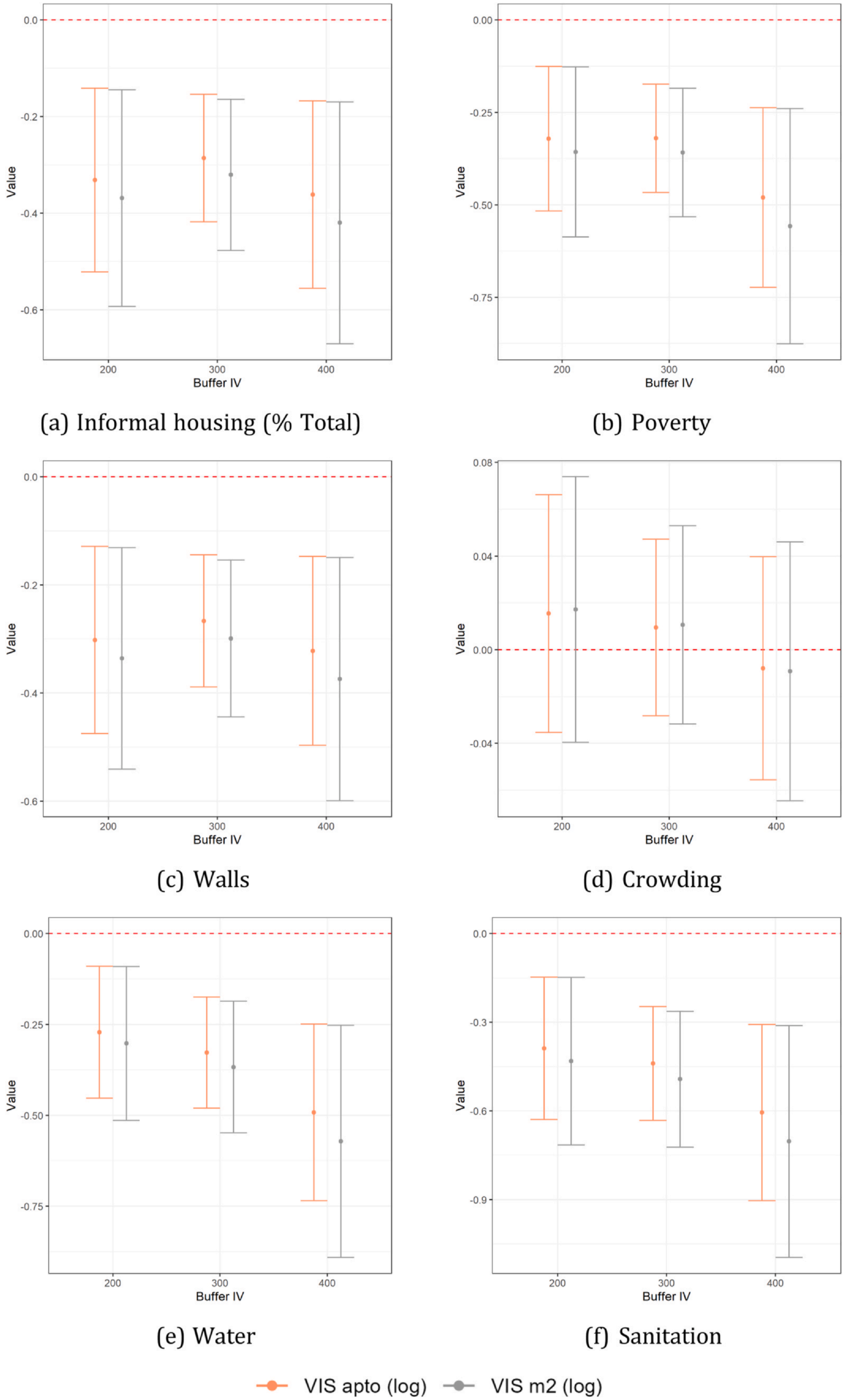


Fig. 10. Estimation results (Census blocks).

