Equilibrium Effects of Housing Subsidies: Evidence from a Policy Notch in Colombia

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Abstract

This paper studies how the housing market in Colombia responds to a set of policies designed to increase homeownership among low-income households. Private sector developers received tax incentives to build *low-cost housing*, and households received subsidies to buy them. *Low-cost housing* units are priced at or below a cutoff. This cutoff introduces non-linear incentives inducing households and developers to bunch at the cutoff. Households change the type of housing they buy, and developers modify the type of units they build to be eligible for the policy. This outcome can be rationalized as an equilibrium in a market where heterogeneous developers build differentiated housing, and heterogeneous households buy them. I recover the parameters describing households' preferences and developers' technology using the discontinuous incentives, and rich administrative and census data. I use the model and the estimated parameters to evaluate the policy. I calculate the efficiency cost induced by the notched subsidy scheme, and I show that without supply-side incentives, developers may exit the market; their profits would be up to 14 percent lower. However, the existence of these tax incentives artificially increases the profits of developers who would build *low-cost housing* even in their absence.

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I. Introduction

Many governments implement housing subsidies or tax incentives to provide affordable housing, promote housing solutions for low-income households, and incentivize homeownership. Approaches such as mortgage interest deduction (MID) aim to encourage homeownership through tax incentives. Although widely used, there is little evidence that they increase homeownership and raise concerns because they mostly benefit the rich. Alternative strategies, which face the same concerns as MID incentives, include downpayment assistance, subsidized interest rates, and incentives for developers to build affordable housing. Some governments try different mechanisms to target low-income households to avoid benefiting the rich. We know little about the effect on the housing market of alternative housing policies and the efficacy of targeting tools; they can be effective but can introduce market inefficiencies.

This paper studies the housing policy in Colombia, which combines subsidies and tax incentives for developers and households buying and building *low-cost housing*. *Low-cost housing* is defined using a market price cutoff of 135 times the monthly minimum wages (roughly $USD\,40,000$). The Colombian government aims to target subsidies to lower-income households by restricting subsidies to cheaper housing. The policy design allows overcoming the empirical challenges of evaluating the housing market effects of housing subsidies. This cutoff introduces notches, or discontinuous incentives, on both the supply and demand sides, triggering bunching at the cutoff. I use this notch and the variation of the notch size over time to provide evidence of how the market responds to these subsidies.

To understand market responses, it is crucial to disentangle demand and supply responses. However, doing this is particularly challenging in markets with heterogeneous agents and differentiated products, such as the housing market.[1] A model that does not allow product differentiation could not account for changes in the type of housing built and consumed, which, as shown by Gruber, Jensen, and Kleven (2021), could be the main housing market response to policies that try to encourage homeownership.

To overcome this challenge, I propose a model that rationalizes the observed equilibrium and a method that integrates the bunching, and hedonic equilibrium literature to identify and estimate the parameters describing households' preferences and developers' technologies.[2] Hedonic equilibrium models are a common approach to modeling

[1] Zoutman, Gavrilova, and Hopland (2018) shows that a single tax or subsidy can help to identify supply and demand responses in a market with homogeneous goods and agents. Implementing this approach to a market with differentiated products will require multiple instruments.

[2] This is not the first paper suggesting to use bunching to identify hedonic or sorting equilibrium

differentiated product markets and have been widely used to model housing markets. However, most empirical analyses assume that the supply of homes is fixed (Parmeter & Pope, 2013, p.9). This assumption does not make sense in this case because the subsidies apply only to new housing units. Therefore, in contrast with most of the literature, I explicitly model the supply of housing and allow for developer heterogeneity. Most of the literature also focuses on estimating hedonic regressions that provide equilibrium marginal willingness to pay (MWTP) for different housing characteristics. Few papers attempt to estimate structural parameters, and they usually rely on strong assumptions (Greenstone, 2017; Parmeter & Pope, 2013). Although MWTP estimates can be informative, they do not allow for non-marginal policy evaluations or counterfactual policy analysis. The identification proposed in this paper, which is inspired by the bunching literature, is more transparent, estimates demand and supply side parameters, and relies on evidence from a natural experiment.

The evidence of the housing market responses is based on data from a construction census that contains the universe of new housing developments in Colombia and administrative records for the subsidies awarded by the Ministry of Housing between 2006 and 2018. During this period, the policy expanded; an interest rate subsidy was introduced, the downpayment subsidy increased, and eligibility expanded. This policy expansion and the cutoff defining which units are eligible for the subsidy, allow me to provide compelling evidence of the market response.

I show evidence of bunching at the cutoff, and estimate a counterfactual distribution of market shares by price. I recover the behavioral responses induced by the subsidy by comparing the observed distribution with the counterfactual distribution. The households that change their housing consumption to receive the subsidy spend up to 85 percent less in housing to take advantage of the subsidy. Given the equilibrium prices, this is translated into a housing unit up to 90 percent smaller. Using the variation in the subsidy over time, I show that increasing the generosity of the subsidy increases the share of units sold at the *low-cost housing* cutoff. Between 2006-08 households received around 13 percent of the price of the house at the cutoff, and between 20016-18 they received around 24 percent. As a result, the excess mass, or bunching, of units sold at the price cutoff increases from around 3 percent of the market share in 2006-08 to 16 percent in 2016-18. The fact that the share of households bunching at the cutoff increases as the generosity of the subsidies increases demonstrates that Colombia's social housing policy matters a lot and may provide credible identification of market

models. Kuminoff, Smith, and Timmins (2013, p.1009) wrote: "Equilibrium sorting models provide the means to implement both the original Blinder and Rosen (1985) idea and the Saez (2010) test and extend them for policies that target public goods or other amenities that affect agents differently." However, I am not aware of any paper that implements this approach.

structure.

This type of response could be driven only by changes in price without changes in characteristics. However, are usually considered highly competitive, and I show suggestive evidence that housing characteristics and, in particular, a reduction in the size of the houses being built drive the behavioral responses resulting in the bunching.

I introduce and estimate a competitive housing market equilibrium model to rationalize the observed equilibrium responses. The model introduces the policy-induced notch to a hedonic – or sorting – equilibrium model.[3] Households are heterogeneous in income, developers in productivity level, and housing in size. I use the model to show how the notch incentivizes developers and households to bunch at the threshold. Like in the observed equilibrium, in the model, buyers and developers change the type of units they buy and build to take advantage of subsidies. Consequently, the equilibrium density has bunching at the cutoff point.

The identification strategy is based on a two-step procedure suggested by S. Rosen (1974). To estimate the first step, I follow standard practices in the literature. I focus on estimating the implicit price function for the house size. The main innovation of this paper is in the second step. To estimate the second step, I use the discontinuity and estimated behavioral responses and adapt the identification strategy proposed in the literature using notches to estimate structural parameters.[4] Using the model, I show that there are marginal buncher households and developers that are indifferent between receiving the subsidy but consuming and building smaller housing and not receiving the subsidy and consuming and building their optimal amount of housing. Empirically, comparing the counterfactual distribution and the observed distribution allows me to identify two points on the same indifference curve for the marginal buncher. Using the parameters of the first step and the marginal buncher indifference conditions, I estimate the parameters describing characterizing the shape of the utility and cost functions.[5] I can do that because I have three different prices; the market

[3]For a reviews of the general approach see Palmquist (2005); Parmeter and Pope (2013); Kuminoff et al. (2013); Greenstone (2017). For recent applications, see Epple, Quintero, and Sieg (2020) and Chernozhukov, Galichon, Henry, and Pass (2021).

[4]Best, Cloyne, Ilzetzki, and Kleven (2019) use the same identification idea to estimate the intertemporal elasticity of substitution from the behavioral responses induced by notches in the interest rates for loan refinancing. Other examples are Einav, Finkelstein, and Schrimpf (2015); Chen, Liu, Suárez Serrato, and Xu (2021); Kleven and Waseem (2013); Cox, Liu, Morrison, et al. (2021). Bertanha, McCallum, and Seegert (2021) and Blomquist, Newey, Kumar, and Liang (2017) discuss how in contrast with changes in the slope, or kinks, notches allow recovering structural parameters.

[5]To estimate the shape of the indifference curve and offer curve, I impose functional forms for the utility function and a cost function. The utility function is a CES utility function depending on the

price, the price received by developers, and the price paid by households. These exist because the policy scheme has one subsidy targeted at developers and households using the same cutoff.

The model and estimated parameters are used to evaluate how marginally subsidized households and developers benefit from the subsidy scheme and what are the efficiency losses. On the demand side, I compare the utility levels of marginally subsidized households in two counterfactual scenarios. In the first counterfactual scenario, households do not receive subsidies. Marginally subsidized households that reduce their housing consumption to benefit from the subsidies could be better off if they receive the money without a restriction on the cost of the house. I calculate this welfare loss associated with the policy design. Quantifying this is relevant to assessing whether a notched policy design is better than a linear subsidy. Using some simulations, H. S. Rosen (1985) studies the efficiency losses associated with targeting policies. He shows that, depending on the elasticity of substitution, notched policy designs may be more effective than linear incentives in targeting subsidies. The estimated parameters suggest that housing and other consumption are gross substitutes; the elasticity of substitution between housing and other consumption is higher than one.

I compare the observed equilibrium with a counterfactual scenario where households receive subsidies, but developers do not receive tax incentives. Between 2006 and 2009, the profits of marginally subsidized developers would be 5 percent lower, and by 2016, after the expansion of the subsidy, their profits would be 14 percent lower. The marginally subsidized developers have higher marginal costs when producing at the price cutoff. They are competing with more productive developers, who profit when building *low-cost housing* even in the absence of subsidies. A price increase, desirable for both developer types, will lead to non-eligibility for the subsidies. Due to the price cap, marginally subsidized developers need tax incentives to build *low-cost housing*, and without them, the market may face a rationing problem in the short term. The existence of these tax incentives can prevent the exit of the marginally subsidized developers; however, they artificially increase the profits by more than five percent for developers that would produce *low-cost housing* even in the absence of these incentives.

Because housing is a durable good, the type of housing solutions that different policies incentivize will have lasting consequences (Glaeser, Gyourko, & Saks, 2006). The policy incentives shape the type of housing that is built and sold, which has implications for how the city grows and develops. For example, the policy design in Colombia

consumption of housing and consumption of other goods, and the cost function depends on housing size and the number of units built. I observed equilibrium relationships non-parametrically.

incentivizes the construction of *low-cost housing* by moving away resources from more expensive housing units. This means that the country may face a price increase in the middle market segment in the next couple of years because the policy design eschewed the way the city evolved, favoring smaller housing units. It is important to identify this type of response to determine if a housing policy is effective or not.

Related Literature

The main contribution of this paper is to provide a method that allows recovering structural parameters describing developers' and households' technologies and preferences in a setting where they build and produce a vertically differentiated product. I bring the *bunching* approach to the literature on hedonic models and housing markets. In the hedonic literature, I contribute with a new approach to estimating S. Rosen (1974) second stage. Also, in contrast to the existing literature, I explicitly model the supply side and show how the housing policy affects households' and developers' incentives and the market equilibrium.

I make two contributions to the bunching literature. First, I show how the same identification principle can be applied to recover the primitives of hedonic models. Second, I complement approaches that use discontinuities or notches in incentives that induce bunching to recover structural parameters. Some examples in other settings are Einav et al. (2015) for the drug market, Best et al. (2019) for mortgage markets, and Chen et al. (2021) for incentives for research and development in China.[6] The evidence of bunching in this paper also complements the existing evidence of the housing market responding to discontinuous incentives. Carozzi, Hilber, and Yu (2020) provide evidence of bunching in response to *help to buy*, a United Kingdom housing policy similar to the Colombian housing policy studied in this paper. McMillen and Singh (2020) show that apartment rents cluster at values near the fair market rent in Los Angeles, California. There is also evidence of bunching in the density of mortgages with notches in the interest rate schedule. For example, DeFusco and Paciorek (2017) use these bunching responses to estimate the interest rate elasticity of mortgage demand. Best and Kleven (2017); Kopczuk and Munroe (2015); Slemrod, Weber, and Shan (2017) report bunching around notches in transaction costs. The existence of bunching in housing markets with discontinuous incentives and the method proposed in

[6] In contrast to this approach, alternative approaches implemented, for example, by Saez (2010), Chetty et al. (2011), or Chetty, Friedman, and Saez (2013) use the bunching moments to derive reduced form elasticities and use them as sufficient statistics for welfare analysis. See Kleven (2016) for a review of the literature using bunching. Some recent applications include studies on minimum wage (Cengiz, Dube, Lindner, & Zipperer, 2019; Harasztosi & Lindner, 2019; Jales, 2018), overpay hours (Goff, 2021; Bachas & Soto, 2018; Abel, Dey, & Gabe, 2012), marriage market (Persson, 2020), Crime (Goncalves & Mello, 2021) among others.

this paper suggest that the bunching techniques that have been successfully used to identify tax elasticities in the labor market can be used to study housing markets and evaluate the effectiveness of different housing policies. Other examples of situations where this methodology could work are cutoffs defining lot size or height limits in construction, and rent ceilings for housing vouchers, among other cutoffs introducing discontinuous incentives that can trigger bunching.

This paper also contributes to the literature on how the housing market responds to different policy interventions. Although other articles investigate the effects of housing programs on households, my study contributes to the literature by also focusing on studying the effects of housing programs on developers, and the market equilibrium.[7] The complexities of the housing market, data limitations, and the lack of valid natural experiments make it challenging to provide rigorous evidence on the market effects of housing programs. Consequently, there is not enough evidence and frameworks to validate the effectiveness of different policy approaches, such as housing vouchers, rent controls, regulations, public housing, or subsidies to build social housing.[8] To the extent that most of the evidence is concentrated in the USA, we know less about alternative housing policies like the Colombian housing policy, which is similar to the other policies implemented in Latin America and around the world. This paper contributes to filling that gap.

The paper also complements other approaches that carry out counterfactual and welfare analyses on housing policies Galiani, Murphy, and Pantano (2015); H. S. Rosen (1985); Poterba (1992); Quigley (1982); Geyer (2017). Galiani et al. (2015) use the Moving to Opportunity experiment in the USA to estimate a model of neighborhood choice. They use the model, and estimated parameters to show how changing the restrictions of where households can move would reduce the take-up rate. This is a well-

[7]The apporach of this paper different than the studies evaluating the effect of housing programs on households and individuals Kumar (2021); Franklin (2019); van Dijk (2019); Camacho, Caputo, and Sanchez (2020); Lopez and Sanchez (2021)

[8]Many papers study housing market policies implemented in the USA. For example, Baum-Snow and Marion (2009); Soltas (2022); Sinai and Waldfogel (2005) study the LIHTC, Collinson and Ganong (2018), McMillen and Singh (2020) study housing vouchers, Glaeser and Shapiro (2003); Sommer and Sullivan (2018); Hilber and Turner (2014); Rappoport (2016); Gruber et al. (2021); ? (?) study mortgage interest deductions (MID), and Hembre (2018) studies *first time buyers programs*. In addition to housing subsidies, there is literature on alternative approaches to affordable housing including public housing (Kumar, 2021; Franklin, 2019; van Dijk, 2019), rent control (Glaeser & Luttmer, 2003; Autor et al., 2014; Diamond et al., 2019), maximum permitted construction (Anagol, Ferreira, & Rexer, 2021), slum upgrading (Harari & Wong, 2021) and other regulations (Turner, Haughwout, & van der Klaauw, 2014). Olsen (2003) and Olsen and Zabel (2015) describe and compare the different approaches implemented in the United States. McTarnaghan et al. (2016); Gilbert (2014b); Cohen, Carrizosa, and Gutman (2019) summarize and describe the housing policies implemented in Latin America. OECD (2021a, p.19-20) describes the different approaches implemented in OECD countries and OECD (2021b) describes the policy objectives and goals.

intended restriction that could backfire and increase the average exposure to poverty, affecting the effectiveness of the policy. Like this paper, Galiani et al. (2015) is a good example of how combining credible empirical evidence with economic models helps to understand better how households and developers respond to the particularities of policy design. This type of analysis is crucial for designing effective housing policies that can mitigate housing affordability problems and help build better cities.

There is a large literature studying the positive effects of homeownership (DiPasquale & Glaeser, 1999; Engelhardt, Eriksen, Gale, & Mills, 2010; Jiang, 2018; Coulson & Li, 2013; Aaronson, 2000). However, there are some concerns regarding how much should the government distort the incentives to achieve this goal (Goodman & Mayer, 2018; Economist, 2020). Usually, few lucky households benefit from the subsidies to become homeowners, there is some recent evidence that homeownership can also have negative effects (Munch, Rosholm, & Svarer, 2006), and there is little evidence that the housing policies incentivize homeownership work. For example, Gruber et al. (2021) use quasi-experimental evidence for Denmark, to show that MID has no effect on homeownership and has a positive effect on the size and value of homes. More generally, OECD (2021a, p.20) concludes that "some tax relief, such as mortgage-interest rate deductibility, is regressive and tends to benefit higher-income households." This is consistent with findings from earlier papers (Glaeser & Shapiro, 2003; Sommer & Sullivan, 2018; Hilber & Turner, 2014; Rappoport, 2016).

This raises the question of whether targeting a wider population with other subsidies like rent vouchers or unconditional cash transfers could be better. For example, Egger, Haushofer, Miguel, Niehaus, and Walker (2019) show that sizeable conditional cash transfers can have large positive spillovers. They calculate a local transfer multiplier of 2.4. The Colombian conditional cash transfer, *Familias en Acción*, costs 3 billion COP in 2019 and benefits almost 4 million people. Colombian housing demand subsidies cost 2 billion COP and benefit about 100,000 households. Could it be more effective to use the resources invested in the housing subsidies in some unconditional cash transfers? This discussion highlights the importance of understanding the welfare effects of housing subsidies and the effect on the housing market, which are the objectives of this paper.

The paper has three parts. The first part introduces the reduced-form analysis. In the next section, I present the Colombian housing policy, institutional context, and the discontinuities created by the subsidy scheme. Section III presents the housing market data and provides reduced-form evidence of the housing market response. The second part of the paper contains the housing equilibrium model and identification strategy. Section IV, introduces the model, section V, presents the identification strategy. The third part, presented in section VI, shows the estimates for the structural parameters, the policy counterfactuals, and welfare analysis.

II. Institutional Context and Data

This section introduces the Colombian housing policy, describes the expansion of subsidies, and shows how the price cutoff defining *low-cost housing* creates discontinuous incentives, or notches, that induce households and developers to bunch at the price cutoff to benefit from the subsidies.

A. Colombian Housing Policy

Institutional context. Colombian housing policy aims to provide a decent home and suitable living, reduce housing deficits and achieve the dream of being a country of homeowners.[9] Since the 1990s, Colombia and other Latin American countries have changed their approach, moving from state-provided housing to a market-oriented solution based on subsidies.[10] This policy approach aims to incentivize the purchase and construction of low-cost housing through subsidies to households and developers. On the demand side, the main tool is a downpayment subsidy, complemented by a subsidized interest rate since 2009. On the supply side, the policy tool is a tax refund for developers who build low-cost housing.[11]

Low-cost housing definition. To target subsidies, the government limits the subsidy to *low-cost housing*, which are units priced at or below 135 times the monthly minimum wage (mMW), around $US\$40,000$.[12] This arbitrary threshold is the same for all cities, and changes over time are only associated with changes in the minimum wage.[13]

[9]The first and second goals are based on Article 51 of the Colombian Constitution. The goal of being a country of homeowners appears in the country's last three National Development Plans (e.g., DNP, 2002, p.104).

[10]For example, in a 1993 report, the World Bank said that "housing policy-making must thus move away from its previously narrow focus on a limited engagement of the government in the direct production of low-cost housing." World Bank Group (1993, p.1) Chile and Colombia, among other countries, followed that advise and abandoned the construction of public housing and implemented a market-oriented approach called ABC (from Spanish, *Ahorro*-Savings, *Bonos*-Bonds, *Creditos*-Credit) (Gilbert, 2014b; Cohen et al., 2019).

