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Subsidies to Electricity Consumption and Housing Demand in Bogotá*

Camila Casas†

Abstract

In this paper, I estimate the demand for housing in Bogotá, modeling electricity consumption explicitly to take into account the crossed subsidies included in Colombian utility rates. I use household level data on housing prices, observable dwelling attributes, and demographic variables to recover the willingness to pay for housing characteristics following the three-step estimation procedure suggested by Bajari and Kahn (2005). First, I regress the price of housing against different observable dwelling characteristics to recover the implicit price of each feature. Next, I infer household-specific preference parameters from the utility maximizing first-order conditions, where a household's utility depends on these observable characteristics. Finally, I analyze the relationship between demographic variables and the taste parameters estimated in the previous step. In order to study the impact of subsidies on households' housing decisions, I focus on the impact of changes in the price of electricity on the choice of dwelling size. I find that subsidized households choose bigger dwellings than they would in the absence of subsidies, while those who are taxed choose smaller ones.

Keywords: Housing Demand, Hedonic Prices, Subsidies, Stratification

JEL Classification: H2, H4, I3, R21

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1 Introduction

Individual housing choices are an important element of several issues in applied economics. These choices determine different urban characteristics, including access to public goods, traffic patterns, and urban segregation. Hence, understanding the housing market and its outcomes is of utmost importance when formulating economic policies that affect household's housing decisions. The estimation of the demand for housing, however, is a challenging empirical exercise. Dwelling choice depends on several attributes of both the dwelling itself and of the surrounding areas. Moreover, some of these attributes may be impossible to quantify, and preferences towards particular characteristics vary greatly across households.

The objective of this paper is to estimate the demand for housing in Bogotá, taking into account the effects of the Colombian subsidy scheme on public utilities' rates, and to analyze the impact of this policy on housing choices. In Colombia, Law 142 of 1994 (known as the Law of Public Utilities) established a consumption cross-subsidy scheme that seeks progressive income redistribution through differentiated utilities' rates. Rate structures are designed in a way such that households living in wealthy dwellings, along with commercial and industrial establishments, are taxed, and the collected resources are used to subsidize those living in poor units. Taxes and subsidies are assigned through a system that classifies all dwellings into six categories, or strata. The poorest dwellings are classified in stratum 1, and, as conditions improve, dwellings are assigned to a higher category. Since the final object of this classification is the dwelling, not the household, the cross-subsidy scheme distorts housing decisions. Therefore, it must be taken into account when analyzing the housing market.

For my estimation, I use household-level data on housing prices, housing characteristics (including stratum), and demographic variables. I first regress the price of housing against different observable dwelling characteristics to recover the implicit price of each feature. Next, I infer household-specific preference parameters from the first-order conditions of a utility maximization model, in which the utility of a household depends on the consumption of housing, defined as a bundle of characteristics. Once I recover these parameters, I analyze the relationship between tastes and demographic variables. I then conclude my exercise by using the demand parameters estimated in the second step to study the distortions introduced to the housing market by the cross-subsidy scheme.

In order to analyze the impact of subsidies on households' housing decisions, I focus on the impact of changes in the price of electricity on the choice of dwelling size. All public utilities (piped water and sewerage, telephone land lines, and natural gas) have stratum-specific rates, such that dwellings in the lowest strata pay subsidized prices while those in the highest strata are taxed. I focus on electricity for two reasons. First, it has a direct relationship with size, an observable dwelling characteristic. Second, electricity has the highest coverage rate across public utilities in Bogotá, estimated to be 100%. With every dwelling presumably connected to the network and paying the regulated rate corresponding to its stratum, I can focus on electricity consumption rather than connectivity decisions.

This paper is closely related to the vast literature on hedonic prices, and, specifically, their use in the estimation of housing demand.[1] In hedonic models, goods are valued for the underlying utility that consumers can obtain from their characteristics. Hedonic prices are the implicit prices of each attribute, and the demand for the observed product and its equilibrium price are the result of the aggregation across all components.