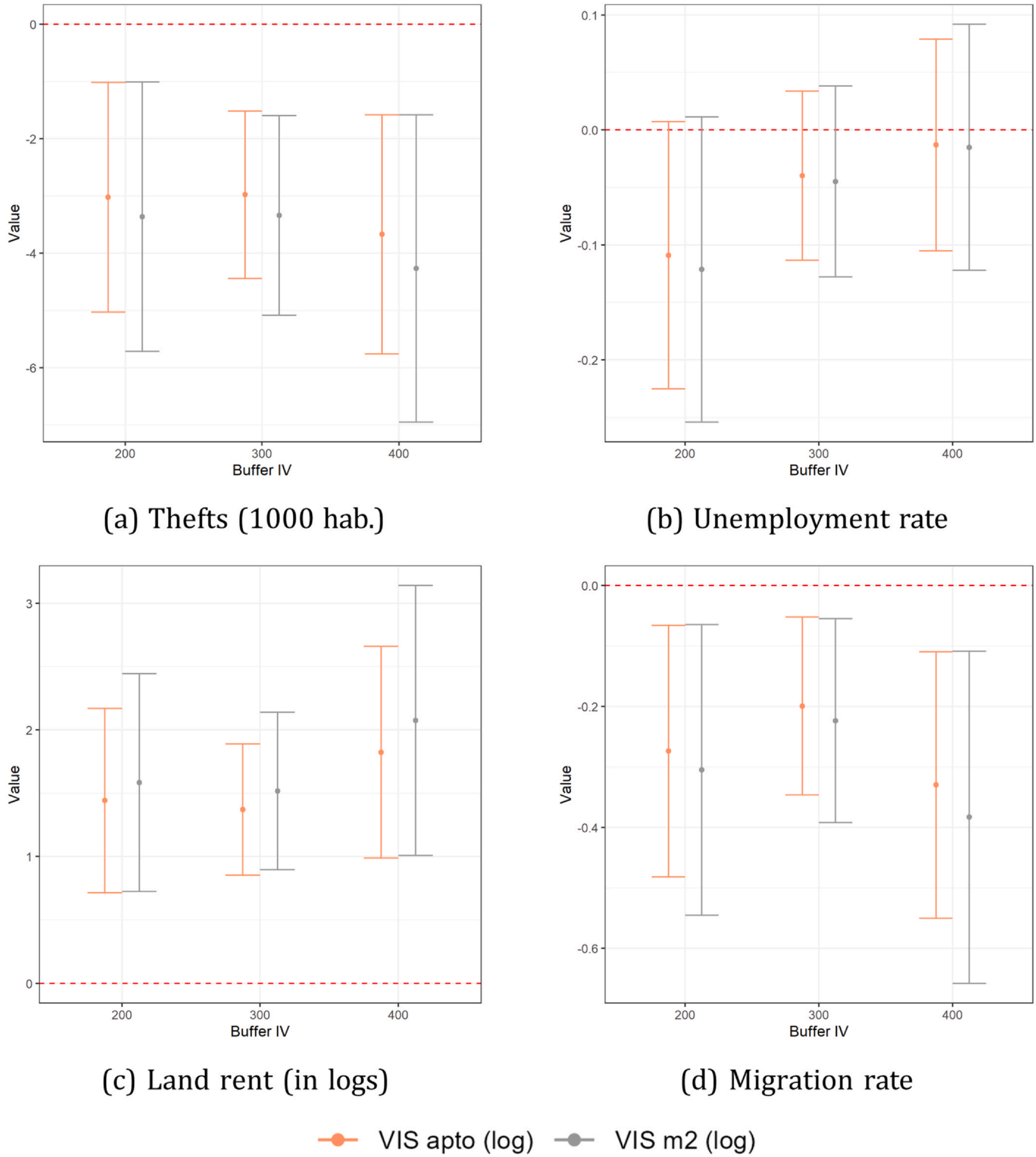


Fig. 11. Estimation results (Census blocks).