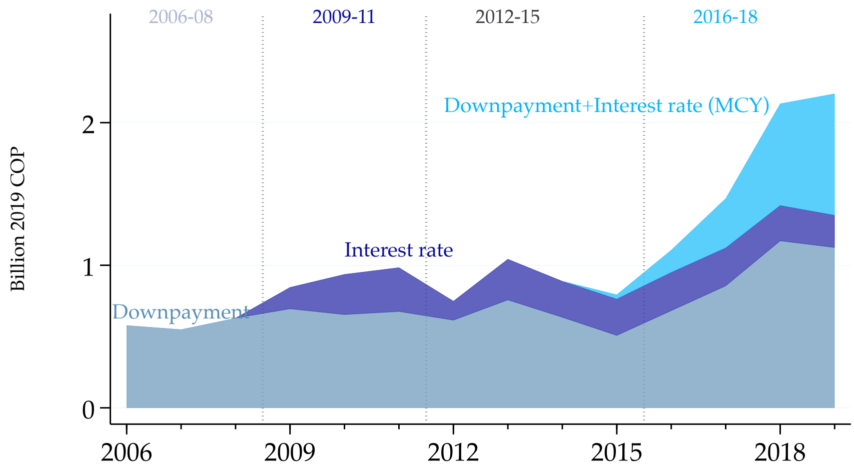
[11]For more details about the Colombian housing policy see Gaviria and Tovar (2011); Hofstetter, Tovar, and Urrutia (2011); Gilbert (2014b); Lopez and Sanchez (2021); Camacho et al. (2020) and Appendix A

[12]In Colombia, the minimum wage is adjusted every year based on inflation, productivity growth, and an agreement between different representatives of the different economic sectors. Appendix Figure A.3a shows the evolution of the minimum wage and inflation.

[13]This price limit is set by the government's National Development Plan. It was the same from 1997 until 2019. With law 1467 of 2019, the it increased to 150 mMW for the five largest cities (including the metropolitan areas) and remained the same in the other cities.

There is an additional definition creating a similar discontinuity at a lower price cutoff. Housing units below $70 \times mMW$ (around $US\$20,000$) classify as *priority low-cost housing*. This cutoff defines eligibility for some subsidies for the extremely poor and those affected by forced displacement or natural disasters.[14] This paper focuses on subsidies for the population buying *low-cost housing* units.

Figure 1: Total Government Expenditure on Demand Subsidies over Time



Source: Administrative records from the Ministry of Housing. Appendix A provides more details about the data.
Note: This Figure shows the evolution of total government expenditure by type of subsidy. The downpayments are the subsidies awarded to employees affiliated with family funds. The interest rate represents the total amount paid by the government to the banks corresponding to the interest rate payments for the loans supported in a given year. I calculated this amount using the administrative data containing detailed information on each loan. Mi Casa Ya corresponds to the payments for the interest rate and the downpayment subsidy. Figure A.1 shows the number of assigned subsidies targeted to a price at or below 135 mMW and 70 mMW over time.

Subsidy expansion. The government expenditure on these subsidies doubled between 2006-2018. During that period, the interest rate subsidy was introduced, the subsidy amount increased, and individuals in the informal sector became eligible. These changes allow me to show how the Colombian housing policy plays a crucial role in the market equilibrium of new housing units. Figure 1 shows the total government expenditure from 2006 until 2018. The **gray blue** area shows the expenditure on downpayment subsidies. The expenditures were stable until 2015, when the subsidy's size increased. The **dark blue** area shows the total government expenditure on the

[14] Including the provision of *100,000 free housing units* between 2012-2015 and the country's primary mortgage downpayment subsidy program for the vulnerable population (VIPA). For more details, see Camacho et al. (2020) and Gilbert (2014b)

subsidized interest rate. The number of households that received this subsidy was stable over time, but government expenditure decreased slightly due to the lower interest rate. Households can get both subsidies but must apply separately for each subsidy program.[15] The **light blue** area shows the expenditure related to the *Mi Casa Ya* program, which provides downpayment assistance and covers the interest rate discount without any restrictions on employment status. Before this program was introduced, only workers employed in the formal sector were eligible to receive the downpayment subsidy.

Four different periods. In the empirical analysis, I show four sub-periods corresponding to the distinct set of policies available; **2006-08** had a downpayment subsidy available only to formal employees, **2009-11** had a downpayment subsidy and an interest rate subsidy available only to formal employees, **2012-15** this period had many changes in interest rate subsidy and many programs targeted to the extremely poor, and **2016-18** had a higher downpayment subsidy for formal employees and interest rate subsidies, and, additionally, the program *Mi Casa Ya* which is available to households in the informal and the formal sector with earnings of 4 mMW or less, and automatically includes the downpayment and the interest rate subsidy.

Supply subsidy–value-added tax (VAT) refund. To encourage developers to build low-cost housing, the government introduced a VAT refund. Developers get a tax refund, δ, of up to 4 percent of the sale price of each unit as a refund for taxes paid on construction materials. This subsidy was introduced in 1995, a couple of years after the beginning of the downpayment subsidies.[16]

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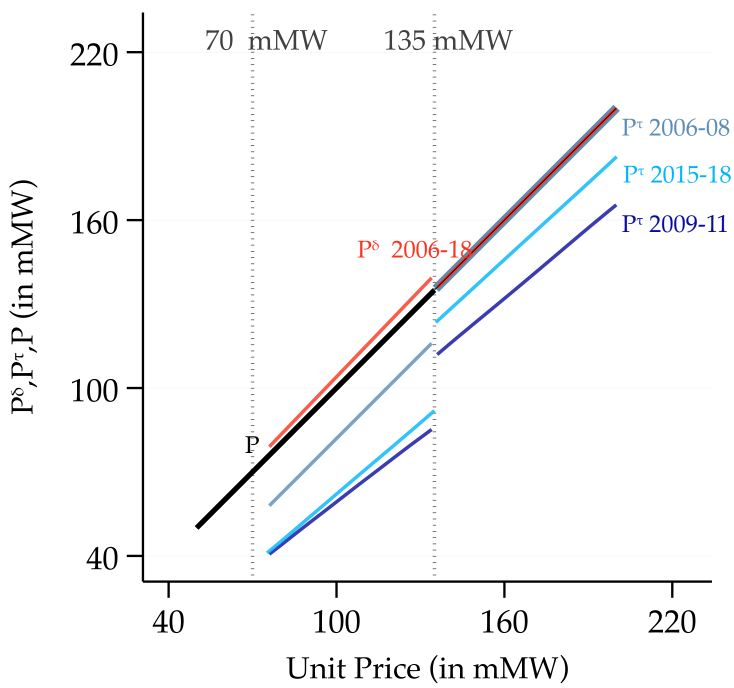
[15] To obtain the government expenditure, I calculate the total savings on mortgage payments induced by the discount at the interest rate. I calculate the monthly payments of each loan using the administrative records for the subsidy and the formula for monthly payments on a mortgage, $L_{monthly} = L \cdot \kappa(i, n)$ with $\kappa(i, n) = \frac{i}{12} \cdot \left(1 + \frac{i}{12}\right)^{12 \cdot n} / \left(\left(1 + \frac{i_h}{12}\right)^{12 \cdot n} - 1\right)$. Where i is the interest rate, $i_{subsidy}$ is the interest rate discount, n is the loan term in years, L is the loan amount. The government pays the difference in the amount paid by households $(L \cdot \kappa(i_\tau, n)$, with $i_\tau = i - i_{subsidy})$ and the amount received by the bank $(L \cdot \kappa(i_\tau, n))$. In particular, $\tau^i = \sum_{t=1}^{84} L_{month}(i, n)(i, n) - L \cdot \kappa(i_\tau, n)$, the sum of monthly payments for seven years, the period during which the subsidy applies. Figure A.4 shows the loan terms by unit price, and Figure A.3b shows the market interest rate and the interest rate that households pay.

[16] Even though it has been regulated by different laws and acts, the incentive is always capped at 4 percent of the value of each unit (Camacol, 2016, p.25). This subsidy could be compared to the Low Income Housing Tax Credit (LIHTC) in the United States studied by Baum-Snow and Marion (2009); Soltas (2022). In contrast to LIHTC, the Colombian policy aims to incentivize the construction of units to be owner-occupied and not rental units.

B. The Notch

The subsidy scheme creates three different prices, P, P^δ, and P^τ. P is the transaction or market price. P^τ is the price households pay net of subsidies τ, $P^\tau = P - \tau$. P^δ is the price developers receive after including tax refunds, $\delta = 4$ percent, $P^\delta = P \cdot (1 + \delta)$. Figure 2 illustrates how the different prices defined by the subsidies have a discontinuity at the *low-cost housing* cutoff, creating a notch in incentives for households and developers and inducing them to buy and build housing units with a price at or below the cutoff.

Figure 2: The Notch



Note: This figure compares the **market price P**, the price received by developers P^δ, and the price households pay net of subsidies, P^τ **2006-08**,P^τ **2009-11** and P^τ **2016-18** at different unit prices. The 45-degree black line represents the market price P. The price paid by households is $P - \tau^m - \tau^i$, τ^m represents the downpayment subsidy, which is a fixed amount independent of the price. τ^i represents the savings in interest rate payments. Because the interest rate payments depends on the mortgage; it is calculated by taking a typical mortgage at each market price using administrative records from the Ministry of Housing.

The supply notch. The supply notch is the difference between the red lines, representing the developer's price P^δ, and the black lines, representing the transaction price P in

Figure 2. Developers who, in the absence of the tax refund, would build a project with housing units with a market price above the cutoff have incentives to build cheaper units priced below the cutoff.

The demand notch. The difference between the blue and black lines in Figure 2 represents the savings for the households that receive the subsidy. The fact that subsidies only apply to low-cost housing creates discontinuous incentives on the demand side. The blue lines in figure 2, represent the household's price P^{τ}. The gap between the black and the blue lines is the money paid by the government $\tau = \tau^{m} + \tau^{i}$. The government pays a fixed amount, the downpayment assistance subsidy, τ^{m}, and the amount corresponding to the interest rate subsidy, τ^{i}. The interest rate subsidy is related to the housing price to the extent that they depend on the mortgage. I use administrative records to calculate the government expenditure on interest rate payments using a typical mortgage at each price level (see details in Appendix A).

Notch over time. The notch on the demand side increases over time. The **gray blue** line in figure 2 shows P^{τ} when only the downpayment subsidy was available between 2006-08. Households buying a unit priced above the cutoff paid the full price of the house, therefore the black and blue lines coincide above the cutoff. In 2009, the interest rate subsidy was introduced. The **dark blue** line shows the price paid by a household that receives the downpayment subsidy and the interest rate subsidy during 2009-11. In contrast to the downpayment subsidy, there is an interest rate subsidy above the low-cost housing cutoff, but there is a discontinuity in the subsidy at that cutoff. For example, in the 2009-11 period, the interest rate subsidy is 5 percentage points for a house with a price below 135 mMW, and 4 percentage points for houses above that price. The **light blue** line shows the price paid by households who received the two subsidies after the *Mi Casa Ya* program was introduced between 2016-18. Between 2009 and 2018, there was a drop in the interest rate, from 13 to 10 percent, leading to lower government payments related to the interest rate subsidy.[17] This explains why P^{τ} below the cutoff was similar during 2009-11 and 2016-18. It also explains why the price in 2016-18 was lower above the cutoff. I exclude 2012 and 2015 because there were many changes in the interest rate subsidy during that period.[18]

[17] Figure A.3b shows the interest rate evolution with and without the subsidies between 2006-2018.

[18] During this period, the subsidy changed many times and additionally, the government granted 100,000 fully subsidized housing units priced at $70 \times mMW$ or below the interest rate. For completeness, I include this period when presenting the data and results; however, I see it as a transition period and, therefore, pay little attention to it.

Notch size. Table 1 shows the size of the jump at the cutoff during the study period and the number of assigned subsidies for each program. Around 45 thousand households receive the downpayment subsidy each year, around 22 thousand households receive the interest rate subsidy each year, and around 17 thousand households receive the subsidy from the *Mi Casa Ya* program, which grants both subsidies.

Table 1: Notch and number of subsidies by period

	Notch *(in mMW)*			Subsidies *(in thousand)*		
	τ^M	τ^i	τ	*downpayment*	*interest rate*	*Mi Casa Ya*
2006-2008	18.0	.	18.0	47.1	.	.
2009-2011	20.0	5.85	25.9	46.4	16.7	.
2012-2015	19.9	9.55	29.5	41.1	22.2	.
2016-2018	25.3	7.24	32.6	44.5	23.4	16.8

NOTE: This table shows the size of the notch in figure and by period and differentiating the discount coming from the interest rate subsidy and the discount from the downpayment assistance. It also shows the number of subsidies (in thousands) assigned to each type of program each year. The value for each period is the average number. Figures A.3b and A.4 shows the loan terms and interest rate over time.

C. Housing Market Data

In addition to the administrative records for the subsidies that I presented above, the main analysis of the paper is based on a census of all new construction projects. This subsection introduces that census.

Data sources. The data are from a monthly census, called *Coordenadas Urbanas*, collected by the Colombian Chamber of Construction-CAMACOL and containing all new construction units built in 126 Colombian municipalities between 2006 and 2018.[19] The observation unit is a type of housing unit. For example, there may be three different types of apartments in housing developments: studios, one-bedrooms, and two-bedrooms. I observe the price and characteristics of each of them. I observe all housing development projects of at least 300 square meters of construction. The census excludes small single-family homes and informal housing and does not contain information on the resales of existing housing units. Although this is a limitation of the data, the subsidies apply only to new housing, so the data cover the directly affected part of the market.

[19]Not all cities have information starting in 2006, the census expanded its coverage over time.

General characteristics. The data contain detailed information about the house, such as the unit size; location, including the exact latitude and longitude coordinates; rooms; quality of appliances; estrato, which is an index summarizing neighborhood quality; and *developer and project characteristics*, such as the firm's tax identifier and the number of units built in each project, the number of parking spots, the number of towers built, the lot size and an indicator variable for single-family units, among other details. Conditional on lot size, regulation, and location of the lot, developers have to choose which type of units and how many units to build. The data allow me to differentiate the product choice from the number of units that developers build. I leverage this advantage of the data in the model presented in section IV.

Price. The data contains the sale price at different stages of the construction process. To facilitate the comparison, I take the price at the beginning of the project's construction. All prices are in 2019 COP or mMW to make it comparable to the price cutoff defining *low-cost housing* units.

III. Housing Market Responses

This section uses the housing market data to describe the equilibrium response to the Colombian housing policy described in section II. Households and developers respond to the discontinuous incentives by bunching at the price cutoff. The generosity of the incentives changed over time, generating a more pronounced bunching in the later years.

A. Bunching in Observed Market Outcomes.

Bunching around the price limit. Figure 2 shows how the subsidy scheme creates incentives for households and developers to buy and build housing units priced at or below the cutoff. The discontinuous incentives determine the market equilibrium for all years and cities in the data. Figure 3a shows the distribution of the type of units, or product space, by price. This figure shows how the subsidy scheme changes the type of units built. Because developers who build smaller units can build more units, the bunching in product space is amplified when we consider the number of units built of each type, resulting in a more pronounced bunching in market shares.

Counterfactual. The solid line in Figure 3 represents a counterfactual distribution. That is the distribution of housing units that would exist without the subsidy scheme. The idea behind this estimation is that the distribution should be smooth without discontinuity in the incentives. To construct the counterfactual distribution, I follow the standard techniques from the bunching literature (Kleven, 2016). The standard approach is to run a regression with shares or the number of units on the left-hand side and on the right-hand side, a flexible polynomial on the running variable, in this case, price, and dummies for the bins around the discontinuity. The counterfactual distribution is the prediction using the coefficients of the flexible polynomial and excluding the bins around the cutoff. This estimation relies on three parameters: the size of the bins, the polynomial degree, and the number of dummies around the discontinuity. Following Diamond and Persson (2016); Chen et al. (2021), I chose the degree of polynomials and the number of dummies around the cutoff to match the missing and excess. The estimation details and sensitivity analysis to different parameter choices are discussed in Appendix B.

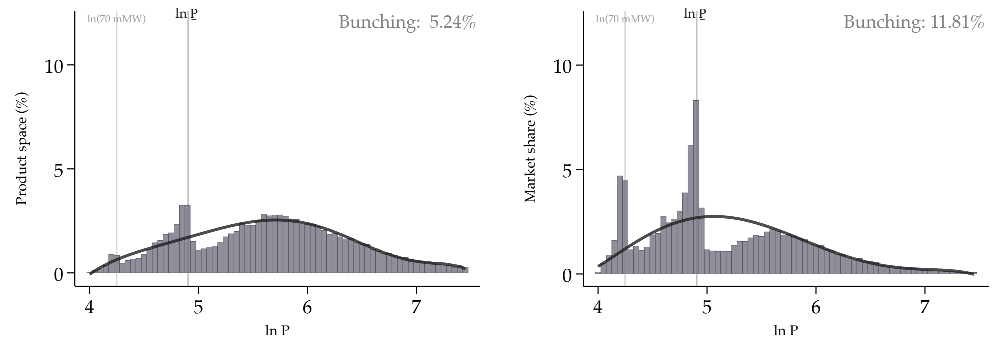
Bunching description. Figure 3 shows a sharp and clear excess mass, or bunching, around the price cutoff defining *low-cost housing*. About 12 percent of the market share moves from above the cutoff to below the cutoff. This response is the result of the notched policy design. The figure shows a clear change in the type of new construction. The subsidy moved households and developers from above to below the cutoff. In the absence of the policy, they would buy and build more expensive housing, but they modify their behavior to take advantage of the subsidy. Note that there is also bunching at *lowest cost housing* 70 mMW. This is mostly explained by the 100 thousand free housing units granted by the government between 2012 and 2015. See figure 4. As mentioned before, the 2012-15 period is presented for completeness but it is not part of the main analysis of the paper.

Intensive margin response. Evaluating this policy without accounting for an intensive margin response, would lead to miss leading results. In this case, the intensive margin response corresponds to changes in the type of units that households and developers decide to build. This type or response is the most prevalent response in policies such as MID that aim at increasing homeownership (Gruber et al., 2021). Figure 3 highlights the importance of the intensive margin response in this setting and shows why a naive policy evaluation that compares the number of units to the left and right of the cutoff would be misleading. This naive policy evaluation would create the illusion that the policy induces the construction of housing units that would not be built without the subsidy. However, in that comparison, the treated group, *low-cost housing* units, would be "inflated" and the control group, housing units above the cutoff, would be "deflated" by households that modify their consumption, but in both scenarios buy a house. Therefore, accounting for the intensive margin response becomes essential to understand the effect of the policy.

Figure 3: Bunching around the *low-cost housing* Price Limit

All Data 2006-18

a. Product Space *b. Market Shares*



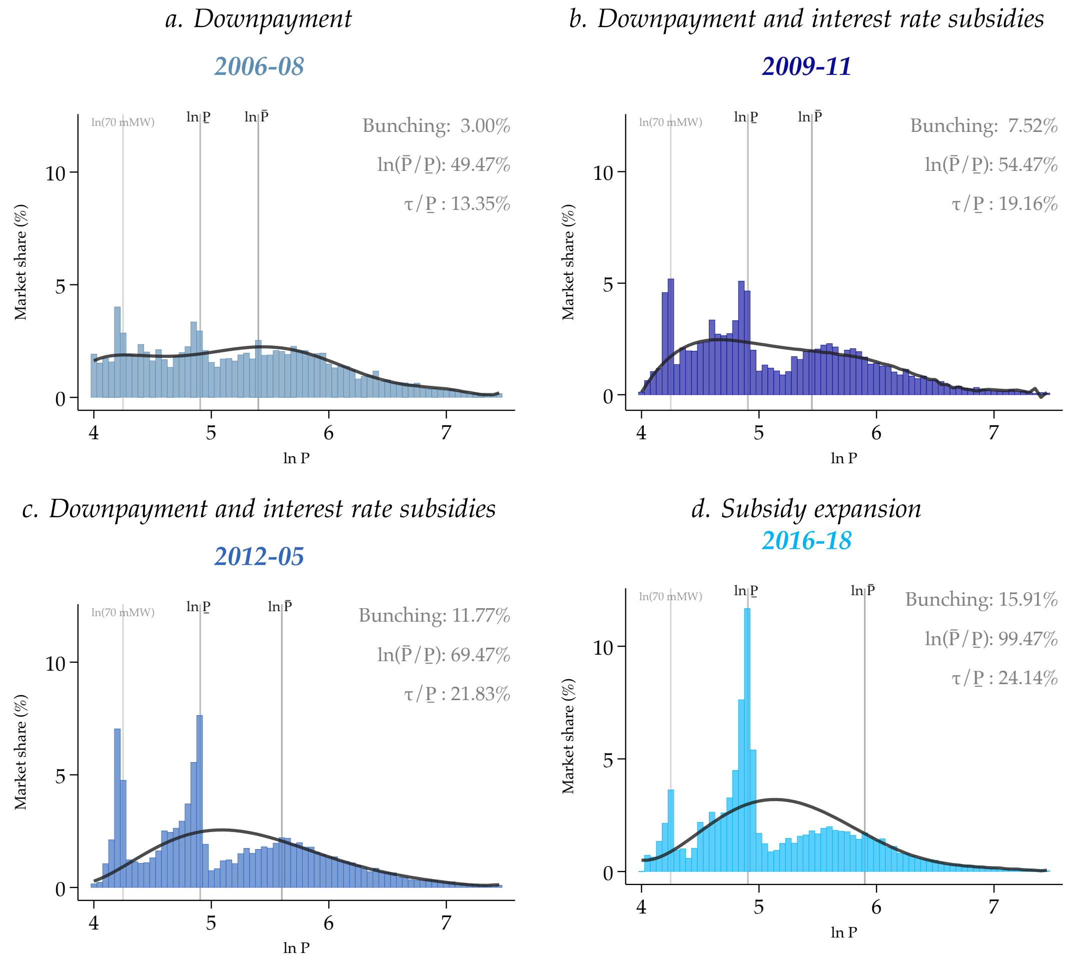
Note: The figure shows all the units from 2006 to 2018 in all the cities. Figure 3a shows the distribution of the type of housing units being built or product space. Figure 3b shows the distribution or the market share of housing units by sale price (expressed in logs (mMW). The vertical lines are the cutoffs defining *low-cost housing* $\underline{P} = 135$ mMW and *priority low-cost housing* 70 mMW. The bunching numbers on the top right represent the difference between the counterfactual distribution (black line) and the observed distribution at the cutoff.