Starting with the work of Court (1939), hedonic regressions have been used in the construction of price indexes for a wide range of differentiated products.[2] Once indexes are constructed, one particular application of hedonic prices is the estimation of consumer demand for differentiated goods. Rosen (1974) provides the seminal framework to integrate hedonic theory with the estimation of demand. Under the proposed approach, demand parameters are estimated in two stages. First, the observed prices of the differentiated products are regressed on all their characteristics, and the estimates are used to compute the estimated marginal prices for each individual feature. Second, these marginal prices are equated to the marginal benefits for all characteristics, such that prices are used as endogenous variables in the estimation of the inverse demand and supply equations, written as functions of product characteristics, consumers' demographic vari-

[1]For a review of the literature on the use of hedonic models for the study of the Colombian housing markets, se Castaño, Laverde, Morales, and Yaruro (2013).

[2]For an comprehensive review and a good example of the broad applicability of this technique from its start, see Griliches (1971).

ables, and sellers' attributes. As noted by Epple (1987), however, if the hedonic price is not linear, there is a simultaneity problem in the second stage of Rosen's algorithm. Since consumers with a strong preference for a particular characteristic are expected to purchase a product with a great amount of that feature, the resulting hedonic price will vary with the quantity consumed. As is, unobserved tastes determine both the quantity demanded *and* the hedonic price of that characteristic. To overcome this difficulty, several studies have proposed alternative modifications to Rosen's second stage that allow to recover structural demand parameters. Ekeland, Heckman, and Nesheim (2004), Bajari and Benkard (2005), and Bishop and Timmins (2011) are examples of different approaches in which parameters can be recovered using data from just one market.

Bajari and Kahn (2005) is an application particularly relevant for this paper. It applies the methodology proposed by Bajari and Benkard (2005) to estimate the demand for housing and evaluate racial segregation in American cities. Bajari and Kahn (2005) follows a three-step estimation procedure. The first step consists of the estimation of a non-parametric hedonic price function, that includes both continuous and discrete variables and accounts for unobserved features. These estimates allow one to recover the marginal prices of different housing attributes. For the second step, some structure is imposed on the consumers' utility function. From the utility maximization first-order conditions for both observed and unobserved features, it is possible to infer household-specific preference parameters for each characteristic. Finally, in the third step individual taste coefficients are recovered as functions of household demographics and household-specific preference shocks.

Following the estimation strategy proposed by Bajari and Kahn (2005), I estimate the demand for housing in Bogotá, and then I use the estimated demand parameters to calculate the effect of the cross-subsidy scheme on the choice of dwelling size. Previous studies on the distortions generated by these subsidies include Medina and Morales (2007a, 2007b). The first study finds that the estimated increment in the value of a dwelling due to its eligibility to receive public utility subsidies is of similar magnitude to the present discounted value of the subsidy flow. This can be interpreted as evidence of capitalization of subsidies on housing prices. The second study focuses on the effect of subsidized rates on consumption. It presents an estimation of demand functions for piped water and electricity in Colombia's main cities that follows a Discrete Continuous Choice methodology in order to account for the block rate pricing scheme implicit in the subsidy scheme. Given the corresponding elasticities, the deadweight loss in the electricity sector is estimated to be almost US$20 million in 2004.

In this paper, I explore a third aspect in which subsidies may distort household's housing decisions. Specifically, I test whether subsidies are affecting the size chosen by households by exploiting the positive correlation between dwelling size and electricity consumption. I find that households living in the three lowest strata choose bigger dwellings than they would choose in the absence of subsidies, while those living in the highest two strata choose smaller ones.

The remainder of the paper is organized as follows. In the following section, I describe the data used for the estimations, and present some descriptive statistics of the housing market in Bogotá. In section 3, I present the model. In section 4, I describe the estimation strategy. In section 5, I present the results of the estimations, and based on these results, in section 6, I analyze the impact of the subsidy scheme on household choices. Section 7 concludes and sets the guidelines for future work.

2 The Data

The primary data source is the Colombian 2003 Living Standards Survey (*Encuesta de Calidad de Vida*, henceforth ECV), collected by the National Department of Statistics, DANE. This survey is a random sample of households living in private dwellings, designed to be a representative sample for the whole country, for nine regions, and for rural and urban areas.[3] For my estimations, I use the information corresponding to the urban segment of Bogotá.