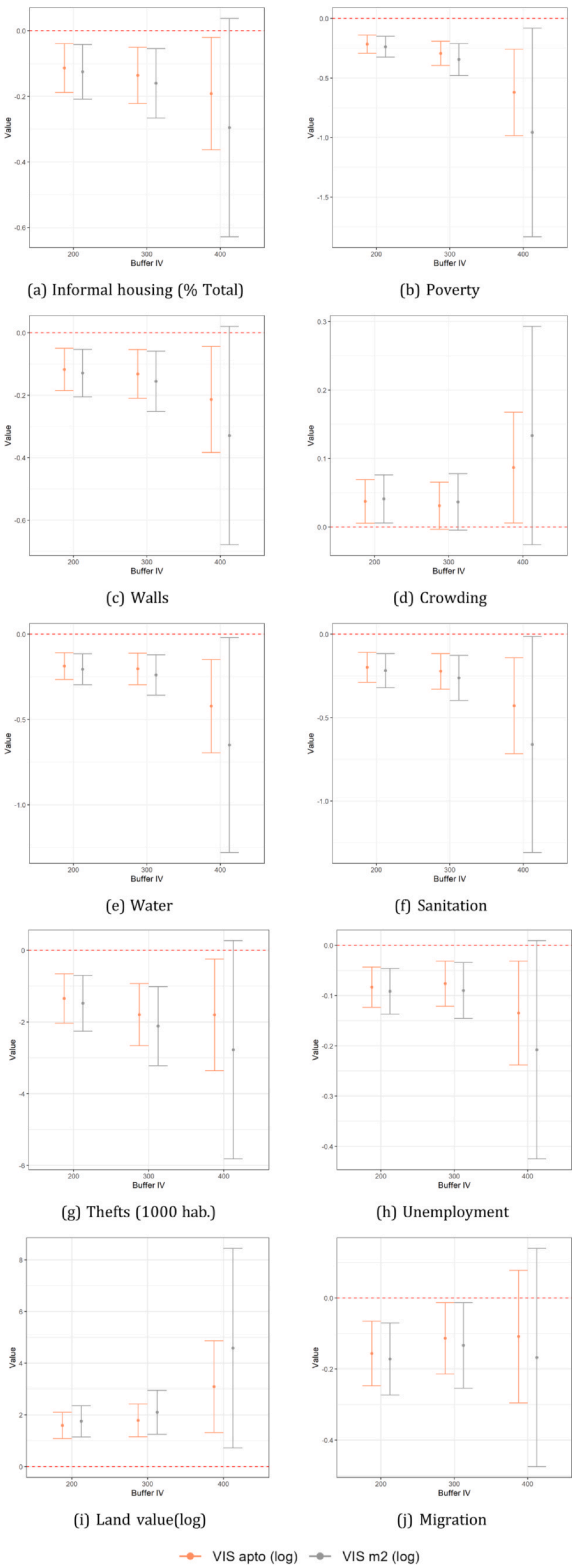


Fig. 12. Estimation results (Grid).