B. Bunching Over Time and Counterfactual Distribution

Changes over time. Because the subsidy scheme evolved during my study period, I can show how the market equilibrium responds to policy changes. Figure 4 shows the distributions of market shares by price for the 4 different subsidy levels. The figure also shows the counterfactual distribution, and on the top right, it shows the share of the market share that bunches, the size of the notch as the percentage of the price of a house at the cutoff, $\frac{\tau}{\underline{P}}$, and the maximum change in housing consumption, $\ln\left(\frac{\overline{P}}{\underline{P}}\right)$. The relationship between these two magnitudes provides a reduced-form semi-elasticity. It tells us how much housing consumption households are willing to give up to take advantage of the subsidy.

Bunching over time. Figure 4 provides compelling evidence that the housing market responds to the subsidy scheme. Between 2006-09 only the downpayment for formal employees was available. Households receive a subsidy of 13 percent of the house's value, and developers receive a tax refund of 4 percent of the value of the house. Around 3 percent of households reduced their housing consumption bunching at the cutoff, and developers changed the type of units they build making them up to 50 percent cheaper. The semi-elasticity is $\frac{\ln\left(\frac{\overline{P}}{\underline{P}}\right)}{\frac{\tau}{\underline{P}}} = 3.85$. In 2009-11, when the interest rate subsidy was introduced, the notch jumped to 19.2 percent of the house price at the

Figure 4: Bunching over time



Note: This figure shows the distribution or the market share of housing units by sale price (expressed in log of mMW). The lines are the cutoffs defining *low-cost housing* $\underline{P} = 135$ mMW and *priority low-cost housing* 70 mMW. The additional line is at $\ln \overline{P}$, this is the point where the counterfactual and observed distribution are the same. The figure panels represent the different periods for all available cities.

cutoff. Consequently, the share of households bunching increased to 7.5. In 2012-15 there is a big bunching point at the cut-off point of 70 mMW. This corresponds to the program of 100 thousand free housing units for the most vulnerable, which took place during that period (Gilbert, 2014b; Camacho et al., 2020). In 2016, when the program *Mi Casa Ya* was introduced, households could receive almost a quarter of the house's value if they reduced their consumption to qualify for the subsidy. Up to 16 percent of households modify their behavior in this way. The semi-elasticity for this period is 4.12.

C. Bunching as an Equilibrium Response

The previous subsection provides compelling evidence of the Colombian housing market responding to the discontinuous incentives generated by the subsidy scheme. However, to be able to learn something about the market structure from the reduced-form evidence presented so far, it is crucial to know the specific responses of developers and households that lead to the observed market equilibrium. Understanding these responses would allow as to answer questions such as; How does the supply side adjust? How is the equilibrium price set? Is the subsidy to developers necessary to prevent housing rationing? Are there any inefficiency gains or welfare losses associated with the subsidy scheme? The purpose of the remaining sections of this paper is to provide a framework for answering these questions. But, before transitioning to the model's description, this subsection justifies the explanation explored in this paper which is that the equilibrium outcome is achieved in a competitive market where agents modify the characteristics of the housing units they buy and build to take advantage of the subsidy. Changes in characteristics could include lower quality, smaller units, or fewer amenities.

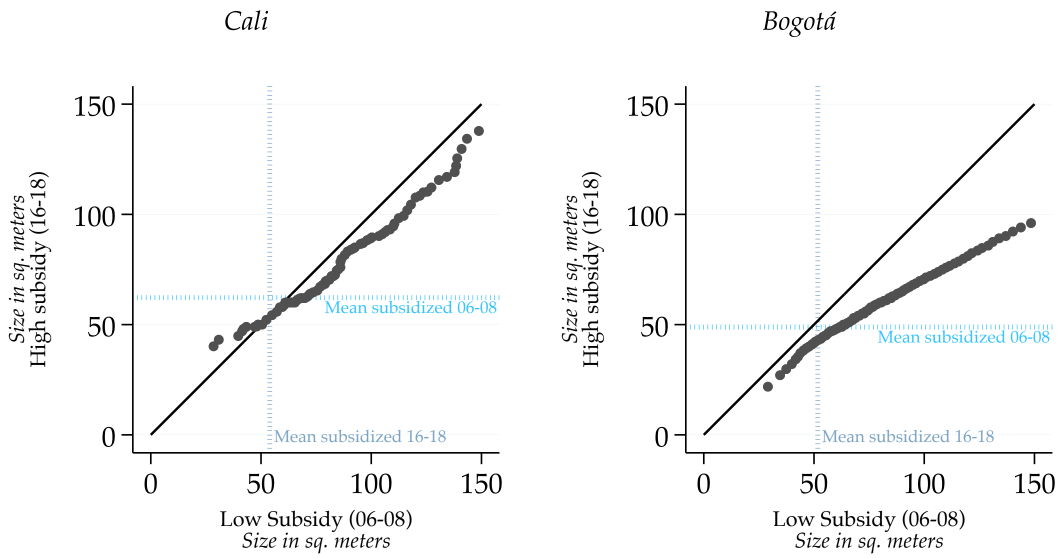
Mechanism justification. There are two main reasons for the explanation explore in this paper. First, the construction sector is perceived as highly competitive, and developers have no incentive to build larger units when, for the same price, households would buy smaller units.[20] Second, Figure 5 provides suggestive evidence that the subsidy scheme affects the characteristics of the housing stock.

Housing characteristics. It is difficult to summarize housing units into a single variable, as they differ in many dimensions. However, focusing on a single characteristic makes the analysis more tractable. I observe the size of each unit. This allows me to use this feature to analyze the structure of the housing market. Choosing size as the main variable in the analysis has several advantages. First, as opposed to the neighborhood's amenities, size is a concrete feature of the apartment itself, that is easy for builders to adjust in response to government policy. Second, the detail of the data allows controlling for an unusually large set of variables that may be correlated with size, including apartment and building characteristics, neighborhood quality (estrato, exact location), and structural characteristics of the house, such as the number of rooms and bathrooms, if there is a porch, among others. Third, size has the strongest reduced-form association with the housing unit price. Fourth, size is a continuous variable that allows me to estimate the implicit price function, which is important for

[20]This argument will be clearer when I introduce the model in the next section. The argument applies for any characteristics that imply any cost for developers.

the modeling approach considered in this paper; Fifth, size has a monotonic relationship with price, this is unlikely to be the case for other continuous variables such as exact location. Finally, other characteristics, such as quality, more prone to measurement error, and are not detailed enough to allow for a plausible analysis of the overall market structure.

Figure 5: Quantile-to-Quantile Plots of Housing Size: Low versus High Subsidy Periods



Note: This figure shows the quantile-to-quantile plots for observed housing size in square meters for two representative cities, Cali and Bogotá. The y-axis shows the size at the end of the period when subsidies are high, and the x-axis shows the size at the beginning of the period when subsidies are low. The dotted vertical and horizontal lines show the average size of subsidized units. The dots represent the same quantiles in both years. If there are no changes in housing size, they would be on the 45-degree line. Instead, the figure shows how there are changes in size at the quantiles near the average subsidized house.

Size response. To show that size is a relevant characteristic, Figure 5 shows that with the increase in subsidies, the housing size distribution is affected. Specifically, it is affected around the median size of the subsidized housing. Figure 5 has quantile-to-quantile plots for housing size at the beginning and end of the study period for two different cities (Figure C.3 in the appendix shows more cities). During this period, the notch induced by the policy increased from 18 mMW to 33 mMW. If the distribution of housing size did not change from the beginning to the end of the study period, the black dots would be on the 45-degree line. The blue dotted lines show the average size of a subsidized house. These figures suggest a change in the size distribution around the average subsidized unit. Changes in housing characteristics, particularly size, can explain the increase in bunching from 2006-08 to 2016-18, and is the leading explanation explored in this paper.

Alternative explanations. There could be alternative explanations that I do not explore in this paper. Bunching has been identified as a behavioral response in other settings. For example, Chetty et al. (2013) show that individuals adjust their tax reports to maximize the tax returns. Chen et al. (2021) show that a notch in the incentives for R&D leads to some relabeling of types of investments as R&D to take advantage of the tax incentive. This type of response is unlikely in the institutional setting studied in this paper. There are many agents with competing interests; households, banks, developers, and the government, and the transaction involves all of these agents. This makes a simple reporting response costly and less likely; banks have no incentives to under-report the house price for the mortgage.[21]

Another explanation could be a response only in prices. Households and developers buy and produce the same type of housing, but developers reduce the price for units above but close to the cutoff, allowing households to get the subsidy. This explanation would imply that developers have high markups and market power. Although these two alternative explanations are plausible, a detailed investigation of them is beyond the scope of this paper. Moreover, the explanation explored in this paper rationalizes the observed equilibrium and is consistent with anecdotal evidence.

IV. Competitive Housing Market Equilibrium Model

This section introduces a model that rationalizes the observed equilibrium and describes the economic behaviors driving it. The proposed model introduces the discontinuous incentives produced by the Colombian subsidy scheme into a standard hedonic equilibrium model or sorting model.[22] The model also motivates the identification approach to recover the parameters describing households' preferences and

[21] Anecdotal evidence may suggest that some housing units sold in expensive neighborhoods as *low-cost housing* are the result of miss-reporting. However, in many cases, those houses are extremely small (20 square meters) (UniMinuto, 2022) or are sold without appliances (Metrocuadrado, 2022). These last two responses fall in the category studied in this paper; households reduce their housing consumption to take advantage of the subsidy, in this case they reduce the size of the house or quality.

[22] This is a canonical version of a model with heterogeneous households and developers buying housing units of different sizes. Some of the main references of these types of models, without a notch in the budget set, are S. Rosen (1974); Epple (1987); Ekeland, Heckman, and Nesheim (2004); Bajari and Benkard (2005); Heckman, Matzkin, and Nesheim (2010); Epple et al. (2020); Chernozhukov et al. (2021). The literature based on this models is summarized by Kuminoff et al. (2013) and Greenstone (2017). Palmquist (2005); Parmeter and Pope (2013); ? (?) summarize the empirical application that are mostly concentrated estimating the hedonic price of an environmental amenity whitout an implicit market.

developers' technologies, which in the hedonic literature is usually called the second step. Recovering the primitives of the model allows for a welfare evaluation of the policy.

A. Model Setup

Housing. Housing is a vertically differentiated product characterized by a continuous variable h. h can represent any continuous vertically differentiated attribute such as quality or size. In this paper, all units are standard units that differ only in how large they are.[23]The price of the housing unit P depends on the size h, and is described by $P(h)$, the hedonic price function.

Households. Households looking to buy a *new* housing unit are indexed by i, and are heterogeneous in their wealth level $Y_i \sim F_Y$.[24] F_Y is the cdf describing the wealth distribution. Households decide how much housing to buy, h_i and how much to consume of other goods, C_i, to optimize utility $U(C_i, h_i; \theta)$, where θ is a preference parameter to be estimated.

Developers. Developers are indexed by j and heterogeneous in their productivity $A_j \sim G_A$. G_A is the cdf describing the productivity distribution. Developers own a lot with set characteristics and decide what type of housing units they want to build to maximize profits. The number of units, Q_j, is determined exogenously by the function $Q\left(h_j\right)$, and this affects the optimal choice in terms of unit size. Developers face construction costs $B(h_j, Q\left(h_j\right); \beta)$[25]where β characterizes the cost function and is the supply parameter to be estimated.

Simplifying assumptions. I introduce three simplifying assumptions. First, I assume that the market is perfectly competitive, that is, developers cannot individually affect prices, and $P(h)$ is independent of Q. Second, developers only choose the unit size they build. They follow an exogenous and differentiable unit supply function $Q = Q^S\left(h\right)$. The number of units does not need to be predetermined since apartment

[23]For simplicity, the model presented in this section omits other characteristics. The model can be extended to include multiple characteristics. In fact, this is one of the main characteristics of hedonic models (S. Rosen, 1974).

[24]I call Y_i wealth for simplicity. It is a measure containing wealth, assets and their returns, transfers, income, etc.

[25]The cost function $B\left(Q, h, A_j; \beta\right)$ is derived from minimizing the production constraints related to producing Q units with characteristics h. A_j reflects underlying variables in the factor prices and production function parameters. Different values of A express different factor prices or productivity among developers. See S. Rosen (1974, p.43) for a discussion.

size is an endogenous choice, but the allocation of property to developers is predetermined. For a given lot, developers decide the size of the units, and the regulatory framework and construction and technological constraints, captured by $Q^S(h)$, determine the number of units they build. The distinction between the number of units and the type of units is relevant because it allows the existence of buildings and multi-family projects, which is essential to describe the construction of new housing units in Colombia, particularly the *low-cost housing*. Third, construction costs depend on $Q(h)$, h, and productivity levels, that is, $B = B\left(Q(h), h, A_j; \beta\right)$. The last two simplifying assumptions make it straightforward to specify functional forms for the profit function and offer curves. Allowing for a completely endogenous choice of Q could be a better characterization, but obtaining a functional form for the offer curve, which is essential in the identification approach, is highly dependent on particular functional forms. Relaxing this assumption and allowing for imperfect competition is feasible but beyond the scope of this paper.

Discontinuous Incentives, Prices, and Size threshold

Price discontinuity Section II explained that given the subsidy scheme, there are three relevant prices. They are the market, household, and developer prices.

$$\text{Market:} \qquad P(h) \tag{1}$$

$$\text{Household:} \qquad P^{\tau}(h,\tau) = P(h) - \tau \cdot \mathbb{1}\left[P(h) \leq \underline{P}\right] \tag{2}$$

$$\text{Developer:} \qquad P^{\delta}(h,\delta) = P(h)\left(1 + \delta \cdot \mathbb{1}\left[P(h) \leq \underline{P}\right]\right) \tag{3}$$

Size threshold. Note that given the price function $P(h)$, there is a maximum size that households can buy to qualify for the subsidy. This is the size threshold;

$$\underline{h} = P^{-1}\left(\underline{P}\right) \tag{4}$$

Discontinuity. A household buying a *low-cost housing* unit pays a price $P^{\tau}(h,\tau)$ instead of $P(h)$, and developers who build low-cost houses can receive a reimbursement for the VAT taxes paid for the construction materials of up to $\delta = 4$ percent of the house's value. In other settings where the price can increase and the limit is set in terms of size, market equilibrium could be achieved by increasing the price, and δ would represent a premium to build *low-cost housing*. The price function $P(h)$ can be a continuous and differentiable function for all $h \in \mathcal{H}$, but the developer and the household price functions, $P^{\delta}(h,\delta)$, and $P^{\tau}(h,\tau)$, are not differentiable at $\underline{P}$.

B. Optimal Choices and Decision Problem

Households. A household $i \in N$ maximizes its utility given its level of wealth Y_i. It solves the following optimization problem:

$$\begin{aligned} \max_{h,C} \quad & U(h, C; \theta) \\ \text{subject to:} \quad & Y_i = P^{\tau}(h, \tau) + C, \\ & h \geq 0. \end{aligned}$$

Bid functions (or indifference curves). $\varphi_D(h, Y, \bar{U}; \theta)$, represent all the combinations of prices P and unit size h that provide the same level of utility $\bar{U}$ to a household with $Y = Y_i$. Therefore, φ_D is such that

$$\bar{U} = U(h, Y_i - \varphi_D; \theta) \tag{5}$$

Developers. Developer's profits $\pi(Q, h, A_j)$ are determined by the total revenue minus costs.

$$\begin{aligned} \max_{h} \quad & \pi(Q, h.A_j) \\ \text{subject to:} \quad & \pi = Q \cdot P^{\delta}(h, \delta) - B(Q, h, A_j; \beta) \\ & Q = Q(h) \end{aligned}$$

Offer function (or iso-profits). The offer function represents the indifference surface for all possible combinations of prices and size h providing the same profits. φ_j^S represents the price that developers are willing to accept at different unit sizes to obtain the same level of profits $\bar{\pi}_j$. To define the offer function, I replace the developers' price, $P^{\delta}(h, \delta)$, by φ_j^s, profits by $\bar{\pi}$, and solve for φ_j^s,

$$\varphi_j^s = \frac{B(Q^s(h), A_j; \beta) + \bar{\pi}}{Q^s(h)} \tag{6}$$

Tangency Conditions

Households. On the demand side, households choose their housing size h to maximize their utility. Due to the notch in the budget set, the standard *tangency condi-*

tions,[26]

$$\frac{\partial P\left(h\right)}{\partial h}=\frac{\dfrac{\partial U\left(h,C;\theta\right)}{\partial h}}{\dfrac{\partial U\left(h,C;\theta\right)}{\partial C}} \tag{7}$$

do not define households' housing demand. Assuming that equation 7 has a unique solution and using the budget constraint, $P^{\tau}\left(h,\tau\right)-Y_i=C_i$, we can *solve* for h^*, the choice of housing satisfying *tangency conditions*.[27]

$$h^*\left(Y_i,\tau;\theta,\underline{P}\right)=\begin{cases} h\left(Y_i+\tau;\theta\right) & \text{if } P\left(h\right)\leq\underline{P} \\ h\left(Y_i;\theta\right) & \text{if } \underline{P}<P\left(h\right)\end{cases} \tag{8}$$

Developers. On the supply side, the design that satisfies the optimality conditions $h^*\left(A_j,\beta\right)$ for a given price function $P\left(h\right)$ is achieved when developers maximize profits subject to the developer's price being equal to the offer curve $P^{\delta}=\varphi^{s}$. The unit size that satisfies the tangency conditions $h^*\left(A_j,\beta\right)$ and the optimal profits $\bar{\pi}\left(A_j,\beta\right)$ are achieved when the price and offer curves are tangent.

$$\frac{\partial\varphi^{s}\left(h,A_j;\beta,\bar{\pi}\right)}{\partial h}=\begin{cases} \dfrac{\partial P\left(h\right)}{\partial h}\cdot\left(1+\delta\right) & \text{if } P\left(h\right)\leq\underline{P} \\ \\ \dfrac{\partial P\left(h\right)}{\partial h} & \text{if } \underline{P}<P\left(h\right)\end{cases} \tag{9}$$

We can *solve* 9 for h, and obtain an expression for the *tangency conditions*,

$$h^*\left(A_j,\delta;\beta,\underline{P}\right)=\begin{cases} h\left(A_j,\delta;\beta\right) & \text{if } P\left(h\right)\leq\underline{P} \\ h\left(A_j;\beta\right) & \text{if } \underline{P}<P\left(h\right)\end{cases} \tag{10}$$

C. Marginal Bunchers and Optimizer Types and Individual-Level Supply and Demand.

The individual level demand and supply do not correspond to optimality conditions in this setting because there is a subset of households for which it is optimal to sacrifice housing consumption to obtain the subsidy. For developers, it is also beneficial to

[26]This follows by defining a Lagrangian and taking first-order conditions with respect to h and C and taking the ratio. I assume that the composite good has a price $p_c=1$

[27]It has been discussed in the literature that a sufficient condition for this to hold is to assume a Spence-Mirrlees type single crossing condition. See for example, Heckman et al. (2010, p.1573) or Kuminoff et al. (2013) for an overview.

produce a smaller housing unit to benefit from the tax refund. There are three types of households and developers; *always-takers*, *marginally subsidized*, and *never-takers*. To define them, I use two key agent types; *marginal buncher* and *threshold optimizer* for both households and developers. The marginal buncher agents are critical as they determine the identification approach presented in Section V. They are indifferent to changing their behavior and receiving subsidies or buying and producing the housing unit they would choose in the absence of the policy.