The ECV data are collected at the household level, and include extensive information on both demographic characteristics of all household members, and attributes of the dwelling they inhabit. Regarding demographic characteristics, the ECV contains information about monthly income and expenditure, the number of household members, and the gender, age, ethnic group, education,

[3]In the survey, a household is defined as a person, or group of persons, who live in the same dwelling and generally share their meals. Under this definition, it is possible that multiple households cohabitate the same dwelling. In such cases, all households living in a sampled dwelling are included in the survey.

and labor experience of each member. Regarding the dwelling, the survey includes information on stratum, the type of building (house, apartment, etc.), the main material of walls and floor, access to public utilities, if the dwelling has a garage, a garden, and/or a porch, and information on its surroundings, like the presence of garbage dumps nearby or an indicator of whether the dwelling is located in an area with a high propensity to flooding or landslides. Finally, the survey contains detailed information about the occupancy status and the price of the dwelling. All variables can be aggregated or averaged using the expansion factors included in the sample to calculate totals at the city level.

Information on electricity rates for Bogotá comes from the National Regulatory Commission for Energy and Gas (*Comisión de Regulación de Energía y Gas*, henceforth CREG). In its website, the CREG reports the valid rates per strata for all companies serving residential buildings on a bimonthly basis. Since the ECV data for Bogotá was collected between June 6 and July 23, I use the rates valid from May 17 to July 16, 2003.

To estimate electricity consumption at the household level, I combine the information on electricity rates with the household expenditure on electricity reported on the ECV. Specifically, the ECV inquires about the amount payed for the last electricity bill and the number of months covered by said bill, so I can calculate the monthly expenditure from the survey data. For households living in strata 4-6 the marginal price for a kilowatt of electricity is constant across all levels of consumption, so I estimate the electricity consumption simply by dividing their reported expenditure by the corresponding rate. For households living in strata 1-3, it is necessary to take into account the block pricing schedule implicit in the subsidy scheme. Dwellings in these strata pay a subsidized rate for the first 200kWh consumed each month, but the pay the full rate (the one charged to dwellings in stratum 4) for any consumption above this "subsistence" threshold. Hence, I first compare each households expenditure with the cost of consuming 200kWh at the corresponding subsidized rate; if the reported expenditure is below this cost, then I divide it by the subsidized rate to estimate their electricity consumption. For those households reporting an expenditure greater than this cost, I estimate their consumption by dividing the difference by the full rate and adding the 200kWh corresponding to the first block.[4]

[4]The subsistence threshold was revised down in 2004 and 2005, and new, differentiated values were set according to each city's altitude. Although the level at which rates are discontinuous changed, electricity rates still exhibit a block

For the 2003 ECV, DANE surveyed a total of $12,771$ households in urban Bogotá, representing an estimated population of nearly 2 million households. In the following tables, I describe some important features of the data.

Table 1 shows the distribution of households across strata.[5] In the first column, I present the distribution for the city's population as a whole, along with the projected number of households. For the second part of the table, I use total monthly expenditure as a proxy for the household's wealth and classify households into expenditure quintiles.[6] It can be seen that over three-fourths of total households are concentrated in strata 2 and 3, and that over 80% are eligible to receive subsidies. Moreover, when I break the distribution by expenditure groups, the data show that even relatively wealthy households live in houses classified in low strata and pay subsidized rates. It is worth noting that there may be some noise within the lowest stratum—historically, there has been an exception to the classification rules that allows for a dwelling to be considered as stratum 1 when it is officially declared to be of cultural, historical, or architectural interest for the city, regardless of its location or quality, as a way of compensation for the ownership limitations that come with such a distinction.

In terms of ownership, Table 2 shows that 40% of the households in Bogotá are renters, while more than half of the households own the dwelling they inhabit. A look at the distribution across building types suggest that renters and owners have a different preferences. While most of the former choose to live in apartments, most of the latter live in houses, although they are more evenly distributed between houses and apartments.

For the remainder of the paper, I will focus on renters. This reduces my sample size to $5,360$ observations, representing an estimated of over $750,000$ households. I estimate the model for this sub-sample only, since I believe the available information on housing prices is cleaner for them. While the ECV directly asks households living in rented units for the value of their monthly rent,

structure.

[5]Since the sample is not representative at the stratum level, households included in the sample are weighted by their corresponding expansion factor in order to get an unbiased estimation of the aggregate distribution.