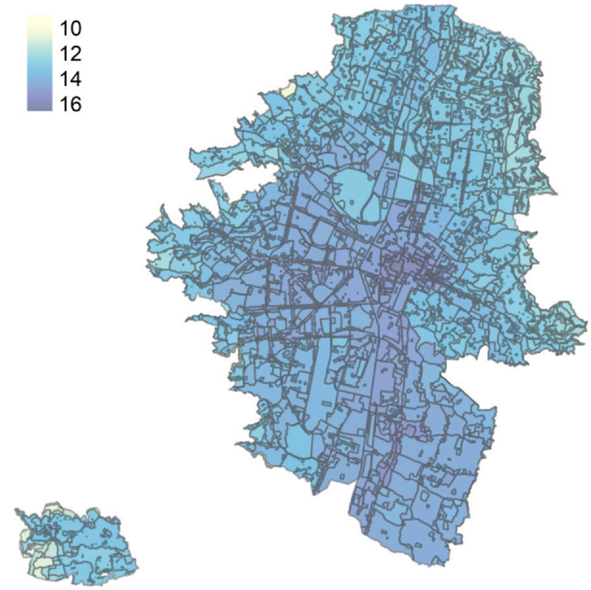


Fig. 13. Geoeconomic Zones. The firgure represents the geoeconomic zones together with land rents (in logs)

8. Concluding remarks

The rapid urbanization of cities and persistently high poverty rates in developing countries have resulted in significant housing deficits. To address this challenge, authorities have implemented public housing programs primarily targeting low-income households. These initiatives are typically situated in areas with limited urban development and lower land rents, thereby bringing about territorial transformations. In this paper, we aimed to assess the impact of new public housing projects, known as VIS, on neighborhood outcomes within locations characterized by a high prevalence of informal housing. Our analysis involved regressing informal housing indexes against measures of exposure to VIS projects, incorporating a comprehensive range of economic and geographical controls. Furthermore, we employ the geological suitability of the surrounding land as an instrumental variable to obtain causal estimates of exposure to new housing projects.

Our findings demonstrate that new VIS housing projects have an indirect positive im- pact on addressing the qualitative housing deficit within their respective areas of influence. This can be in part attributed to the improvement in housing materials, as evidenced by the results obtained for the quality of walls. Although we cannot disentangle whether this effect is more associated with the demonstration effect or the Joneses effect, we can consider some signs of possible mechanisms. While the demonstration effect can be associated with the emergence of new housing projects due to developers perceiving a feasible housing investment, the Joneses effect is associated with housing improvement (see the neighbor). In this perspective, if the demonstration effect were prevalent, better housing conditions should coincide with increases in population density and therefore in migration. However, our results show better physical conditions of housing and reduced migration, which can be associated to a greater extent with investments in housing as a result of increases in land prices which makes housing an attractive asset.

Our results also show that the implementation of new VIS projects has resulted in an increased proportion of houses connected to water and sewerage infrastructure. Given that VIS projects are required to provide adequate connections to water, sewage, and electricity infrastructure, developers and urban authorities often need to extend the public utilities network in the area. As a result, the connection of existing houses to essential infrastructure becomes more accessible.

Our results confirm that public housing programs have positive external effects, making them effective policies for neighborhood revitalization. These effects stem from the elimination of undesirable factors such as crime and from improvements in housing conditions. The existence of these external effects underscores the need for a comprehensive cost-benefit analysis of housing programs, particularly in the context of developing countries' urban areas. From a public policy perspective, our findings contribute to the discussion on the indirect benefits of public housing policies in the developing world. Specifically, we confirm that while the primary objective of these policies is to directly address housing needs for low-income households, additional gains are achieved through improvements in various dimensions within the region or territory.