MARGINAL BUNCHER HOUSEHOLD: $Y_i = \overline{Y}$

$$h^* \left(\overline{Y}, \tau; \theta, \underline{P}\right) = \overline{h} \iff U\left(\overline{Y} - P^\tau\left(\overline{h}, \tau;\right), \overline{h}; \theta\right) = U\left(\overline{Y} - P^\tau\left(\underline{h}, \tau\right), \underline{h} : \theta\right) \tag{11}$$

MARGINAL BUNCHER DEVELOPER: $A_j = \overline{A}$

$$h^* \left(A_j, \delta; \beta\right) = \overline{h} \iff \pi\left(Q(\underline{h}; \alpha), \overline{A}; \delta\right) = \pi\left(Q(\overline{h}; \alpha), \overline{A}; \delta\right) \tag{12}$$

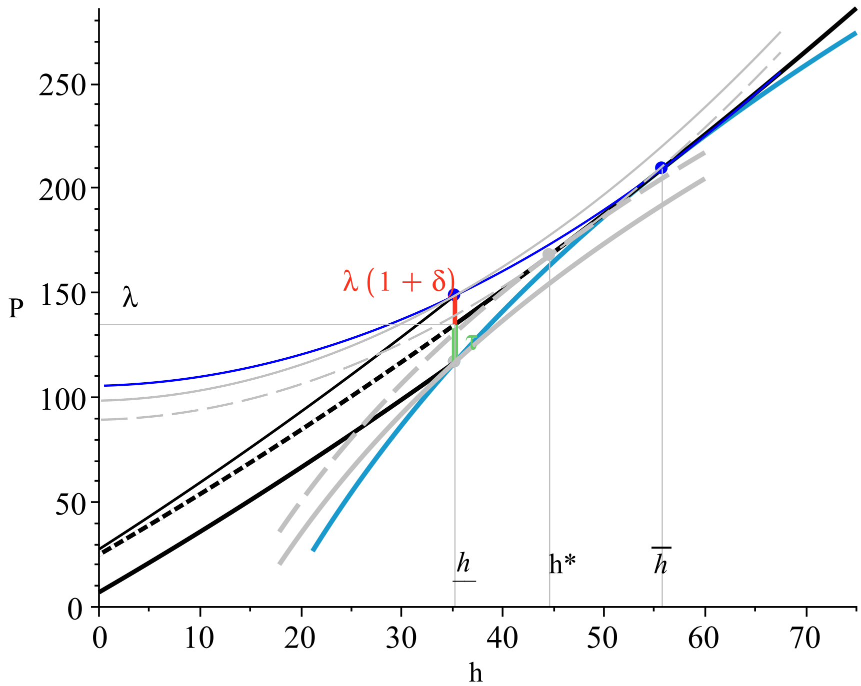
Threshold optimizer. are the households and developers optimizing at $P^{-1}\left(\underline{P}\right) = \underline{h}$. They are have wealth and productivity $Y_i = \underline{Y}$ and $A_j = \underline{A}$ respectively.

Individual-Level Supply and Demand. The demand and supply functions are different for the three groups of agents. The *always-takers* with $Y_i \in (0, \underline{Y})$ and $A_j \in (0, \underline{A})$, receive subsidies and optimize at the tangency point below $\underline{h}$. The *Marginally subsidized* with $\underline{h}$ $Y_i \in (\underline{Y}, \overline{Y})$ and $A_j \in (\underline{A}, \overline{A})$, are the ones that bunch at the cutoff. The policy design induces a change in their behavior; they consume and produce less housing than they would in the absence of the policy. The *never-takers* $Y_i > \overline{Y}$ and $A_j > \overline{A}$ do not find it beneficial to modify their behavior to take advantage of the subsidy.

$$h^{\mathrm{D}} = \begin{cases} h^*\left(Y_i, \tau; \theta, \underline{P}\right) & \text{if } Y_i \leq \underline{Y} \\ \underline{h} & \text{if } Y_i \in \left(\underline{Y}, \overline{Y}\right) \\ h^*\left(Y_i, \tau; \theta, \underline{P}\right) & \text{if } \overline{Y} \leq Y_i \end{cases} \quad h^{\mathrm{S}} = \begin{cases} h^*\left(A_j, \delta; \beta, \underline{P}\right) & \text{if } A_j \leq \underline{A} \\ \underline{h} & \text{if } A_i \in \left(\underline{A}, \overline{A}\right) \\ h^*\left(A_j, \delta; \beta, \underline{P}\right) & \text{if } \overline{A} \leq A_j \end{cases} \tag{13}$$

Figure explanation. Figure 6 shows an example of the equilibrium choices of developers and households. The price function is the envelope of the offer curves when developers produce their optimal unit size and the assigned number of units. The figure shows a representative marginal buncher household and developer. It also shows in gray marginally subsidized households and developers, which are the agents that change their behavior to take advantage of the subsidy. A developer type A_j matches with a household type Y_i in terms of their optimal choice of h when the dashed lines meet. However this is not an equilibrium choice because both developers and households can be better off if they reduce size h. Figure D.4a, shows the case of subsidized households and developers. Below $\bar{h}$, developers receive $P(1+\delta)$ and households pay $P-\tau$. Developers and households increase their utility and profits as a result. The marginal bunching agents are indifferent between getting the subsidy or not. The identification approach in this paper relies on these agents and therefore the main identification strategy is conveyed in Figure 6. The idea is that the bunching in the observed equilibrium distribution allows me to recover $\overline{h}$. Therefore, I can observe two points, $\underline{h}$ and $\overline{h}$, on the same indifference curves and offer functions and recover their shape. Figure D.4 shows the optimal choices for other types of developers and types of households.

Figure 6: Marginally Subsidized and Marginal Buncher Agents' Choices



NOTE: This figure shows the optimal choices for the marginal buncher household and developer. The figures present the intuition for the identification idea. The gray offer and bid functions represent the indifference curves for the marginally subsidized agents. These are the ones who can increase their profits or utility by increasing or reducing h to take advantage of the subsidy and tax incentives. The demand and supply functions are defined as follows:

D. Market-Level Supply and Demand

The market level demand and supply are defined by the individual demand and supply represented in Figure 6 and the distribution of wealth and productivity. The approach to derive the market-level supply and demand is to use the optimality conditions and the distributions F_Y and G_A and a change of variable formula.[28]

Graphical Representation. Figure 7c shows the product space or developer density and the exogenous unit supply function. Figure 7a shows an example of the equilibrium density when f_Y and g_A follow a log-normal distribution. The equilibrium price makes the product of the functions in figures 7c and 7b to match the demand density in Figure 7c. The observed density function suggests that the market equilibrium has a discontinuous density and that this stylized model can explain the observed equilibrium represented in Figure 4.

Productivity and Income Mapping to Housing Size. Households and developers only differ in wealth Y_i, and productivity A_j. If $h^*(Y_i, \tau; \theta, \underline{P})$ is strictly monotone, there is a one to one mapping between Y_i and A_j and the optimality conditions.[29]

$$Y_i = \tilde{Y}(h, \tau; \theta, \underline{P}) = h^{*-1}(h_i, \tau; \theta, \underline{P}) \tag{14}$$
$$A_j = \tilde{A}(h; \beta, \delta) = h^{*-1}(A_j, Q(h); \beta, \delta, \underline{P}) \tag{15}$$

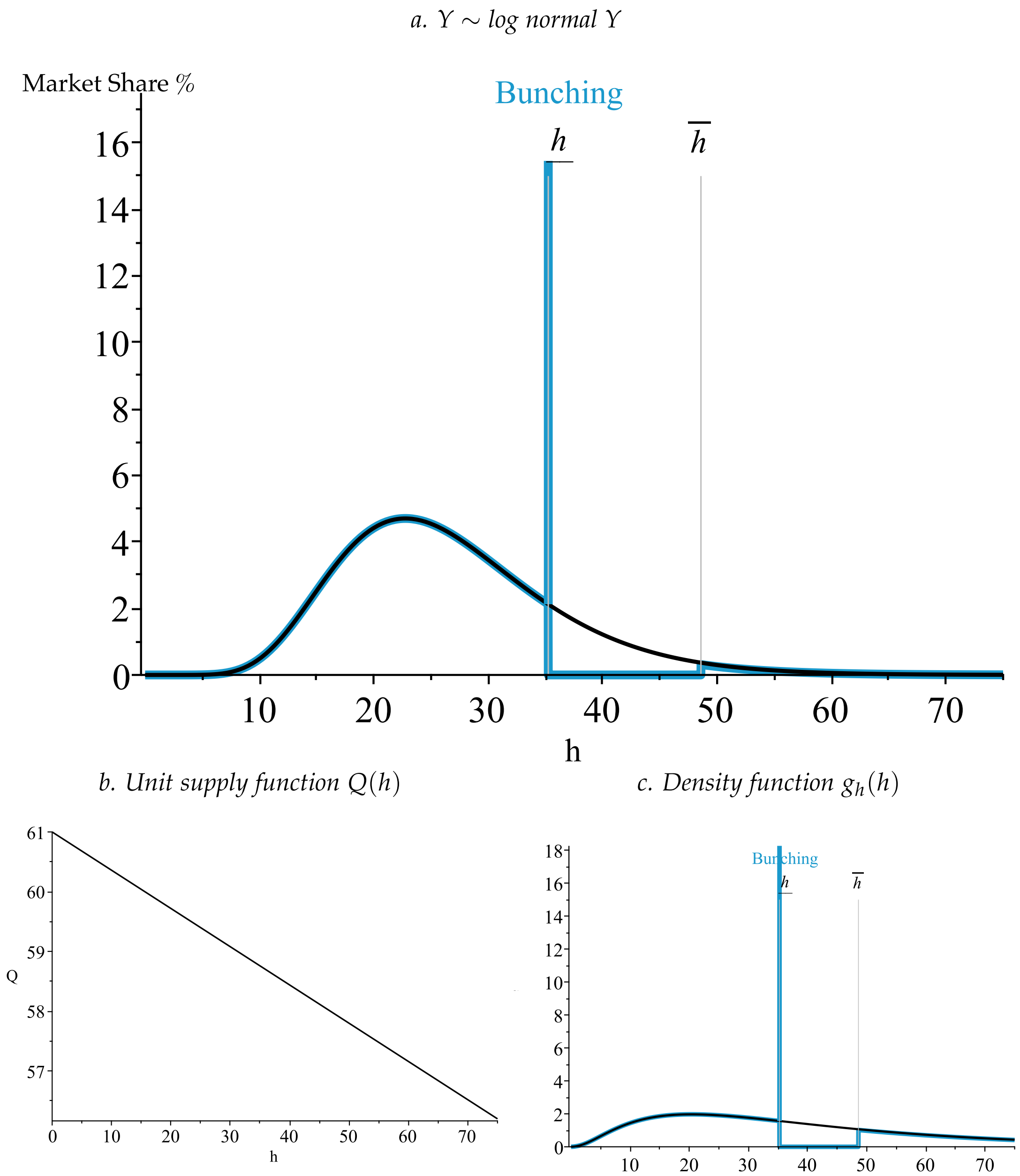
From distribution of income and productivity to a size distribution. The share of households and developers choosing h determines the market-level demand and supply densities. Using equations 14 and 15, we can get the distribution of market shares and the product space that satisfies the optimality conditions of the market.

$$f_{h^*} = \begin{cases} f_Y\left(\tilde{Y}(h, \tau \neq 0; \theta, \underline{P})\right) \frac{\mathrm{d}}{\mathrm{d}h}\tilde{Y}(h, \tau \neq 0; \theta, \underline{P}) & \text{if } h < \underline{h} \\ f_Y\left(\tilde{Y}(h, \tau = 0; \theta, \underline{P})\right) \frac{\mathrm{d}}{\mathrm{d}h}\tilde{Y}(h, \tau = 0; \theta, \underline{P}) & \text{if } \underline{h} < h \end{cases} \tag{16}$$

[28] Heckman et al. (2010, p.1571) derives the market demand and supply densities in this way for the case without a notch.

[29] This mapping from housing consumption to income is a consequence of the assumption $\theta_i = \theta \, \forall i$. If I allow heterogeneity in θ, the same demand for housing h can come from different combinations of Y_i, θ_i.

Figure 7: Equilibrium Density, Developer's Choice Density and the Unit Supply Function



Note: This figure shows the equilibrium market share or distribution of units by standard unit size for a given income density f_y following a log-normal distribution. Figures 7c show the product space or share of developers choosing to build at each unit size and Figure 7b shows the unit supply function.

$$g_{h^*} = \begin{cases} g_A\left(\tilde{A}\left(h;\beta,\delta\neq 0\right)\right)\dfrac{\mathrm{d}\tilde{A}\left(h;\beta,\delta\neq 0\right)}{\mathrm{d}h} & \text{if } h < \underline{h} \\[2ex] g_A\left(\tilde{A}\left(h;\beta,\delta= 0\right)\right)\dfrac{\mathrm{d}\tilde{A}\left(h;\beta,\delta= 0\right)}{\mathrm{d}h} & \text{if } \underline{h} < h \end{cases} \tag{17}$$

Densities

The distributions f_{h^*} and g_{h^*} and the demand and supply functions, $h^{\mathrm{D}}\left(Y_i;\tau,\theta,\underline{P}\right)$ and $h^{\mathrm{S}}\left(A_j,\delta;\beta,\underline{P}\right)$, allow to derive the market-level demand density, $D_h\left(h;\tau,\theta,\underline{P}\right)$, and the market-level supply function $S_h\left(h,\beta,\delta\right)$.

Aggregate Demand density. The demand for housing at the size limit $\underline{h}$ contains the demand for the *threshold maximizing households*, $f_{h^*}\left(\underline{h};\tau,\theta\right)$, and *the marginally subsidized households* $\int_{\underline{h}}^{\overline{h}} f_{h^*}\left(h;\tau,\theta,\underline{P}\right)\ \mathrm{d}h$. Finally, there is no demand for housing units with $h \in \left(\underline{h},\overline{h}\right)$.

$$D_h = \begin{cases} f_{h^*}\left(h;\tau,\theta,\underline{P}\right)\ \mathrm{d}h & \text{if } h<\underline{h} \\ f_{h^*}\left(\underline{h};\tau,\theta,\underline{P}\right)\ \mathrm{d}h \\ \quad +\int_{\underline{h}}^{\overline{h}} f_{h^*}\left(h;\tau,\theta,\underline{P}\right)\ \mathrm{d}h & \text{if } \underline{h}=h \\ 0 & \text{if } \in\left(\underline{h},\overline{h}\right) \\ f_h^*\left(h;\tau,\theta,\underline{P}\right)\ \mathrm{d}h & \text{if } \overline{h}\leq h \end{cases} \qquad S_h = \begin{cases} g_{h^*}\left(h;\beta,\delta\right)\cdot Q\left(h\right) & \text{if } h<\underline{h} \\ g_{h^*}\left(h;\beta,\delta\right)\cdot Q\left(h\right) \\ \quad +\int_{\underline{h}}^{\overline{h}} g_{h^*}\left(h;\beta,\delta\right)\ \mathrm{d}h\cdot Q\left(h\right) & \text{if } \underline{h}=h \\ 0 & \text{if } \in\left(\underline{h},\overline{h}\right) \\ g_{h^*}\left(h;\beta,\delta\right)\ \mathrm{d}h\cdot Q\left(h\right)\left(h\right) & \text{if } \overline{h}\leq h \end{cases} \tag{18}$$

Given the hedonic price function $P(h)=P$, we can use a change of variable formula to get the market distribution in terms of price analogous to Figures 3 and 4.

E. Market Equilibrium

The housing market achieves an equilibrium E when, a given price scheme $P\left(h\right)$, market-level demand and supply are equal for all values of h:

$$E=\left\{P\left(h\right)\in\mathcal{P}:D\left(h;\tau,\theta,\underline{P}\right)=S\left(h;\delta,\beta,\underline{P}\right)\forall h\in\mathcal{H}\right\} \tag{19}$$

When households decide the type of units they buy, they implicitly choose the developer type from which to buy, and vice versa. The equilibrium price function $P(h)$ makes matches between types of households and developers that clear the market.[30]

[30]The existence of a hedonic equilibrium has received comparatively less attention than the identification of this type of model. S. Rosen (1974) and Epple (1987) describe a closed-form solution for the equilibrium price function. These solutions rely on specific functional forms describing for the households' preferences and developers' technologies, and particular distributions for the unobserved heterogeneity. Heckman et al. (2010); Ekeland (2010); Bajari and Benkard (2005) provide conditions for the existence of

V. Identification and Estimation of Developers' Technologies and Households' Preferences

The bunching induced by the discontinuous price function enables the identification and estimation of the parameter describing households' preferences, θ, and developers' technology, β. This section describes the identification details and the estimation of the different parameters required to recover β and θ. Following the hedonic literature, the identification and estimation approach follows a two-step procedure. The first step characterizes the observed equilibrium. The second step estimates the structural parameters. For this step, I deviate from the existing approaches used in the hedonic literature and adapt the identification approach by Best et al. (2019) to the hedonic framework.[31]

A. Identification of the First Step

First step description. In the first step, I use the analysis in Sections IV and III, to obtain the size of the notch, and the two key points $\underline{h}$ and $\overline{h}$, which are estimated using the evidence of bunching. Additionally, I need to estimate the hedonic price scheme and the unit supply function at $\underline{h}$ and $\overline{h}$. The hedonic price function plays two roles. First, it allows us to identify, $P(h)$ and marginal willingness to pay for the size of the house $p(h)$ conditional on the other observed characteristics. Second, it allows to use the bunching on the housing price, P described in Section III to recover $\underline{h}$ and $\overline{h}$.

Identification of the hedonic price function. The model presents a version of the hedonic equilibrium with a single characteristic, h, which is interpreted as size. However, one of the main advantages of hedonic models is that it allows one to write down the price of a differentiated product P as a function of the implicit prices of its different characteristics (S. Rosen, 1974). This characteristic makes the hedonic model a popular model representing housing markets, computers, or labor markets. Housing units differ in many different observed and unobserved characteristics, both of which have

an equilibrium and explicitly describe how the equilibrium price function depends on the distributions of characteristics of firms and workers. Generally, an equilibrium exists if utility is continuously differentiable, monotonic in numeraire, and Lipschitz continuous. The model presented in this paper can have an analytical solution using some particular functional forms. A particular example is available upon request.

[31] Bertanha et al. (2021); Blomquist, Newey, Kumar, and Liang (2021) describe the identification assumptions under which structural parameters can be estimated using observed bunching. They show the conditions under which elasticities can be identified under notches and kinks, and explain why in contrast to kinks, notches allow the identification of structural parameters. Best et al. (2019) Proposition 1 and Bertanha et al. (2021) Theorem 1 both prove identification using the same identification idea as in this paper.

an implicit price, as represented in the following equation,

$$P_{ltc} = P\left(h_{ltc}\right) + \Gamma' X_{ltc} + \varepsilon_{ltc} \tag{20}$$

where l is a type of unit in city c at time t. I assume that the housing price is additive and separable in the size of the house h_{ltc}, the observable characteristics are included in X_{ltc}, and ε_{ltc} represents the unobserved characteristics. Hedonic regressions isolate the implicit price of different characteristics. The equation 20 shows how the implicit price of size can partial-out the other characteristics, and in that sense, they are accounted by. For the reasons mentioned in section III.C, I focus exclusively on size. However, the approach can be used to for the other characteristics such as distance to the central business district ("CBD") or a quality index, or any other continuous characteristic of interest.