[6]The ECV has detailed information on household's monthly income and expenditure. I choose expenditure over income since, according to Deaton (2000), in developing countries expenditure is a better measure of wealth than of income, since it tends to be smoother and have less reporting errors. It is important to note, however, that expenditure is still subject to measurement error. Moreover, it may not be a perfect proxy for a household's wealth due, for example, to the differences in the marginal propensity to consume across wealth levels.

Table 1: Household Distribution Across Strata

	All	By Expenditure Quintile				
	Households	Q1	Q2	Q3	Q4	Q5
Stratum 1	6.1%	13.5%	7.9%	5.9%	2.0%	1.1%
Stratum 2	33.7%	51.9%	49.6%	38.3%	21.8%	7.2%
Stratum 3	43.0%	32.1%	39.3%	48.8%	55.3%	39.4%
Stratum 4	9.9%	1.8%	2.6%	5.5%	14.0%	25.6%
Stratum 5	4.3%	0.6%	0.4%	1.1%	5.1%	14.1%
Stratum 6	3.0%	0.1%	0.2%	0.4%	1.8%	12.5%
Total	1,930,850	100%	100%	100%	100%	100%

Table 2: Occupancy and Types of Housing

	Owned	Rented	Other*
Total	53.0%	39.7%	7.3%
House	53.2%	25.2%	41.1%
Apartment	45.6%	64.2%	44.5%
Occupancy by rooms	1.2%	10.7%	14.5%
Households	1,024,532	766,512	139,806

* Other types of occupancy include households living in usufruct (those allowed by the owner to inhabit a dwelling without paying any rent), and *de facto* occupants (those occupying a dwelling without its owners authorization) .

owners are asked to provide estimates of their home's value and of the monthly payments they think they would receive if they rented their unit. Medina and Morales (2007a) match the ECV data with the real state appraisal values used by the city's government to calculate property taxes, and find the ECV values reported by owners to be highly subjective. It is important, therefore, to keep in mind that the results that I present in section 5 should not be generalized since owners and renters have different preferences for housing.[7]

Table 3 shows the distribution of renters across strata, along with some statistics for the monthly rent values. The percentages from the first column are similar to those presented in Table 1, although they are slightly lower for the highest three strata. This may suggest that ownership is more common for better dwellings. Regarding the rent statistics presented in columns 2-4, the average rent increases with stratum, as expected, except between strata 1 and 2. This may be the effect of having special interest houses classified as 1, as mentioned above. The median rent, not being affected by these outliers, is strictly increasing across all strata. The positive correlation between housing prices and strata reflects the fact that better housing units with more desirable characteristics, both observed and unobserved, are indeed classified in higher strata.

Table 3: Monthly Rent Statistics

	Distribution	Monthly Rent (thousands of COP)		
	by Strata	Mean	Median	Std. Deviation
Stratum 1	5.5%	164.8	100	223.6
Stratum 2	36.3%	148.0	130	102.1
Stratum 3	44.8%	248.6	240	132.7
Stratum 4	8.9%	460.2	420	230.4
Stratum 5	2.4%	595.6	550	304.1
Stratum 6	2.1%	1,125.8	916	688.9
Total	766,512	252.7	200	240.6

Dwelling characteristics contained in the survey include the type of building, materials, neighborhood characteristics, and stratum. A full description of the variables included can be found in

[7] Besides the differences in preferences for building type described above, there are other ways in which owners and renters differ. Arbeláez, Steiner, Becerra, and Wills (2011) identify several socioeconomic factors that affect housing tenure choices.

the appendix. Table 4 presents the summary statistics for rented dwellings.