Appendix

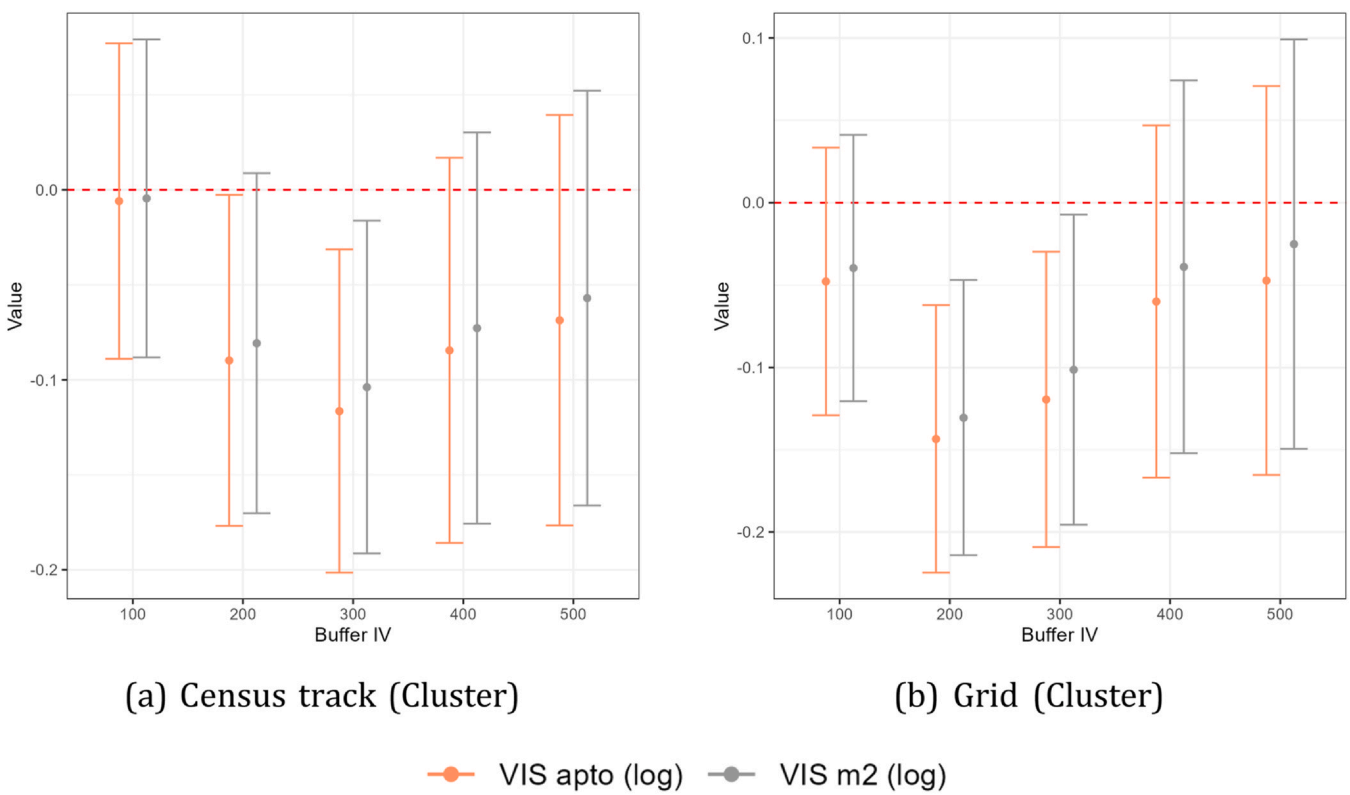


Fig. 14. Instrument relevance (with clustered errors)