Main Identifying assumption. I rely on independence conditional on observable characteristics to identify the implicit price of size:[32]

$$\mathrm{E}\left(h_{ltc} | X_{ltc}, \varepsilon_{ltc}\right) = 0 \tag{21}$$

It is common to rely on conditional independence to recover the implicit price function of specific characteristics. In my setting, I observe a rich and unique set of controls. This includes the exact location of the unit and general characteristics of the house, including the number of rooms and the neighborhood quality index. The assumption of conditional independence can be problematic in many settings. For example, Chay and Greenstone (2005) shows that using a hedonic model to recover the marginal willingness to pay for air quality without using instruments generates biased results. Generally, biases coming from unobserved characteristics are very prevalent in hedonic equations (Parmeter & Pope, 2013). However, I argue that this type of problem is more important in other settings where the purpose is to estimate the marginal willingness to pay for amenities without an implicit market such as pollution, congestion, contamination etc. For example, in contrast to air quality, the hedonic regression does not show the opposite of the expected sign. Additionally, when I include characteristics, such as an indicator function equal to one, if the house has an extra bathroom, or a studio, or a porch, the magnitudes of the coefficients do not change. This type of characteristic is potentially unobserved by the econometrician in other settings, as it is

[32] Bajari and Benkard (2005) propose three different identification assumptions; i) Independence conditional on observables, ii) Option packages and iii) instruments. My setting and data allows an implementation of each of the three identification approaches. However, the results presented in this paper rely on the first condition.

related to size; so, it is reassuring that including it does not affect the size of the coefficients. However, this does not rule out the fact that other omitted variables could bias the results. For example, if there is market power in this market and the price change generating bunching, is a pure price reduction without changes in housing characteristics, the error term could be correlated with size, particularly for observations around the price cutoff.

Estimation

Observed Equilibrium. Figure 8 shows the joint densities of unit size and market price for all cities between 2006-2008 when the subsidy notch on the demand side was small and between 2016 and 2018 when the subsidy was twice as big. In each market, heterogeneous agents buy and sell different housing units. The same money may buy larger housing units in separate submarkets; therefore, agents cluster at different housing sizes for which the sale price is at or below the cutoff point. This figure would be the analog of figures 6 and 7a, if the only characteristic of a house was size. However, there are other characteristics such as neighborhood quality or structural parameters such as the number of rooms or the availability of extra space such as a studio or a porch. The hedonic price estimation allows as to account for all the different characteristics.

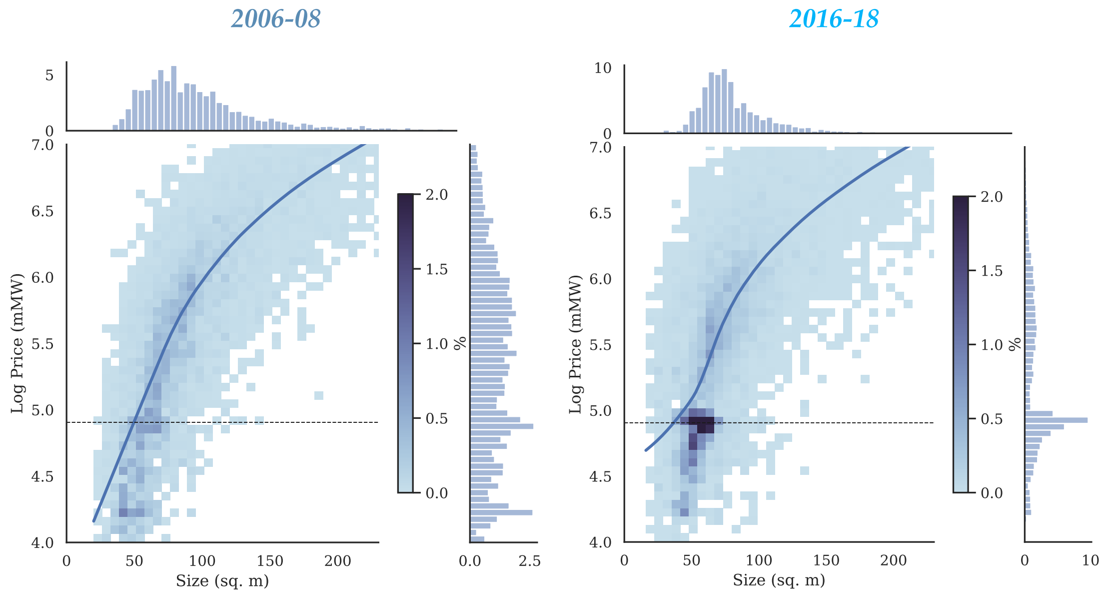
The solid line in Figure 8 shows that the non-parametric bivariate relationship between price and size is positive. This pattern follows the expected positive relationship and suggests that it could be nonlinear. However, this unconditional relationship may not represent the marginal equilibrium willingness to pay for housing size. There could be observable and unobservable characteristics that affect size and price, creating bias. I follow common practice in the hedonic literature to estimate the equilibrium implicit– or hedonic– price of housing size (Bishop & Timmins, 2019; Bajari, Fruehwirth, Kim, & Timmins, 2012; Bishop et al., 2020).

Equation 20 represents a general specification for the price function. Where h_{ltc} is the size of the house, X_{ltc} is a vector containing all other characteristics of the house, and ε_{ltc} represents the residual containing unobserved characteristics. I follow Cattaneo, Crump, Farrell, and Feng (2019b) and Cattaneo, Crump, Farrell, and Feng (2019a) to estimate the function $P(h)$ and $p(h)$ non-parametrically.[33]. The vector of additional characteristics, X_{ltc}, includes location, quality, number of rooms and neighborhood quality index (*estratos*),[34] among others. $P(h)$ is the implicit price function for housing

[33] An alternative estimation method Robinson (1988) or a parametric approximation.

[34] The *estratos* are codes from 1 to 6. They summarize the quality of the block, for more details, see Uribe (2021)

Figure 8: Observed Market Equilibrium



Note: This figure shows the joint and marginal densities for housing size (x-axis) and price (y-axis). Darker dots inside the graph represent a higher market share. The figure contains all available cities in each period, and all the different unit types, that is, single-family homes, multifamily homes, condos, two bedrooms, one bedroom, and so forth. The solid line represents the non-linear relationship between housing size and price (using lowess).

size.

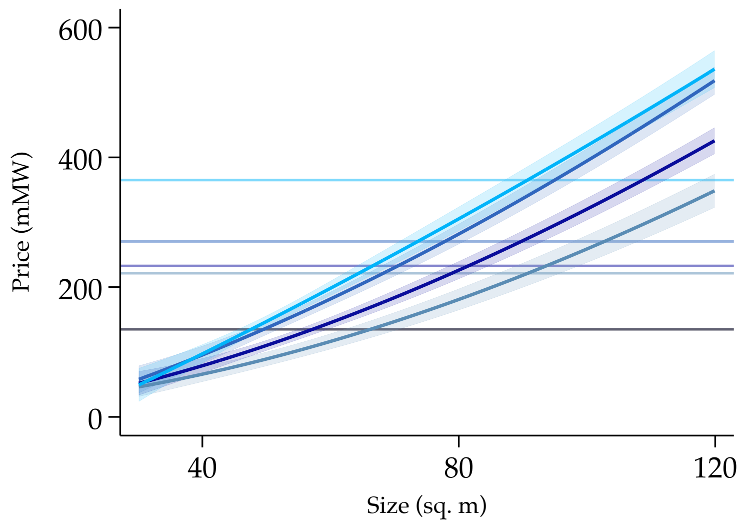
Describing observed equilibrium prices. Figure 9 illustrates the estimated implicit price function $\hat{P}(h)$ and the marginal willingness to pay $\hat{p}(h)$ by size, once we isolate the effect of the other characteristics. The figure shows a change in the equilibrium price scheme. It is not possible to know if this change is only associated with the policy changes as other general demographic and economic factors changed during the same time period. Over my study period, housing became more expensive, particularly above the policy cutoff. The figure also shows that accounting for non-linearities in the estimation of $P(h)$ is important. Note that in contrast to figure 8, I show the prices in levels and not logs. In terms of the marginal price for the size, $p(h)$, Figure 9b shows differences over time, particularly around the marginally subsidized households.

Marginal Bunching Thresholds

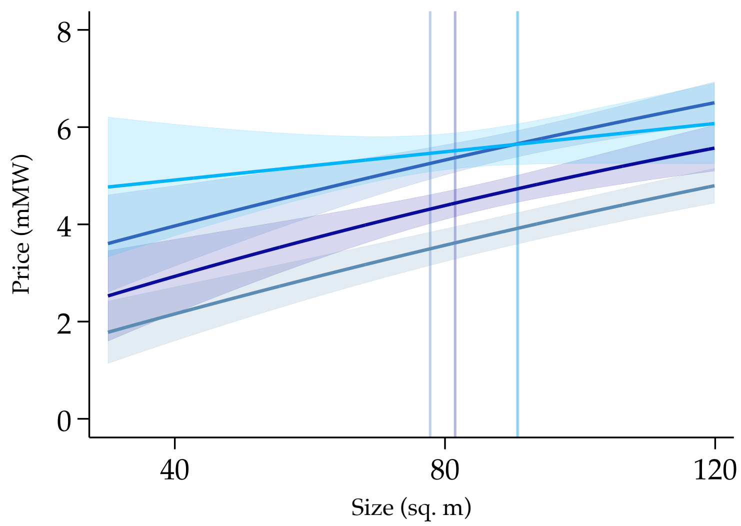
The two relevant points, $\underline{h}$ and $\overline{h}$, are not directly observable but can be recovered from the data using the estimates of the hedonic price function $\hat{P}(h)$ and the values of $\underline{P}$ and

Figure 9: Hedonic Price for Housing Size

a. $P(h)$



b. $p(h)$



NOTE: This figure shows $\hat{P}(h)|X$, and $\hat{p}(h)|X$ where X includes number of bathrooms, number of rooms, an indicator equal to 1 if the unit is a building, location; dummy variables equal to one if the unit has a porch, studio, storage unit, dressing room, service room, dining and living room, fireplace, kitchen, clothes areas, patio; location coordinates interacted with town fixed effects and metropolitan area fixed effects, lot size, number of building blocks, apartments per floor, number of floors, total parking spots, and number of building units. To estimate these figures I use the approach outlined in Cattaneo et al. (2019a).

$\overline{P}$ recovered in Section III.

$$\underline{h} = \hat{P}^{-1}\left(\underline{\hat{P}}\right) \text{ and } \overline{h} = \hat{P}^{-1}\left(\hat{\overline{P}}\right) \tag{22}$$

The vertical lines show the value of $\overline{P}$ for the different periods, and $\underline{P}$. We can see in this figure how the estimation of the hedonic price function allows us to recover the marginal buncher thresholds in terms of size. This figure shows that the marginal buncher is willing to cut the size of the housing almost in half to take advantage of the subsidy, which represents up to 25 percent of the value of housing at the cutoff. This figure also shows that the equilibrium size that you can buy with the 135 mMW decreases over time. In 2006-08, you could buy a house of around 66 square meters whereas in 2016-18 with the same money you can only buy a house of 47 square meters.

Unit Supply Function Notch

How do developers respond? One of the principal objectives of the economic model is to address this question in more detail. Developers built more housing units when they built smaller housing units. One advantage of the data is that I observe the number of units built by unit type; therefore, I can get empirical estimates of the trade-off between unit size and the number of units and account for it in the model. I follow a similar strategy that I use to estimate the hedonic regression to estimate this relationship $Q(h)$ non-parametrically.

$$Q_{ltc} = Q(h_{ltc}) + \Omega' X_{ltc} + \epsilon^{Q}_{ltc} \tag{23}$$

Like in the case of the hedonic regression estimation, I rely on independence conditional on observables.

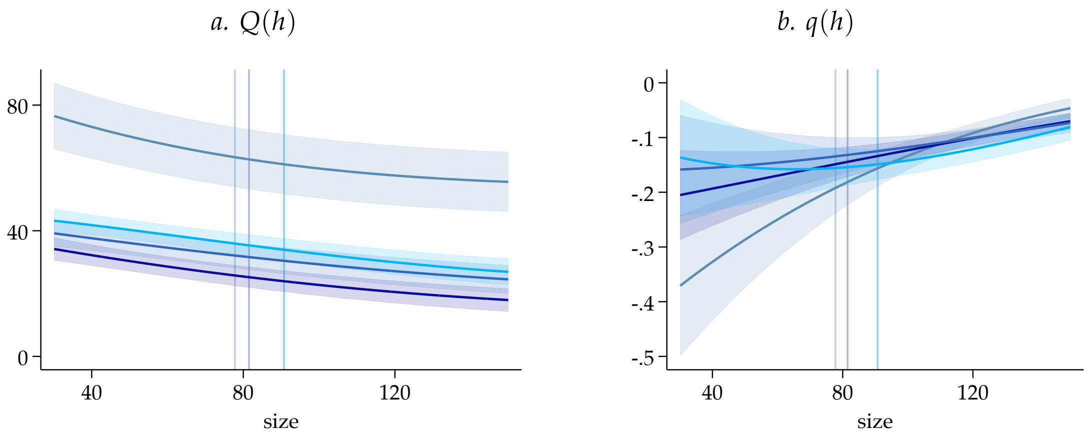
$$\mathrm{E}\left(h_{ltc} | X_{ltc}, \epsilon_{ltc}\right) = 0 \tag{24}$$

Estimation

I estimate $Q(h)$, non-parametrically using the approach proposed by Cattaneo et al. (2019b) and Cattaneo et al. (2019a). This approach also allows me to estimate the derivatives $q(h)$ that I required in the estimation of the structural parameters. In the set of controls, I include detailed characteristics of each project such as a number of towers in each project, the exact location of the lot, etc. The assumption of conditional independence is plausible in the sense that after controlling by all characteristics, the relationship between h and Q is given exogenously by regulatory constraints or the existent technology.

Figure 10 shows the unit supply function adjusted for the characteristics of the unit and the project using observations from all cities available in each period. The figure shows a negative relationship between unit size and the number of units, which is intuitive. Developers face a trade-off between building more but smaller units and fewer but larger units. There was a decrease in the number of units built at all levels. I do not have a clear explanation of this phenomenon, but it could be associated with lower availability of land, increases in the cost of building high, or the fact that for the first years, the census covered mostly the main metropolitan areas whereas later years started to include smaller cities.

Figure 10: Unit Supply Function



Note: This figure shows the bin scatter for the number of units and for unit size after controlling for observable characteristics. In this figure, I use the same controls as in Figure 9. This figure includes the observations for all years and all cities.

B. Identification of the Second Step

Identification Challenge. A fundamental challenge when estimating demand or supply elasticities is to isolate the demand and supply responses from a single observed equilibrium. The common approach in homogeneous goods is to use demand or supply shifters. For example, Zoutman et al. (2018) shows how taxes can be used to estimate supply and demand elasticities in a market for homogeneous goods. However, estimating elasticities in a differentiated product market will require multiple instruments. S. Rosen (1974) proposed a two-step framework. He suggests that the identification of a differentiated product market can be reduced to a system of simultaneous equations equivalent to what characterizes the market of an homogeneous good product. However, Brown and Rosen (1982); Epple (1987); Bartik (1986); Wooldridge (2010) show that the initial approach proposed by S. Rosen (1974) faces additional challenges. First, because the price can be a non-linear function on the characteristics, the error term in the equilibrium equations cannot be uncorrelated with the vector of attributes of each unit (Epple, 1987). Second, because of the matching that happens between heterogeneous sellers and buyers, the supply and demand shifters, which are the natural instruments in other settings, do not work in this type of setting. The demand shifters are correlated with an error term on the supply equation, and vice-versa (Bartik, 1986; Epple, 1987; Wooldridge, 2010).[35] This invalidates demand and supply shifters as instruments. This paper overcomes these challenges using a different approach. The idea is that the price discontinuity and bunching evidence allows us to "observe" two points in the indifference curves for the marginal buncher household and marginal buncher developer.

The approach in this paper uses the marginal bunching condition in equations 11 and 12 to solve for the two parameters of interest, θ and β. I do not observe $\overline{Y}$ and $\overline{A}$, but I use the fact that, given the assumptions I impose in this paper, there is a one-to-one mapping between h and Y, and A, see equations 14, 15. This allows me to express $\overline{Y}$ and $\overline{A}$ in terms of observable characteristics. Therefore, I need estimates for $\frac{\partial P(h)}{\partial h}|_{h=\bar{h}} = p\left(\bar{h}\right)$ and $\frac{\partial Q(h)}{\partial h}|_{h=\bar{h}} = q\left(\bar{h}\right)$. Table 2 shows the functional forms that I use to recover θ and β and the elements that I need to estimate in the first step to be able to recover θ and β in the second step. The two unobservable objects are the parameters that describe the utility and cost functions $\boldsymbol{\beta}$ and θ. All values summarized in Table 2 panel D, can be estimated. The parameter ϑ is not directly observed and it is assumed to be $\vartheta = \frac{1}{2}$. The identification of $\boldsymbol{\beta}$, θ is achieved by solving two equations with two unknowns. The two equations are the ones in Table 2 panel A, after replacing panels B and C.

C. Estimation of θ, and β

Using the functional forms and estimates for the values in panel D of Table 2 and presented in section V.A, I can solve for θ and β. The marginal buncher functions do not have a closed-form solution; therefore, I use numerical methods to find the values of θ and β. I present the estimates separately for each subperiod with specific subsidy schemes.

[35]For example, Bartik (1987) says "the endogeneity problem in hedonic systems is not the simultaneous determination of demand and supply equations. The problem is that because the price is not linear, individuals pick both the quantities they consume and the marginal price they consume."

Table 2: Functional Form and Identification Equations

A. Marginal Buncher Condition		
Household		$V_D = U\left(\overline{Y} - \overline{P}, \overline{h}; \theta\right) - U\left(\overline{Y} - \underline{P}^{\tau}, \underline{h}; \theta\right) = 0$
Developer		$V_S = \pi\left(\overline{Q}, \overline{A}, \overline{P}; \beta\right) - \pi\left(\underline{Q}, \overline{A}, \underline{P}^{\delta}; \beta\right) = 0$
B. Functional Forms		
Utility		$U = \left[(1-\vartheta)\cdot C^{\theta} + \vartheta \cdot h^{\theta}\right]^{\frac{1}{\theta}}$
Cost		$B = A_j \cdot Q \cdot h^{\beta}$
C. Optimality Conditions		
Income		$\overline{Y} = \overline{P} - \left(\frac{\vartheta h^{\theta-1}}{\overline{p}\left(\vartheta-1\right)}\right)^{\frac{1}{\theta-1}}$
Productivity		$\overline{A} = \frac{\left(\overline{P}\cdot\overline{q} + \overline{p}\cdot\overline{Q}\right)\overline{h}^{(1-\beta)}}{\overline{q}\cdot\overline{h} + \overline{Q}\cdot\beta}$
D. First Step Estimates		
Marginal buncher thresholds		$\underline{h} = P^{-1}\left(\underline{P}\right)$ and $\underline{h} = P^{-1}\left(\underline{P}\right)$
Hedonic price	at $\underline{h}$:	$\underline{P}^{\tau} = P\left(\underline{h}\right) - \tau, \underline{P} = P\left(\underline{h}\right)\ \underline{P}^{\delta} = P\left(\underline{h}\right)\cdot(1+\delta)$
	at $\overline{h}$:	$\overline{P} = P\left(\overline{h}\right), \overline{p} = \frac{\partial P(h)}{\partial h}\Big\vert_{h=\overline{h}}$
Unit Supply Function	at $\underline{h}$:	$\underline{Q} = Q\left(\underline{h}\right)$
	at $\overline{h}$:	$\overline{Q} = Q\left(\overline{h}\right), \overline{q} = \frac{\partial Q(h)}{\partial h}\Big\vert_{h=\overline{h}}$

NOTE: This Table summarizes the functional forms used for the estimation of β and θ. ϑ is assumed to be $\frac{1}{2}$, but section VII shows sensitivity to different numbers. This parameter corresponds to the share of expenditure on housing.

Structural Parameters. Figure 11 illustrates the equilibrium of the housing market and the preferences of households and the technology of developers using the estimated parameters presented in Table 3. The parameter $\sigma = 1/(1-\theta)$ represents the constant elasticity of substitution for the specified utility function (CES). It represents how the relative consumption of housing varies when the relative price changes.

Households' parameters. The elasticity of substitution estimates was around 1.2 at the beginning of the period and increased substantially to 3.8 at the end of the period. This could be explained by the introduction of the program *Mi Casa Ya* later in the period. Under this program, subsidies became available to informal employees and applicants automatically received both the downpayment subsidy and interest rate subsidy. The estimated parameters are not to different across years, which is reassuring considering that these are economic fundamentals and, therefore, very unlikely to fluctuate drastically over time. The increase in the estimated parameter at the end of the period is likely given the changes in the policy and the fact that informal employees were now eligible.

An elasticity of 1 corresponds to a Cobb-Douglas elasticity. Therefore, my estimates suggest that a Cobb-Douglas utility function would not be a bad representation, but would be imprecise, particularly at the end of my period. A negative value of θ corresponds to an elasticity of substitution σ less than one, which means that housing and other goods are gross complements. If θ is positive, the elasticity of substitution is greater than one, and the housing and consumption of other goods would be gross substitutes.