Table 4: Rented Dwelling Characteristics

Characteristics	Mean	Median	Std. Deviation
House	0.23	0	0.42
Apartment	0.66	1	0.47
Shared	0.12	0	0.32
Walls	1.06	1	0.47
Floors	3.04	3	1.00
Rooms	2.79	3	1.34
Garden	0.40	0	0.49
Lot	0.04	0	0.18
Garage	0.19	0	0.39
Porch	0.18	0	0.39
Common Areas	0.10	0	0.30
Topography	0.06	0	0.32
Pollution	0.31	0	0.46
Stratum 1	0.05	0	0.23
Stratum 2	0.36	0	0.48
Stratum 3	0.45	0	0.50
Stratum 4	0.09	0	0.29
Stratum 5	0.02	0	0.15
Stratum 6	0.02	0	0.14

In order to analyze the effect of household characteristics on the demand for different dwelling features, in my estimation I include several demographic variables reported in the ECV. In particular, I use information on the total monthly expenditure (as a proxy for households' wealth), household size, age of the head of the household, and binary variables equal to one if the head of the household is male, married and/or has any education beyond highschool. Since my model explicitly includes households' tastes for dwelling size and electricity consumption, I also include the number of appliances owned by the household.[8] This variable ranges from 0 (if the household has no appliances at all) to 12 (if they own all of the goods in my sample). Table 5 shows some descriptive statistics for these demographic variables.

Table 5: Demographic Variables for Renters

	Mean	Median	Std. Deviation
Expenditure (thousands of COP)	1,351.59	912.31	1,438.34
Size of Household	3.4	3	1.6
Age	40.1	38	12.6
Male	0.7	1	0.5
Married	0.6	1	0.5
College or Grad Education	0.3	0	0.4
Appliances	4.4	4	2.6

[8]Appliances included in the survey are: washing machine, refrigerator, blender, sound system, microwave, vacuum cleaner, video player (VHS and/or Beta), personal computer, water heater, air conditioner, fan, and TV. Although it is clear that some of these appliances consume more energy than others, I opt to group them in a single variable for exposition simplicity.

3 The Model

In this section, I describe the model of housing demand that I use to recover the willingness to pay for housing characteristics. The model includes $i = 1, ..., I$ households and $j = 1, ..., J$ dwellings, where each unit is modeled as a bundle of characteristics, including its size. Prices in the housing market are a function of these characteristics, and are determined by the interaction of many sellers and buyers, so each individual household acts as a price taker.[9]

In order to take into account the possible effect of subsidies to public utilities' rates on the housing market, I exploit the positive correlation between the size of a dwelling and the electricity consumption of the household living in it.[10] Therefore the model explicitly includes households' choices of both dwelling size and electricity consumption.

A utility-maximizing household i chooses how much electricity to consume and a housing unit j, characterized by a bundle of characteristics (s_j, X_j, ξ_j). The household's problem can be written as:

$$\max_{e_i, s_j, X_j, c_i} u_i\left(e_i, s_j, X_j, \xi_j, c_i\right) \tag{1}$$
$$\text{s.t. } y_i \geq P_{e_j} e_i + P_j\left(s_j, X_j, \xi_j\right) + c_i \quad ,$$

where e_i is the monthly consumption of electricity in hundreds of kWh, s_j is the size of the dwelling, X_j is a set of other observable characteristics of the dwelling, ξ_j is the value of features observed by the household but unobservable to the econometrician, c_i is a composite consumption commodity, y_i is the monthly total expenditure of the household, P_{e_j} is the price of a kWh of electricity (that depends on the dwelling's stratum), and P_j is the price of dwelling j, measured

[9] In the particular case of Bogotá's housing market, it is likely that the effective rent paid by any household is the result of a bargaining process between owner and renter, such that renters with different negotiation abilities may end up paying different prices for similar dwellings. However, I expect these differences to be relatively small, and that the average market price for housing features is unaffected by any singular transaction.

[10] The coefficients of the estimated demand for electricity presented in Medina and Morales (2007b) imply that the size of a dwelling has a positive and significant effect on electricity consumption, even after controlling for other observable dwelling characteristics, and demographic variables that include the household's income, net of subsidies.

with the monthly rent.[11,12]

This problem is equivalent to:

$$\max_{e_i, s_j, X_j} u_i \left(e_i, s_j, X_j, \xi_j, y_i - P_{e_j} e_i - P_j \left(s_j, X_j, \xi_j \right) \right) \quad . \tag{2}$$

Assuming that the utility function is additive, I divide it in two parts. The first component is a Leontief function that captures the complementarity between electricity consumption and size.[13] For the second part, I assume that utility is linear in all other characteristics. Both components have household-specific coefficients, since preferences for dwelling features are assumed to change with demographic characteristics. Therefore, the utility maximization problem becomes:

$$\max_{e_i, s_j, X_j} \beta_{0i} \log \left(min\{\alpha_{ei} e_i, \alpha_{si} s_j\} \right) + \sum_k \beta_{ki} x_{jk} + \xi_j + \left[y_i - P_{e_j} e_i - P_j \left(s_j, X_j, \xi_j \right) \right] \quad , \tag{3}$$

where x_{jk} is the k-th element of the vector of observable characteristics X_j.