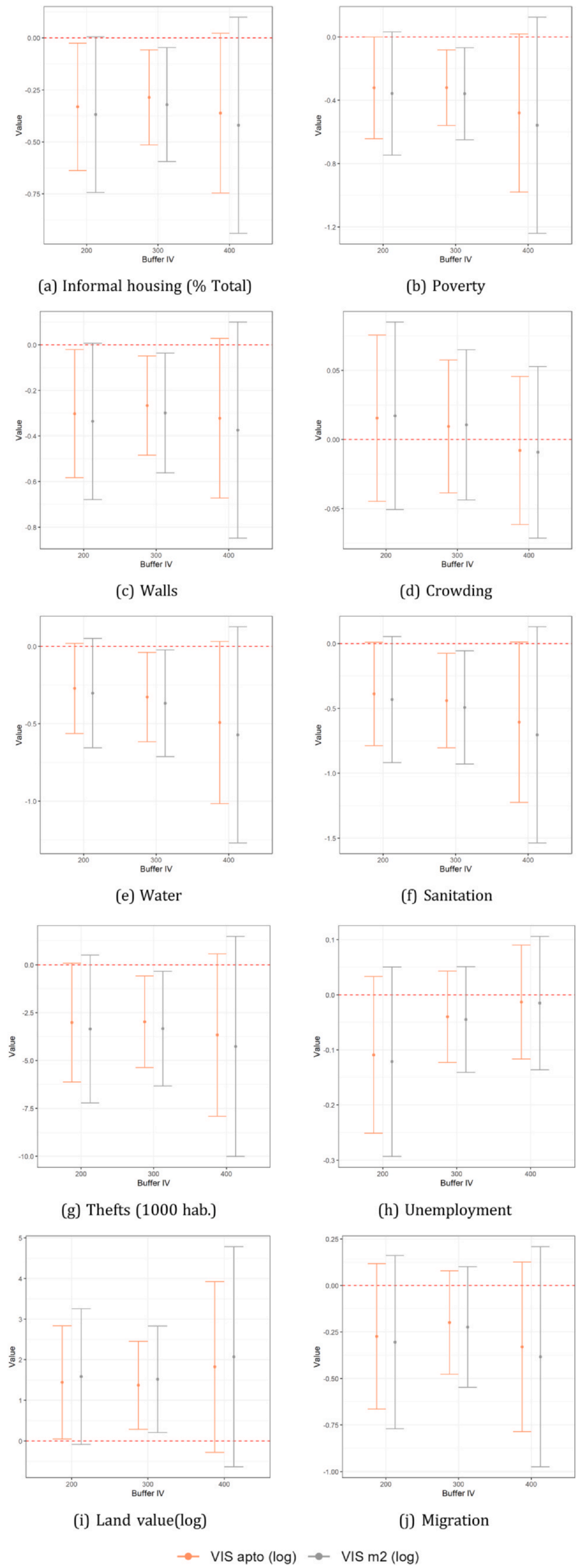
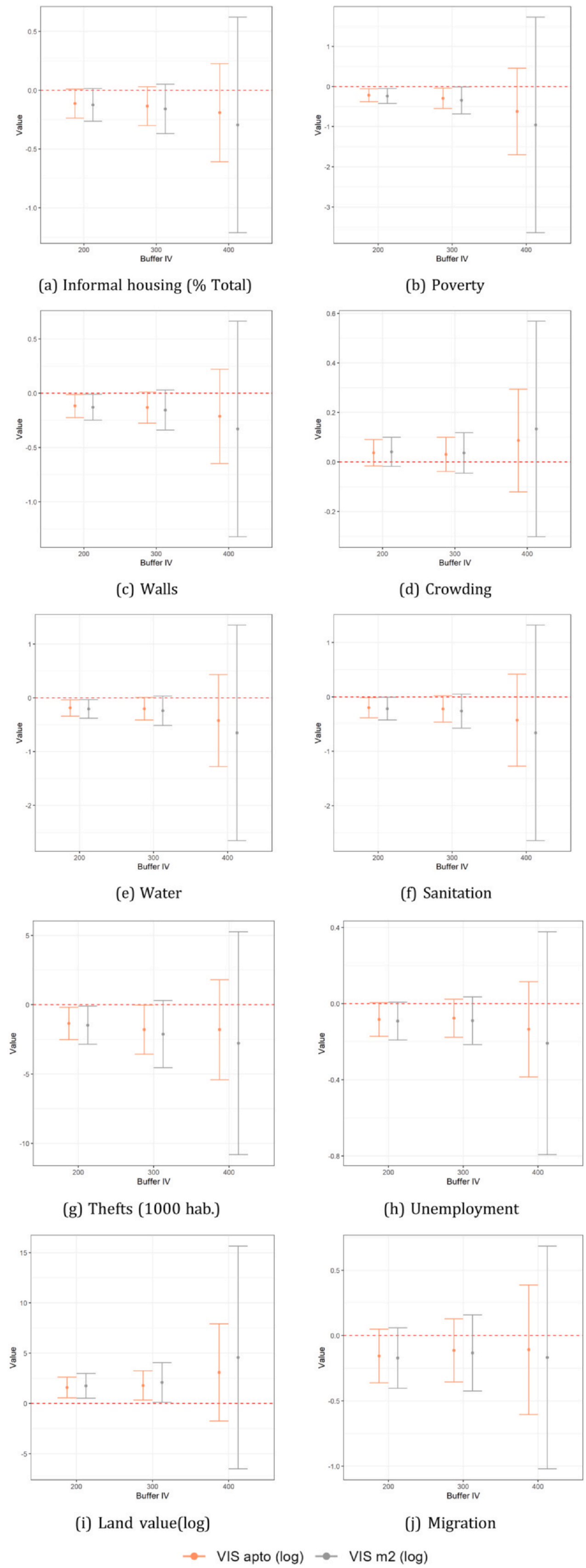