Comparison with the literature. Bayer, Ferreira, and McMillan (2007) present an approach that integrates the hedonic insights into a discrete choice framework. As pointed out by Yinger (2015), their approach implicitly assumes a linear utility function, which violates the strict quasi-concavity postulate. In other approaches in the urban economics literature, the utility function is assumed to be Cobb-Douglas. In my setting, I allow for a less restrictive functional form, but my estimates suggest that the Cobb-Douglas utility function would be a close approximation in some cases but not always.

Developers' parameters. On the developer side, the estimated parameter β, does not change much overtime. In the first period, β is 2.34 , this decreases to around 1.26 in the following periods. This change means that the costs of building bigger houses decreased over time. It is hard to compare these estimates to the literature, as the paper that use an hedonic approach to estimate the housing market usually takes the supply function as given and does not allow for heterogeneity (Bishop & Timmins, 2019) or do not allow for product differentiation (Saiz, 2010). There are not many papers that consider the developer's decisions regarding how many units to build and which unit to build separately.

D. Missing Mass: Model vs. Data

The model predicts a missing demand and supply for housing units between $\underline{h}$ and $\overline{h}$. However, in my setting, I only observe a partial missing mass in the distribution. This partial missing mass is common in bunching analysis using notches (Best et al., 2019; Kleven & Waseem, 2013). This is usually attributed to at least two potential factors, optimization frictions or heterogeneity in the behavioral parameters θ. Some

Figure 11: Equilibrium Choices using the estimated parameters

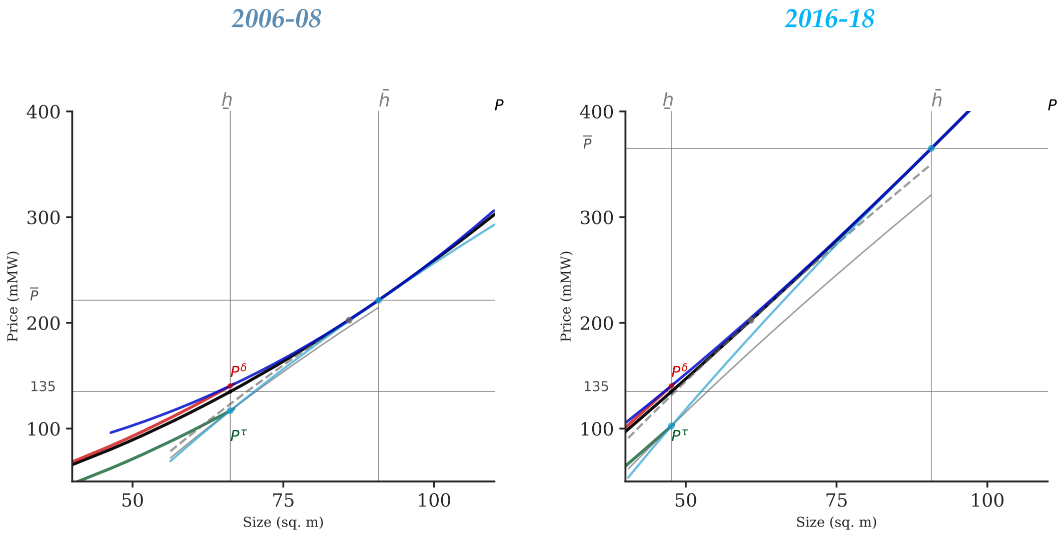


Table 3: Structural parameters

	06-08	09-11	12-15	16-18
β	2.34	2.03	1.65	1.29
θ	0.55	0.40	0.55	0.74
σ	2.23	1.68	2.22	3.88

Note: This figure uses the estimated parameters presented in Table 3 and creates the empirical analog of Figure 6 for the marginally subsidized households and developers. The figure represents the equilibrium choices and bid and offer functions estimated at the beginning and end of the study period. The elasticity of substitution implied by the CES utility function is $\sigma = 1/(1-\theta)$. ϑ is assumed to be 0.5.

households may not be aware of the subsidies, or the application costs may be too high. In my setting, there are a limited number of subsidies, and not all eligible households receive them. It is also the case that some households receive the downpayment and the interest rate subsidy, but others get only one of the two. This means that the notch may vary between individuals due to different types of friction. Moreover, households that are eligible may not see the benefits because living in a low-cost housing unit could create stigma and households may have a large dis-utility related to that.

There may be a preference heterogeneity across cities of family size. In this case, Best et al. (2019) suggests that the behavioral response can be interpreted as the average marginal response.

VI. Welfare and Policy Evaluation

A goal of this paper is to evaluate the effectiveness of the policy scheme implemented in Colombia. The framework and estimated parameters presented in this paper allow for a different type of counterfactual policy evaluation and allows for an assessment of how much households and developers benefit from these policies. In this section, I illustrate the potential of this framework as a policy evaluation tool. I use it towards two aims. First, I compare the how much the government spends on these subsidies to how much the beneficiary households are willing to pay to increase their utility in an equivalent magnitude. The focus on the developer side also allows me to evaluate the efficiency loss induced by the notched subsidy scheme (Blinder & Rosen, 1985). Second, I explore the role of the subsidy on the supply side. I show what happens if the supply side subsidy is removed, and demonstrate that the notch incentive designed in Colombia requires this subsidy to prevent a shortage problem. However, once we account for this additional government expenditure, it is not clear that households value the subsidy enough to justify the government expenditure in these type of policies. I close the section with a discussion of other type of policies that could be evaluated, like the effect of a quality or size limit on the subsidized units.

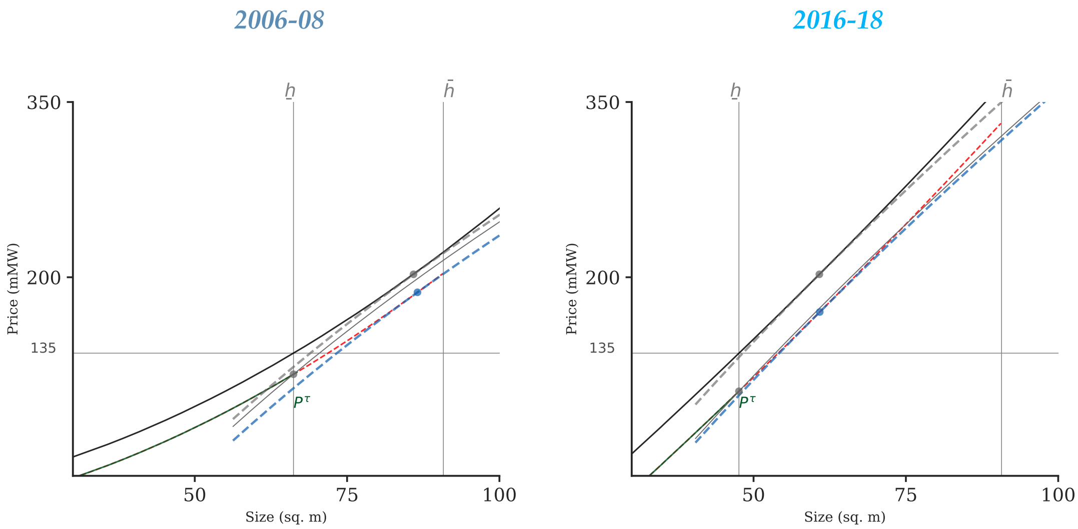
A. Benefits and Efficiency Losses: the households' perspective

To evaluate the benefits of the subsidy, I focus on the effect of marginally subsidized households. Because the market response is a change in housing characteristics, the price limit creates efficiency losses. If the response was a pure price reduction without changes in characteristics, the policy would induce a transfer of welfare from developers to households. Figure 11 illustrates how a representative marginally subsidized household benefits from the subsidy. Households reduce their expenditure on housing to obtain the subsidy. By doing this, the household reaches a higher utility level, the indifference curve moves to the right from the dashed line to the solid blue line. Without the existence of the price limit and if the marginally subsidized household gets the subsidy without being forced to reduce its consumption, a household could increase its utility even more, as illustrated in the graph. This means the notched scheme introduces an inefficiency. However, from a targeting perspective, this type of inefficiency could be justified. Without the price cutoff,richer households could receive the subsidy to buy expensive units which undermines the objective of the program. That is to provide opportunities for low income households to become homeowners.

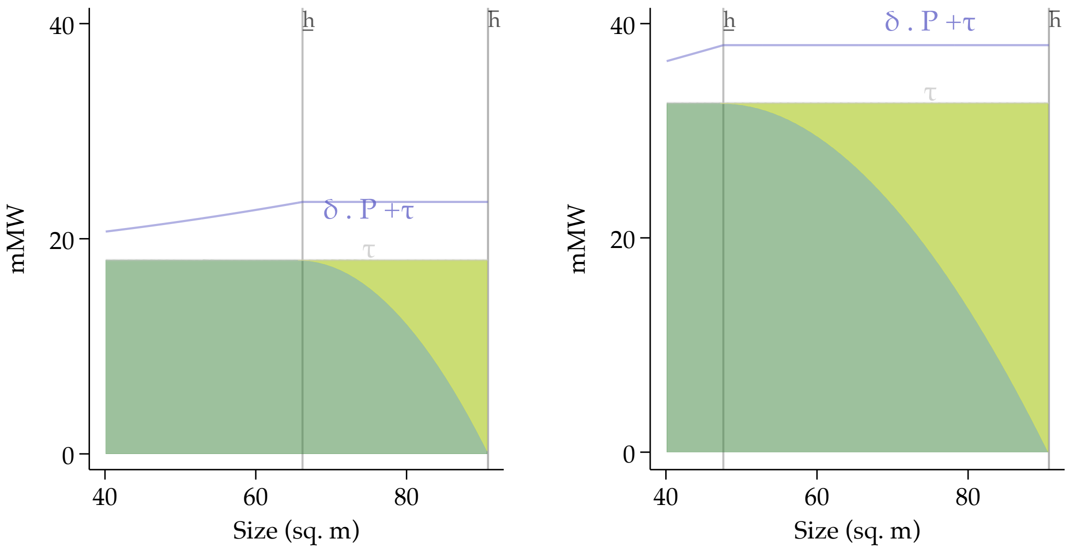
Blinder and Rosen (1985) shows examples where notches can be preferred to alternatives targeting approaches such as slope changes. In that paper we explore under

Figure 12: Welfare Gains and Efficiency Losses for the Marginally Subsidized Households

A. Welfare gains and losses for the marginally subsidized households



B. Equivalent Variation by Unit Size



Note: Panel A illustrates the changes in utility for a representative marginally subsidized household.Panel B shows how much households are willing to pay for their increase in utility (evaluated at $\underline{h}$ for households at different levels. The green are are the welfare gains and the yellow area represents the efficiency losses induced by the notch scheme.)

what circumstances a notch scheme is preferable to a conventional linear subsidy. They show that the elasticity of substitution matters when comparing different targeting approaches. They show that a lower elasticity of substitution increases the efficiency of notches. Based on the elasticities estimated in this paper, it seams that the effectiveness of these subsidy scheme is fading over time as the elasticity of substitution is getting bigger. Moreover, I show that the efficiency losses (yellow area in 12) is larger at the end of the period. The dollar amount households would pay for the increase in utility is around the same value of the notch τ, however, once we include the extra cost induced by the tax refunds to developers we can see that the households do not value the changes in housing units as much as the governement expenditure in a per unit basis. To calculate the total losses and gains we could multiply the share of buncher households by size and calculate their welfare gains and benefit losses.

What happens in equilibrium.

An advantage of this paper is that it allows me to think about market equilibrium. For example, in Section VI.A I showed the efficiency losses that would arise if there is a notched scheme that could be reduced with a linear subsidy. What happens in that case with the developers that bunched? Under that scenario, there would not be any need to have tax incentives for developers. To show how these are very relevant in the type of subsidy scheme in Colombia, the next section explores what happens if the tax incentives are removed.

B. The effect of Removing Developers' Tax Incentives

An important policy debate related to housing policy is whether the use of tax incentives for developers is an effective redistributive tool. In the USA there is the Low Income Housing Tax Credit (LIHTC) which is intended to produce. These types of subsidies could be ineffective or very expensive. They could also benefit developers more than households which would maket them hard to justify. Soltas (2022) shows that these types of subsidies could be very expensive as they force to build low-income housing in expensive areas. Sinai and Waldfogel (2005) shows that Tenant-based housing programs, such as Section 8 Certificates and Vouchers, are more effective than project-based programs such as developers' subsidies. The type of developers subsidy implemented by the Colombian government is a little different, however, as it coexists with a demand-side subsidy targetted at households. The existence of these subsidies is an active policy debate in Colombia. I use the framework developed in this paper to show that these subsidies are required to avoid a shortage problem in a priced-capped policy scheme like the one implemented in Colombia.

In 2021, under the need for tax reforms, there was a policy proposal to remove these subsidies. However, developers actively opposed them, claiming that this would create a shortage problem.
"If these items are repealed, in Valle del Cauca we would go from having an offer of low-cost housing and sales of 23,000 homes, average year, to one of sales of 4,600 homes" [36]

The framework developed in this paper shows that this could be the case. Figure 13 ilustrates the role of these tax incentives. Without the tax incentive, and under the existence of the price cap, developers that would produce housing units of size $\underline{h}$ and $\overline{h}$ would face no demand or a reduced demand. They build cheaper housing units to keep supply the households that changed the type of housing they buy. However, because they would be building units usually build by more productive developers they would have to reduce there profits or leave the market. In this sense the tax incentives guarantees that developers do not leave the market. The dashed yellow line, represents the equilibrium in the absence of the subsidies, the solid yellow line is the observed response and the green line represents the iso-profits if developers stay in the market but they cannot increase the price.

Figure 13 shows these responses at the beginning of my study period and at the end. The top panel illustrates the decision choice of a representative marginally subsidized developer under the observed scenario and two counterfactual scenarios, changing the type of housing to satisfied the subsidy induced demand at h and the scenario under no subsidies. The figure in panel B, shows what would be the changes in profits for households producing different housing units if they do not get the subsidy and reduce their consumption. The figure show that at the begining of the period the losses would have been around 5 percent. However, at the end the losses could be up to 15 percent of the profits they would have in the absence of the subsidy scheme. The gray-red area is the increase in profits that they receive instead. The gray would produce low cost housing even in the absence of the subsidy. This analysis shows that the tax incentives may in fact prevent the exit of some developers and avoid a shortage problem. However, by doing this they artificially increase the profits of developers that would build low-cost housing even in the absence of the subsidy and they make the potential exiters better off than in the absence of the subsidy.

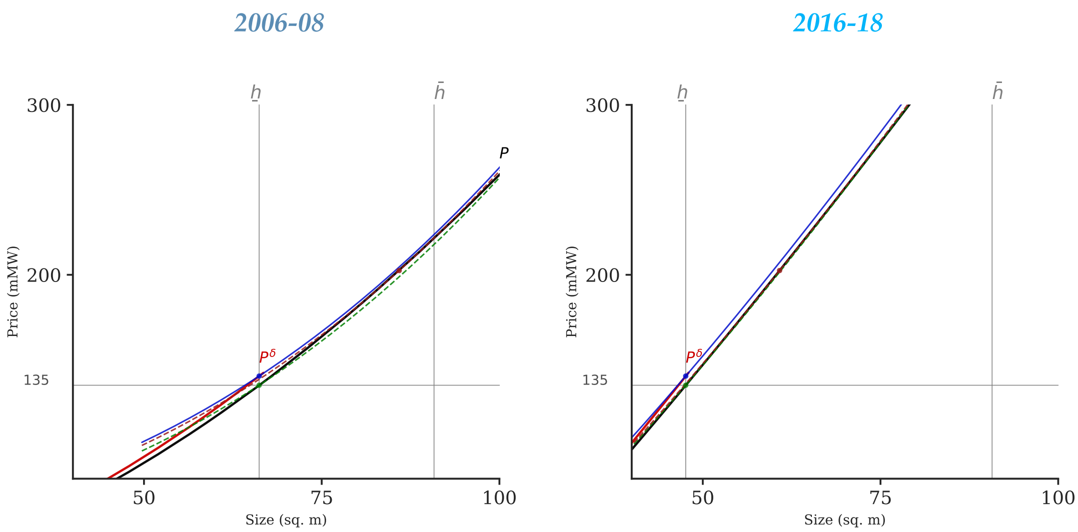
VII. Robustness and Sensitivity Analysis

This section presents sensitivity analysis for the bunching and structural estimates.

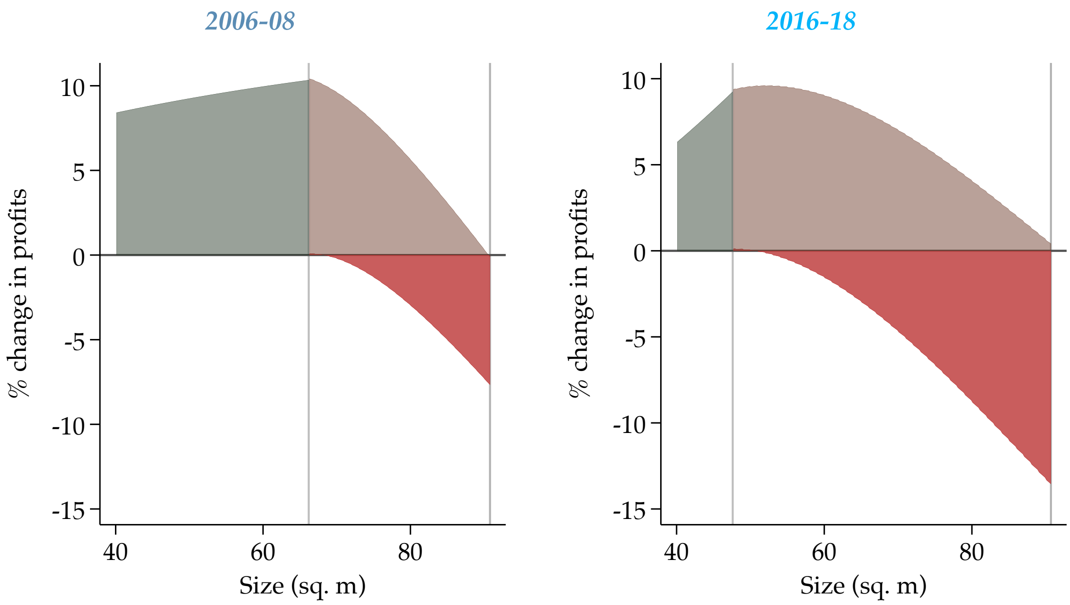
[36]source: El Tiempo (2021)

Figure 13: Developer Response to Tax Incentives

A. Developers Incentives



B. Excess Profit and Potential Losses



Note: Panel A shows the incentives of a marginally subsidized developer if the tax incentives are removed. Panel B) shows the developers if there is not tax incentives as a percentage of their current profits (in red) and the induced excess profits to prevent the exit of those developers (in Green)

Table 4: Structural Parameters Using Different Estimation Approaches for P and Different Values for Consumption Shares ϑ

	$\vartheta = 60$	$\vartheta = 50$	$\vartheta = 40$	$\vartheta = 30$	
	σ				β
06-08					
$bw = 0.05$ (at $\underline{P}$)	1.53	1.32	1.19	1.09	2.70
$bw = 0.05$ (all P)	0.80	0.72	0.66	0.61	5.00
$bw = 0.03$ (around $\underline{P}$)	2.52	2.23	2.08	1.99	2.34
$bw = 0.07$ (around $\underline{P}$)	2.34	2.07	1.91	1.81	2.35
09-11					
$bw = 0.05$ (at $\underline{P}$)	1.13	1.00	0.90	0.82	2.51
$bw = 0.05$ (all P)	1.32	1.18	1.08	0.99	1.13
$bw = 0.03$ (around $\underline{P}$)	1.78	1.57	1.43	1.33	2.08
$bw = 0.07$ (around $\underline{P}$)	1.96	1.73	1.59	1.49	2.00
12-15					
$bw = 0.05$ (at $\underline{P}$)	2.06	1.85	1.72	1.63	1.69
$bw = 0.05$ (all P)	2.64	2.46	2.37	2.32	1.25
$bw = 0.03$ (around $\underline{P}$)	2.27	2.06	1.94	1.86	1.67
$bw = 0.07$ (around $\underline{P}$)	2.43	2.22	2.11	2.04	1.65
16-18					
$bw = 0.05$ (at $\underline{P}$)	2.47	2.28	2.17	2.11	1.32
$bw = 0.05$ (all P)	3.64	3.54	3.51	3.50	1.29
$bw = 0.03$ (around $\underline{P}$)	1.69	1.50	1.38	1.29	1.40
$bw = 0.07$ (around $\underline{P}$)	3.64	3.54	3.51	3.50	1.29

A. Bunching Estimates and Structural Parameters

The estimation of the structural parameters in this paper relies heavily on the estimation of the counterfactual distribution of market shares. These estimates depend on the selection of different parameters. The bandwidth for the bins, the number of omitted bins to the right and the left of the cutoff, and the degree of the polynomial. To select these parameters, I fix a bandwidth and select the excluded number of bins to minimize the difference between the excess mass and missing mass. Figures B.1 and B.2 in the appendix show the bunching analysis for three different bin size and 2 different criteria to select the excluded bins and polynomial degree. Table 4 shows the sensitivity of the structural estimates to different approches to estimate the bunching and the upper limit for the marginal buncher $\overline{P}$. It also shows sensitivity to different values of ϑ which represents the share of income devoted to housing. Overall the parameters are relatively stable to different approaches to estimate bunching. Regarding the share of income devoted to housing. The table shows that different values of ϑ

does not affect the value of the elasticity of substitution. As expected, the elasticity drops as the share of consumption devoted to housing falls.