Fig. 15. Estimation results (Census blocks and clustered errors)



(a) Informal housing (% Total) (b) Poverty

(c) Walls (d) Crowding

(e) Water (f) Sanitation

(g) Thefts (1000 hab.) (h) Unemployment

(i) Land value(log) (j) Migration

Fig. 16. Estimation results (Grid and clustered errors).

Table 3
First stage results

VIS m2 (log)			VIS Apts. (log)			
	(1)	(2)	(3)	(4)	(5)	(6)
Unsuitable (200 m)	−0.082***			−0.091***		
	(0.021)			(0.021)		
Unsuitable (300 m)		−0.104***			−0.117***	
		(0.020)			(0.020)	
Unsuitable (400 m)			−0.073***			−0.085***
			(0.020)			(0.020)
Constant	2.017***	2.071***	2.055***	2.077***	2.138***	2.124***
	(0.196)	(0.196)	(0.195)	(0.195)	(0.195)	(0.193)
Observations	4.619	4.619	4.619	4.619	4.619	4.619
Adjusted R^2	0.101	0.103	0.100	0.105	0.109	0.106
F Statistic (df = 13; 4605)	40.711***	42.009***	40.640***	42.823***	44.503***	42.923***

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

Table 4
VIS effect

Informal housing (% Total)						
Buffer IV	**200**	**300**	**400**	**200**	**300**	**400**
VIS m2 (log)	−0.360***	−0.317***	−0.419***			
	(0.111)	(0.079)	(0.127)			
VIS Apts. (log)				-0.324***	-0.283***	-0.361***
				(0.095)	(0.067)	(0.099)
Constant	0.956***	0.873***	1.071***	0.903***	0.821***	0.977***
	(0.234)	(0.176)	(0.272)	(0.206)	(0.156)	(0.222)
WI stat	19.765	34.964	18.933	24.363	43.948	25.523
WI p-value	0.000	0.000	0.000	0.000	0.000	0.000
Wu-Hausman stat	32.654	44.349	43.266	32.379	43.896	42.747
Wu-Hausman p-value	0.000	0.000	0.000	0.000	0.000	0.000
Observations	4.619	4.619	4.619	4.619	4.619	4.619

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

Geometric operations

Various geometric operations were performed to summarize the spatial information in the observational units of interest to construct some of the variables used in this exercise. In particular, the variables on the state of the road, the slope of the geography, and the value of the square meter are not built initially at the block level. First, a spatial intersection was made to identify which part of each original geometry corresponded to which block or grid. The area of these intersections was calculated, and finally, the variable's value was

weighted by the percentage of the block area that belonged to it. Household variables such as poverty and vulnerability are built at the block level from the source, so we only apply the same process to obtain the measure at the grid level. It is important to clarify that the spatial intersection assumes that the attributes of the original geometry are spatially constant. Hence, the intercepted geometries inherit the same values as the original geometries.

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