VIII. Conclusions

This paper presents compelling evidence of the Colombian housing market responding to a set of subsidies designed to increase home ownership for low-income households in Colombia. The evidence relies on detailed data on the universe of new housing, data on subsidies to both households and developers, the policy cutoff inducing discontinuous incentives and the variation of the subsidy over time. I use the behavioral responses induced by the subsidy and introduce a novel identification approach to estimate a hedonic housing market equilibrium with heterogeneous agents and housing that rationalizes the observed responses. The model-guided estimation approach translates the bunching reflecting the behavioral responses and the reduced form estimates into parameters of both households' preferences and developers' production functions. I use those estimates to illustrate the type of welfare analysis that the estimation approach allows.

I find that households and developers changed their housing consumption to take advantage of the policy. The price cap, which could be important if the response does not induce a change in housing consumption, induced welfare losses. Households would have been better off if they received the subsidy without reducing their housing consumption. The welfare analysis also suggested that in a world with developer heterogeneity, subsidizing the demand side of the market may be insufficient. Developers need to be compensated to produce low-cost housing, which they can produce but at a higher marginal cost. The type of welfare analysis allowed by this approach goes beyond the examples presented here. Because I recovered the wealth and productivity levels of households and developers together with parameters describing their preferences and costs, the approach allows for the evaluation of different housing policies. The method could apply to other markets with vertical differentiation and price caps, such as labor markets, computers or cars.

In this case, thepolicy-inducedd a change in the type of housing bought and built. The housing stock accumulated smaller housing units purchased by households who would prefer bigger houses. Considering that housing is a durable asset that affects urban structure and city planning, this could translate into significant consequences for cities reaching a suboptimal equilibrium. The findings of this paper suggest that a careful evaluation of the market structure matters for effective policy design. Understanding how the policy affects the housing market's incentives is crucial to understanding how the observed equilibrium outcomes inform us about the effects of the policy.

VIII. Appendices

Appendix A. Colombian Housing Policy: Additional Details

I. Subsidies Descriptions.

Downpayment subsidy.

The down payment subsidy was introduced at the beginning of the 1990s and is available to formal employees who contribute to the family compensation funds.[37] The **gray blue** area in Figure A.1 shows the number of subsidies corresponding to the total government expenditure presented in Figure 1 from 2006 to 2019. Only formal households earning less than four times the minimum wage (mMW) are eligible for the subsidy. See more details in Gaviria and Tovar (2011).

Interest rate subsidy.

In 2009, the government introduced a program to subsidize mortgage' interest rates. This program, called *FRECH*, started as a program to incentivize economic growth after the crisis, but became a permanent policy. In contrast to the downpayment subsidies, interest rate subsidies were also available to households buying housing units above the $135 \times mMW$ threshold. However, the subsidy is higher if households buy a *low-cost housing* unit, that is, the price is less than $135 \times mMW$. If a household receives the subsidy, the government pays the bank the corresponding amount during the first seven years of the loan. During the study period, there were three different schemes, but in all schemes there was a discontinuity in the subsidy at the cut-off defining *low-cost housing*. The **dark blue** area in Figure 1 shows the number of subsidies and total government expenditure from 2009 to 2019. The subsidies were more or less stable over time; around 20,000 households received this subsidy. This subsidy represents lower government expenditure, and expenditure has slightly decreased overtime partly due to lower interest rates.

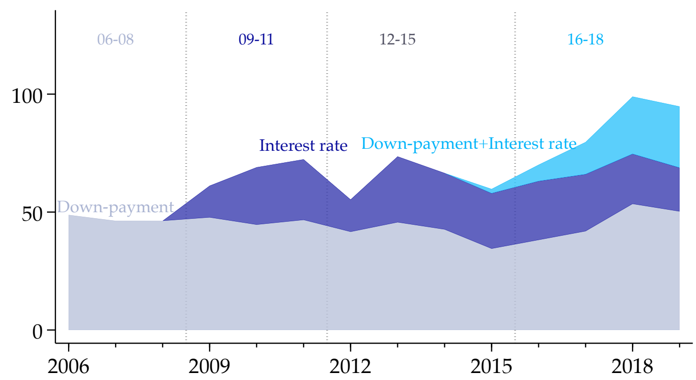
Unlike the downpayment subsidy, interest rate subsidies were also available to households buying housing units above the $135 \times mMW$ threshold. However, there is a notch at 135×m-MW. Figure A.1 shows the interest rate subsidies for all ranges of the house price. Figure A.2b shows the subsidy scheme for the interest rate. Three different schemes existed during my study period. Each scheme is represented in the figure by a different line. The x-axis is the monthly minimum wage and the y axis is

[37] The subsidy is called *Subsidio Familiar de Vivienda (SFV)*, was introduced in the Law 3 of 1991, and is administered by the family compensation funds. (*Cajas de Compensación Familiar*). An employee is formal if she contributes to social insurance and to one of these funds compensation family fund.

the discount in the interest rate.

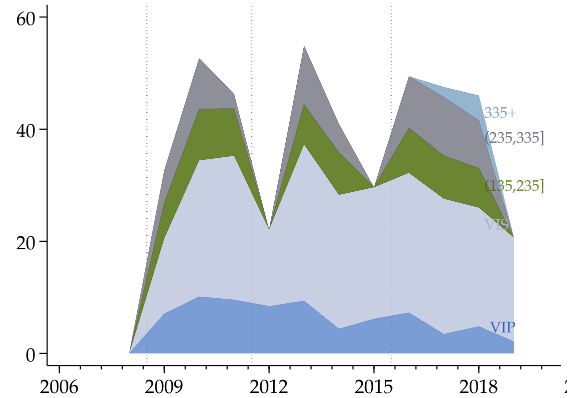
Figure A.1: Description of number of the Subsidies and Number of Subsidies for all the Different Subsidies.

A. Total number of Subsidies Over Targeted around 135 mMW Time

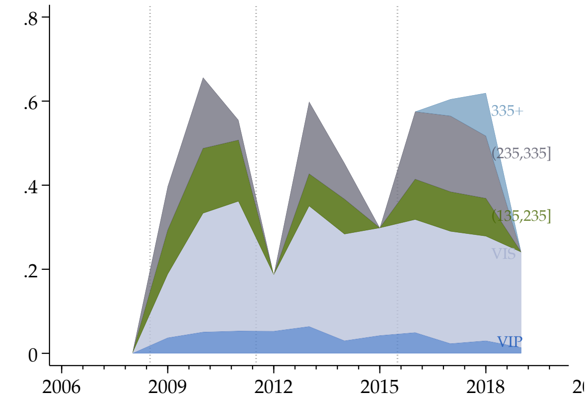


B. Total number and Government Expenditure for Subsidies Over Targeted around 70 mMW Time

a. Total # of subsidies

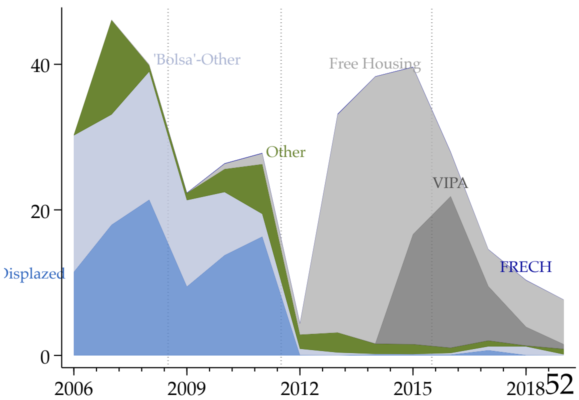


b. Total amount of subsidies

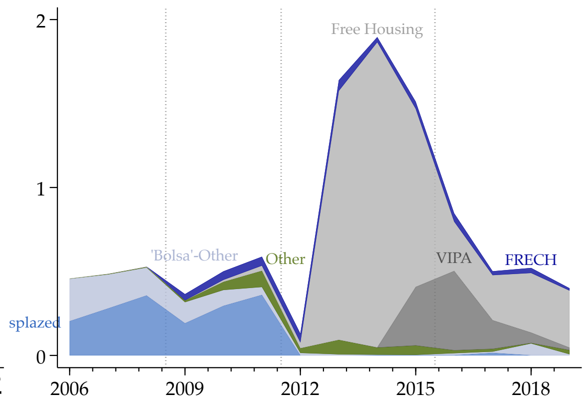


C. Subsidies for the Vulnerable Population. Housing Units Priced Below 70 mMW.

c. Total number of subsidies



d. Total amount of subsidies



The subsidy expansion–*Mi Casa Ya*.

In 2015, the government doubled the effort and introduced a new program *Mi Casa Ya*, (My House Now). Before this program was introduced, the downpayment subsidy was only available to formal employees who contributed to family compensation funds[38] This program expanded the coverage of the downpayment to non-contributing households. The households participating in this program automatically get the downpayment subsidy and the interest rate subsidy with a single application. The **light blue** area in Figure 1 shows the number of subsidies and government expenditure, which is the sum of the downpayment and the total expenditures with the interest rate discount. The figure shows the increase in the number of subsidies. The government expenditure that started in 2015 was mainly driven by the introduction of this program and the increase in the down payment subsidy to formal employees.

Supply subsidy–value added tax (VAT) tax refund.

A couple of years after demand subsidies were introduced, to encourage developers to build *low-cost housing*, the government introduced a VAT tax refund. Developers get up to 4 percent of the sale price of each unit in the refund of taxes paid on construction materials. Different laws regulate this subsidy, but it has been the same value since it first started.

Other subsidies.

The Colombian housing policy includes other subsidies excluded from the main analysis of this paper.[39] These are mainly subsidies to disadvantaged populations. These subsidies exist to follow a constitutional mandate to provide housing to people affected by forced displacement and environmental disasters. They are for cheaper housing units and households in extreme poverty. These subsidies can be used to buy *priority low-cost housing*, which is housing units with a market price of $70 \times mMW$ or less. The approach of using subsidies as an incentive to promote construction and purchase of housing units was mostly ineffective to provide this type of housing. As a result, in 2014, a program to build 100'000 free housing units was launched. The goal was to satisfy the constitutional mandate and provide housing to the disadvantaged population that was neglected by the previous policy approaches.Gilbert (2014a) de-

[38] In theory, informal households could get access to housing subsidies. However, *fonvivienda*, the institution in charge of these subsidies, assigned mostly to vulnerable populations. The vulnerable populations are displaced by armed conflict and affected by natural disasters.

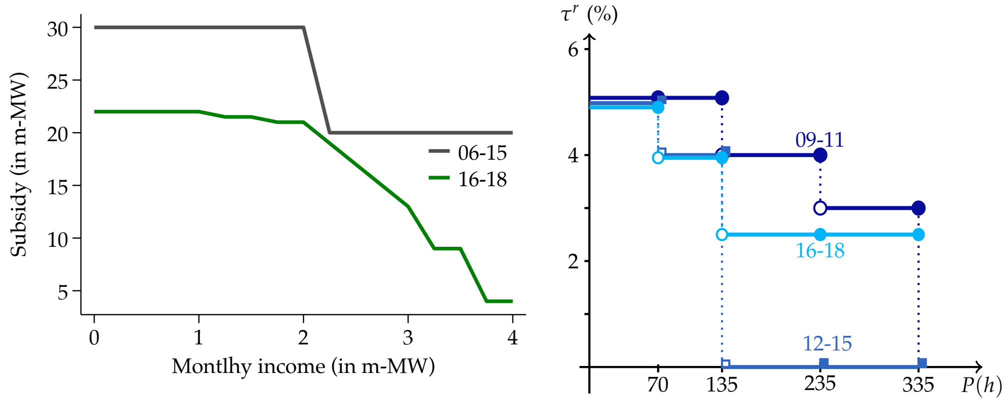
[39] The main reason to exclude these subsidies is that they are concentrated on a lower price threshold and the market forces are less relevant. The bunching at the price threshold at $135 \times mMW$ is the most pronounced. This paper aims to explain what happens around that cutoff.

scribes this program, *100 mil viviendas gratis*, and evaluates its potential effectiveness. Camacho et al. (2020) study the effect of this conditional transfer on the economic outcomes of the receiving households. The appendix Figure A.1 shows the evolution of those subsidies.[40] The program of 100 thousand free housing units occurred between 2012-2015. There is a program for rural housing and subsidies for the military that I ignore in this paper.

Targeting instruments. The authorities use two different tools to determine eligibility; the households' income and the total price of the housing unit. A unit can be subsidized only if the market price is below the *low-cost housing* threshold, 135 times the monthly minimum wage (m-MW). This arbitrary threshold is the same for all cities. Regarding income, only households earning below four times the monthly minimum wage can get the subsidy. Figure A.2a shows the subsidy scheme. Before 2015, the subsidy was decreasing on income, and the maximum possible subsidy was $22 \times$ m-MW. In 2016 the generosity increased, the limit increase to $30 \times$ m-MW for individuals with income below $2 \times$ m-MW and $20 \times$ m-MW for individuals with income between $2 - 4 \times$ m-MW. As the Figure A.1 shows, the increase in the limit is reflected in higher government expenditure. The average subsidies were about 20 percent before 2015 where the mean subsidy is about 26 percent.

[40]Other less relevant policies aim to promote low-cost housing. Most of the additional policies did not change during my study period. These policies include the following: (i) no income tax for low-cost housing unit credit (Law 546 of 1999). This is between 5 and 8 percent of the value of the credit. (ii) Long-term bonds to finance housing (Law 546 of 1999.). (iii) Tax exemption for leasing (2002). (iv) Protection for credit defaults (Access to the Fondo Nacional de Garandias). (v) New credit from the Colombian Development Bank to increase credit for new housing. Housing with a limit of 70 MW is a free housing unit. These subsidies apply to all housing units without targeting low-cost housing.

Figure A.2: Subsidy Scheme and Observed Mean Differences

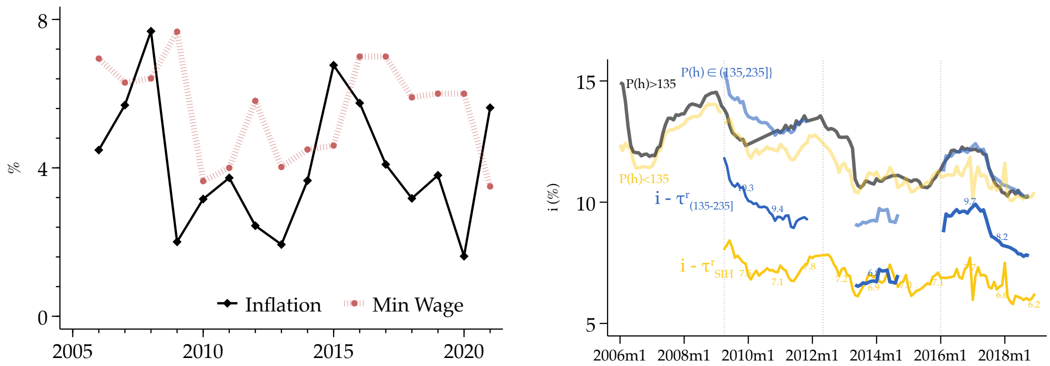


a. downpayment Subsidy Scheme Subsidy *b. Interest rate subsidy scheme*

Note: This figure shows the subsidy scheme and the evolution overtime of the subsidies for the interest rate and downpayment subsidy.

II. Minimum wage, Inflation and Interest Rates.

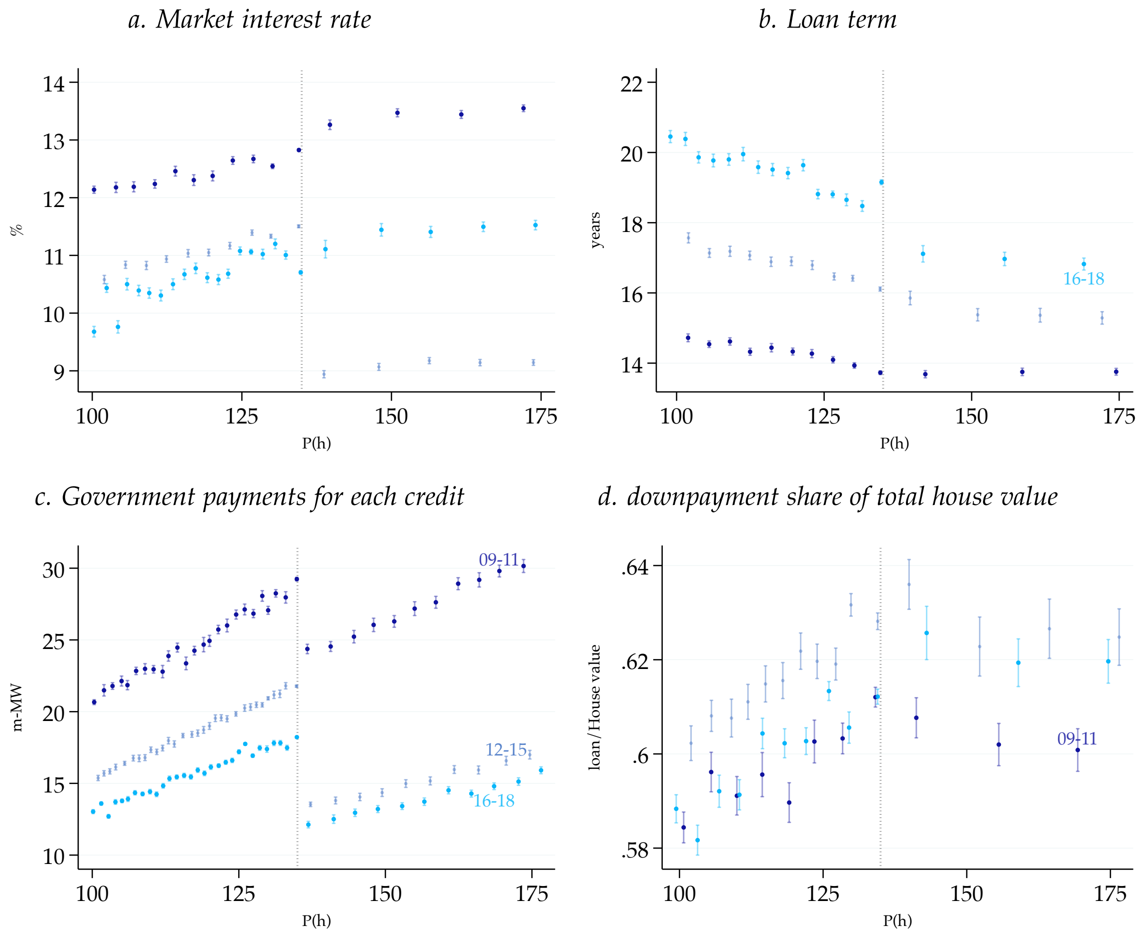
Figure A.3: Minimum Wage, Inflation, and Interest Rates Over Time



a. Inflation and Minimum Wage Over-Time *b. Market interest rate i and subsidy τ^r*

III. Mortgage terms:

Figure A.4: Loan Terms by House Prices



Note: This figure shows the subsidy scheme and the evolution overtime of the subsidies for the interest rate and downpayment subsidy.

Observed differences in monthly payments. I use the administrative records of these subsidies and administrative records on all loans to check that subsidies are reflected in the lower interest rates paid by households. The administrative records for the subsidies contain relevant information about the mortgages. It has the market interest rate i, the loan L, the term n, the discount in the interest rate τ^r, and the house price P. The administrative records for all loans contain less detailed information, but I observe the interest rate of each loan and the average loan amount. I use the loans for housing, which have an indicator variable equal to 1 if the house is *low-cost housing* and 0 otherwise.

Appendix B. Bunching Estimation and Robustness to Parameter Selection

I. Counterfactual Distribution Estimation

In this section, I describe the details of the counterfactual distribution used to estimate the behavioral responses induced by the Colombian housing policy. The response to the policy can be recovered by comparing the observed distribution, f_{h^*}, to the counterfactual distribution, f_{h_0}. This is, the distribution that would exist in the subsidy's absence. I calculate it fitting a flexible polynomial to the observed density and excluding the observations close to the cutoff.

Estimation. To estimate the empirical distribution $\hat{f}_{h^*}$, I calculate the share of units in each bin h_b of size $2 \cdot \epsilon$,

$$h_b = \frac{1}{N} \sum_{l=1}^{N} \mathbb{1} \left[h_l \in (b - \epsilon, b + \epsilon) \right] \tag{B1}$$

The estimated observed equilibrium distribution is

$$\hat{f}_{h^*}(h) = h_b$$

To estimate the counterfactual distribution, $\hat{f}_{h_0}$, I predict the observed values for h_b using a flexible polynomial, $l(h_b) = \sum_{p=0}^{T} \iota_p h_b^p$, excluding a region around the cutoff. The function $o(h_b; L, H)$ includes all the indicator variables for the bins between L and H, the lower and the upper bound of the excluded region. $o(h_b; L, H) = \sum_{k=L}^{H} \mathbb{1} \left[h_k = h_b \right] h_b$

$$h_b = l(h_b) + o(h_b; L, H) + v_b \tag{B2}$$

Counterfactual distribution. The counterfactual distribution is the predicted density using only the flexible polynomial.

$$\hat{f}_{h_0} = \hat{l}(h_b) = \sum_{p=0}^{T} \hat{\iota}_p h_b^p \tag{B3}$$

Bunching. Using the estimated distributions, I can get an expression for bunching or excess mass at $\underline{h}$, and calculate the maximum behavioral change induced by the subsidy Δh:

$$Bunching = \sum_{h<\underline{h}} \hat{f}_{h^*}(h) - \hat{f}_{h_0}(h) \tag{B4}$$

Equation B4 is the difference between the observed distribution and the counterfactual distribution below the discontinuity point, $\underline{h}$, and it represents the share of individuals who would consume $h \in (\underline{h}, \overline{h})$ in the absence of the subsidy, but consume h in a subsidy scenario.

Maximum change in housing consumption. Households consuming up to $\overline{h}$ in the absence of the subsidy change their consumption to take advantage of the subsidy. $\overline{h}$ can be recovered as the minimum value where the counterfactual and observed distributions coincide:

$$\overline{h} = min[h : h > \underline{h} \text{ and } \hat{f}_{h_0}(\underline{h}) - \hat{f}(h_b) = 0]$$

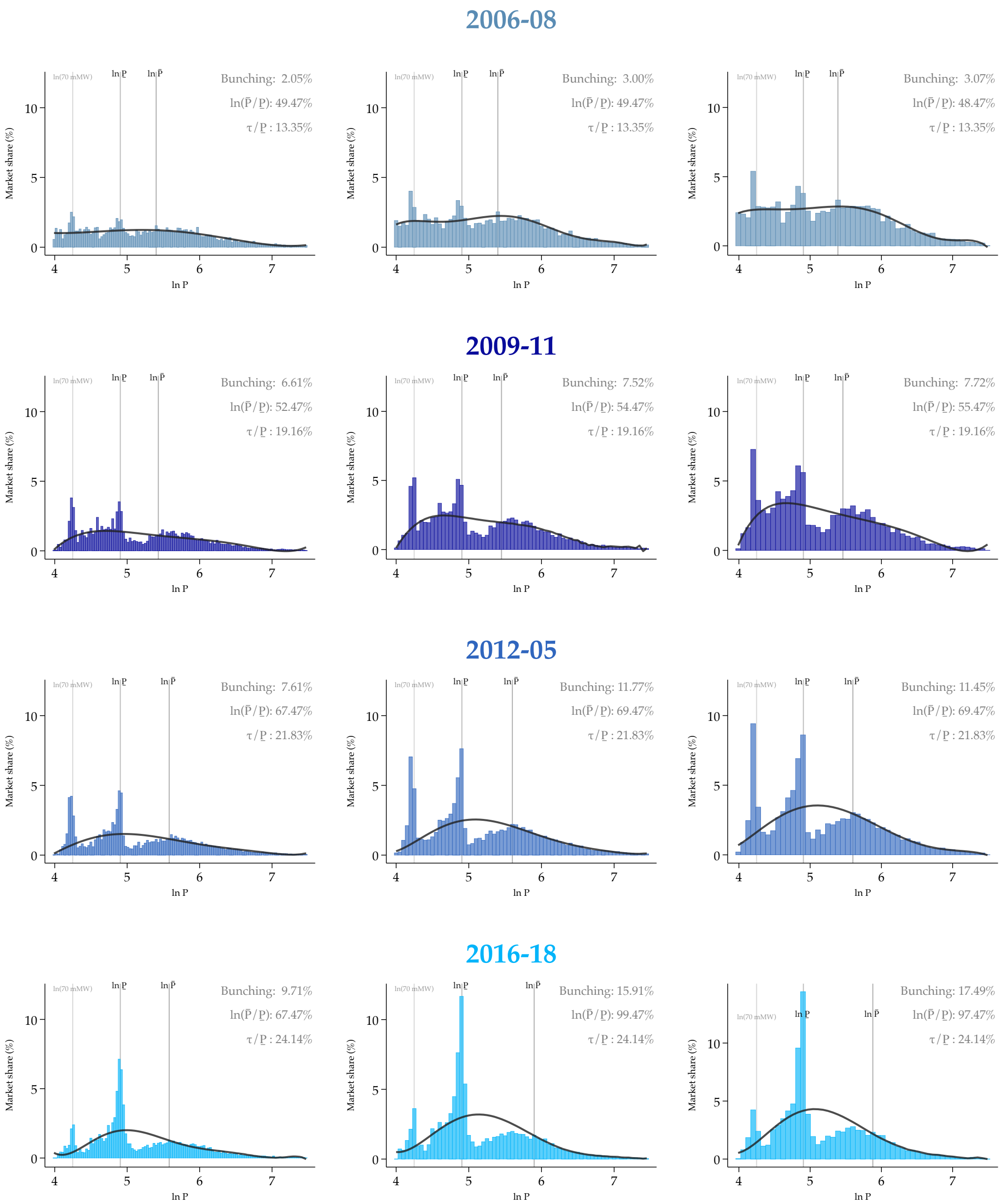
and Δh is the maximum change agents made to take advantage of the subsidy.

$$\Delta h = \overline{h} - \underline{h} \tag{B5}$$

II. Robustness to Different Parameter Choices

The estimation of the counterfactual distribution relies on the selection of 3 parameters, the bin size, ϵ, the degree of the polynomial p and the number of bins to be excluded around the cutoff defined by the L and H. To select p, and L and H, I follow Diamond and Persson (2016); Chen et al. (2021) and pick the values of p and L and H that minimize the difference between the missing mass and the excess mass. Additionally, in this section, I show the sensitivity to the bin size and the definition of the missing and excess mass. Figure B.1 shows three different bin sizes 0.03, 0.05 (bin size for main results) and 0.07, and Figure B.2 shows how the distribution and counterfactual estimation changes when I define the missing and excess mass in 1) the whole distribution, 2) allowing it to include some additional bins below $\underline{P}$, and 3) the excess mass only at P. Overall the results do not change much.

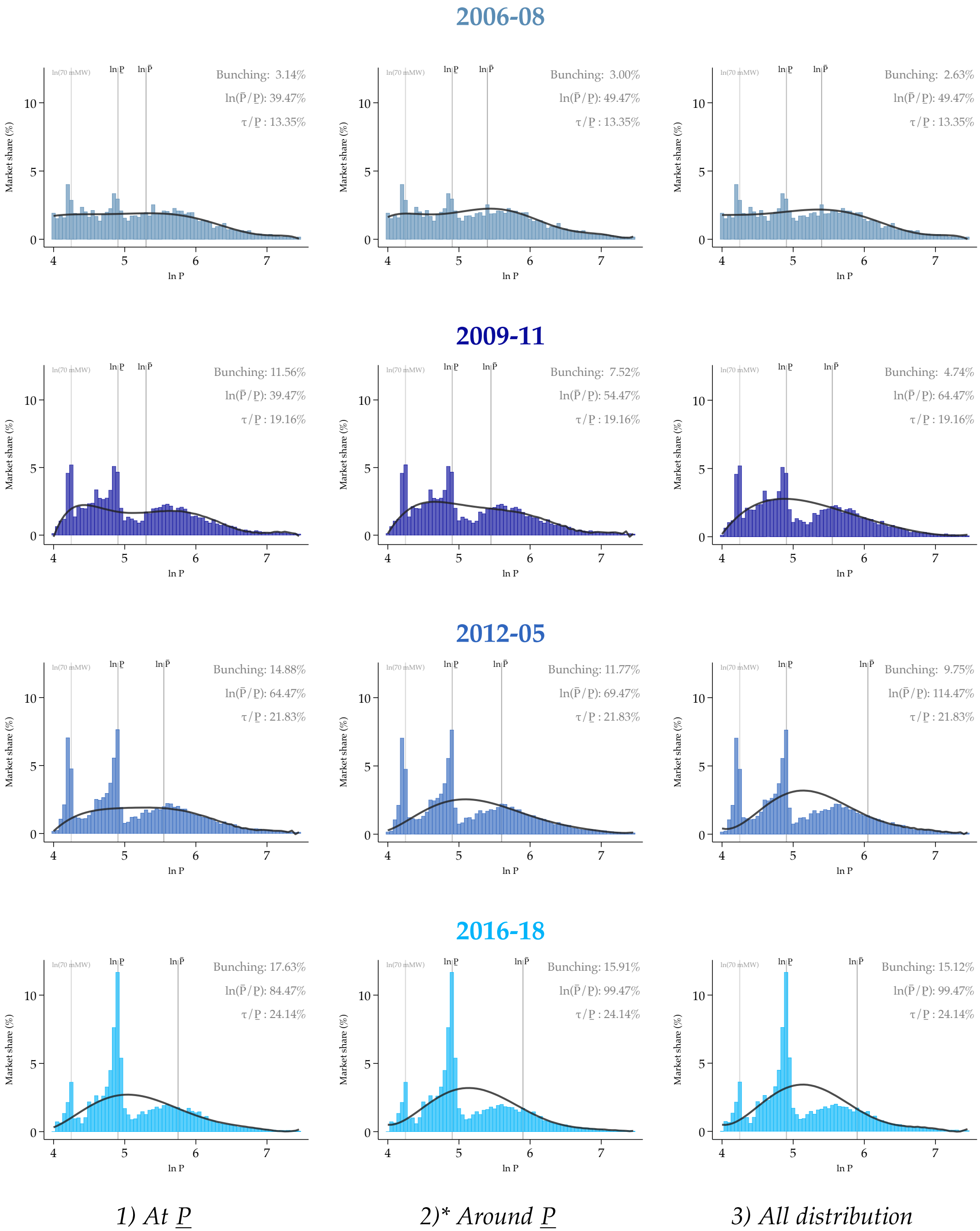
Figure B.1: Bunching Over Time Using Different Binsize



1) binsize 0.03 *2) binsize* 0.05* *3) binsize 0.07*

NOTE: This figure shows the distribution or the market share of housing units by sale price (expressed in log of mMW). The lines are the cutoffs defining *low-cost housing* $\underline{P}$ = 135 mMW and *priority low-cost housing* 70 mMW. The additional lines shows the point, $\overline{P}$, where the counterfactual and observed distribution coincide again after the cutoff. The figure shows for the different period for all available cities.

Figure B.2: Bunching Over Time Using Different Criteria of Missing=excess mass to Select Estimation Parameters



Note: This figure shows the distribution or the market share of housing units by sale price (expressed in log of mMW). The lines are the cutoffs defining *low-cost housing* $\underline{P}$ = 135 mMW and *priority low-cost housing* 70 mMW. The additional lines shows the point, $\overline{P}$, where the counterfactual and observed distribution coincide again after the cutoff. The figure shows for the different period for all available cities.

Appendix C. Response on size: Additional cities.

Figure C.3: Quantile-to-Quantile Plots of Housing Size: Low versus High Subsidy Periods

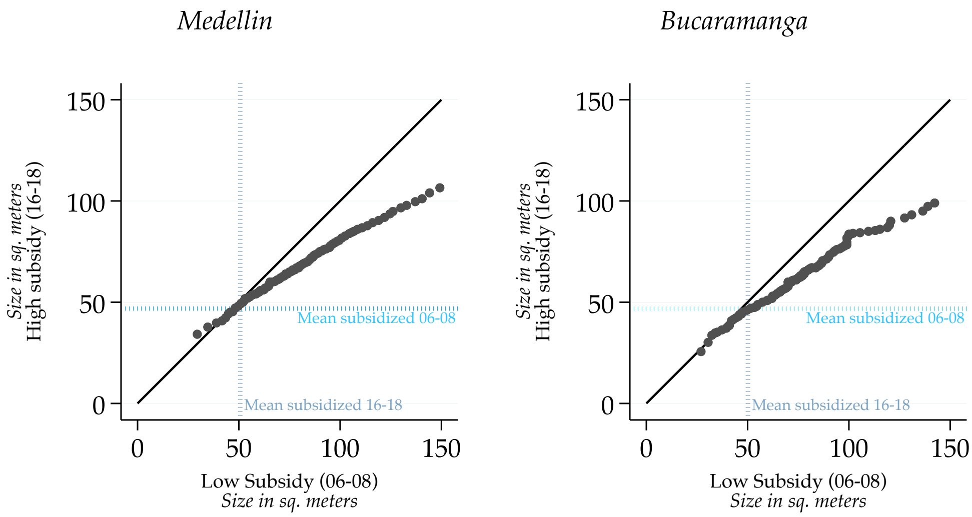
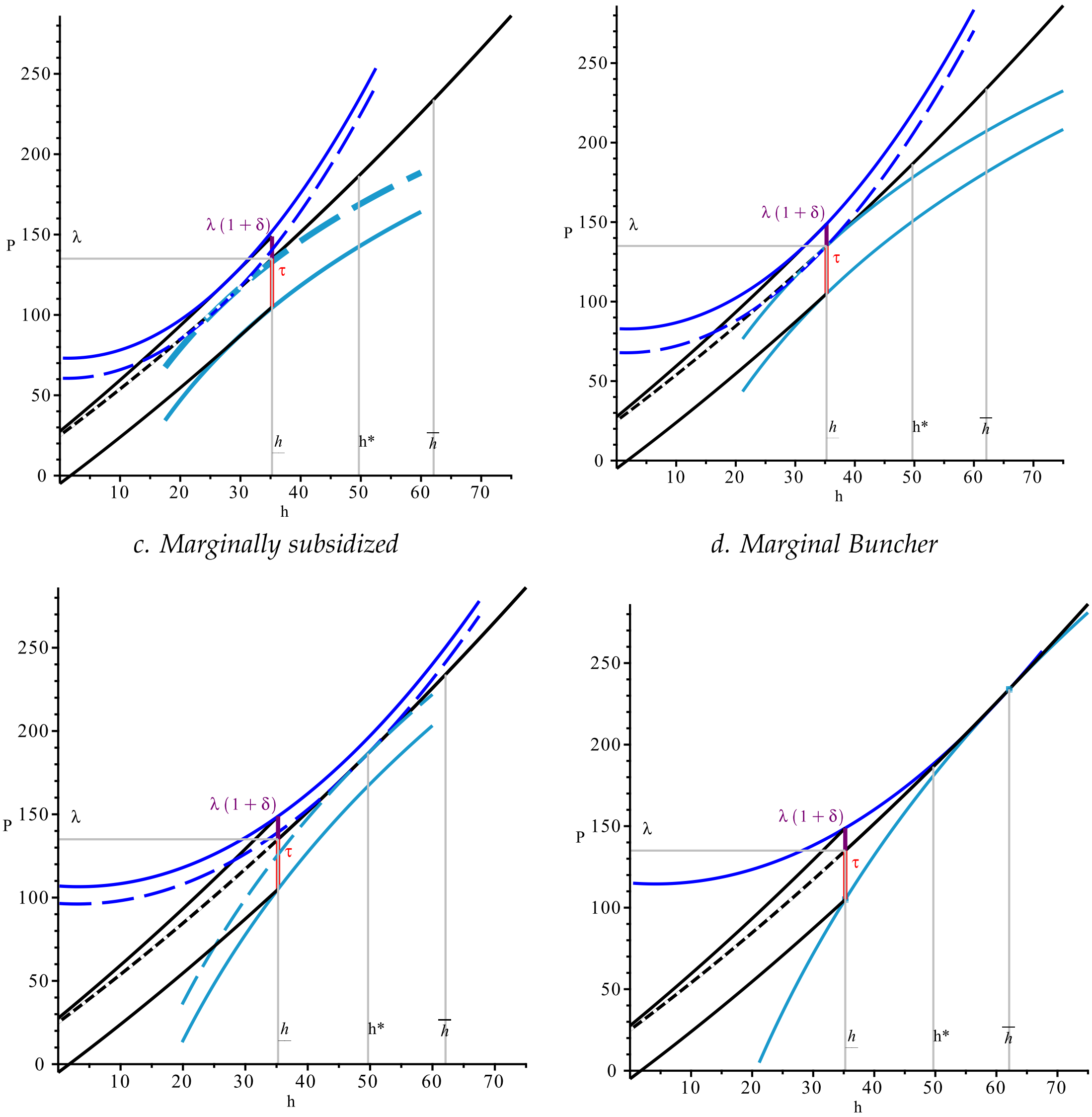


Figure D.4: Graphical representation of equilibrium choices

a. Subsidized *b. Threshold optimizer*



The offer function functional form is: $\varphi_j^S = \frac{\bar{\pi}_j \cdot h^2}{\beta_1} + A_j$. This results from a cost function $C\left(Q(h), A_j\right) = A_j * Q(h)$, and $Q(h) = \frac{\alpha}{h^2}$

I. Standardized Housing and Unit Size

To make all the housing units comparable, I use the hedonic price function to standardize all housing units. In particular, I use the estimates of equation 20 to convert all housing units into a standard unit.

This hedonic price estimation decomposes the unit price into observed and unobserved characteristics. The standardized housing size, which I call h, is the size of a housing unit with average characteristics that will cost the same as the observed price.

$$\rho\left(h_{ltc}\right) + \Gamma'\bar{X} + \bar{\omega} = \rho\left(s_{ltc}\right) + \Gamma' X_{ltc} + \omega_{ltc} \tag{D6}$$

$\bar{X}$,are the means of the observable characteristics and $\bar{\omega}$ equals the average residual. Solving for h in the equation D6, I get the following measure of the standardized size measure:

$$h_{ltc} = \rho^{-1}\big(\rho\left(s_{ltc}\right) + \Gamma'\left(X_{ltc} - \bar{X}_{ltc}\right) + \left(\omega_{ltc} - \bar{\omega}_{ltc}\right)\big) \tag{D7}$$

Intuitively, this means that if a house is more expensive because it has certain amenities or more bathrooms, I convert this characteristic into the equivalent square meters that the household could get if they had a standard house.

In my application, I standardize the units in a way that $\bar{P} = \rho\left(\bar{s}_{ltc}\right) + \Gamma'\bar{X}_{ltc} + \bar{\omega}_{ltc}$ is the average price observed for the average house. For the implicit price function, I use a parametric approximation $\rho(s) = \rho_0 + \rho_1 \cdot s + \rho_2 \cdot s^2$.

Figure 9 shows the functional form of the estimated price function for the four different periods. The Figure 9 shows that the implicit price function has become steeper overtime.

Implied Maximum Size of a Standard Subsidized Unit

0.32

$$135 \times mMW = \lambda = \rho\left(\underline{h}\right)$$

Given a particular assumed functional form,

$$\underline{h} = \frac{-\rho_1 + \sqrt{\rho_1^2 - 4 \cdot \rho_2 \cdot \left(\bar{P} - \lambda\right)}}{2 \cdot \rho_2}, \tag{D8}$$

In Figure 9, $\underline{h}$ corresponds to the value of h at which the implicit price intersects the price cutoff (gray horizontal line).

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