Given the Leontief functional form assumed for the first part of the utility function, and that electricity and the size of a house both have positive prices, a utility-maximizing household will choose e_i and sj such that $\alpha_{ei} e_i = \alpha_{si} s_j$. This implies $e_i = \widetilde{\alpha}_i s_j$, where $\widetilde{\alpha}_i = \frac{\alpha_{si}}{\alpha_{ei}}$. Therefore the optimization problem can be written as:

$$\max_{s_j, X_j} \beta_{0i} \log \left(\alpha_{si} s_j \right) + \sum_k \beta_{ki} x_{jk} + \xi_j + \left[y_i - P_{e_j} \left(\widetilde{\alpha}_i s_j \right) - P_j \left(s_j, X_j, \xi_j \right) \right] \quad . \tag{4}$$

[11] The dwelling size variable included in my data is the number of rooms, excluding bathrooms and kitchen. For simplicity, I will assume that size s is a continuous variable. Therefore, my estimations of the impact of subsidies on size choice represent an upper bound of the real effect.

[12] As noted in Bajari and Benkard (2005), it is necessary to take into account the valuation of unobserved features in order to have accurate estimates for the marginal prices of the observed ones. The inclusion of ξ_j appears to be of utmost importance for the exercise presented in this paper. Using a different dataset for new dwellings in Bogotá, Castaño, Laverde, Morales, and Yaruro (2013) find that several characteristics not included in my data have a significant effect on housing prices.

[13] The complementarity between electricity consumption and dwelling size can be captured in a general way with a CES function, for which the substitution parameter ρ is estimated along the remaining model's parameters. Basic estimations of such a model yield a negative, very large (in absolute terms) value for $\hat{\rho}$, which is consistent with a Leontief functional form. I opt to use the Leontief function throughout the paper, since assuming perfect complementarity between dwelling size and electricity consumption allows me to present the model and its results in a very simple manner. In addition, I believe that, given my estimated $\hat{\rho}$, the results obtained using a Leontief utility function are similar to the ones I would obtain using a less restrictive functional form.

The dwelling characteristics included in X_j are either discrete or binary variables (see Appendix). In these cases, utility maximization implies a threshold rule for each feature. For instance, suppose that household i chooses a house with a garage, so $x_{j,garage} = 1$. The implicit price for a garage faced by this household is $\frac{\Delta P_j}{\Delta x_{j,garage}} = P_j\left(s_j, \tilde{X}_j, \xi_j\right) - P_j\left(s_j, \bar{X}_j, \xi_j\right)$, where $\tilde{X}_j$ is the vector of observed characteristics for the chosen house, and $\bar{X}_j$ is a vector identical to $\tilde{X}_j$, except for $x_{j,garage} = 0$. Utility maximization implies that if household i chooses a house with a garage, it must be true that $\beta_{garage,i} \geq \frac{\Delta P_j}{\Delta x_{j,garage}}$. If, on the contrary, the implicit price exceeds the value of the parameter, the household will choose a house without a garage. Similar conditions can be derived for all the binary variables included in the estimation. In the case of walls'and floor's materials, the discrete variables included in X_j, there will be two thresholds for β_{ki}. In any case, the first-order maximization conditions are independent of the household's choice of dwelling size and electricity consumption, and of the price of electricity.

Regarding the first part of the utility function, the first-order condition for size s_j is:

$$\begin{aligned}\frac{\partial u_{ij}}{\partial s_j} =& \beta_{0i}\frac{1}{\alpha_{si}s_j}\alpha_{2i} - P_{e_j}\widetilde{\alpha}_i - \frac{\partial P_j}{\partial s_j} = 0 \\ \Longrightarrow \beta_{0,i} =& \left[P_{e_j}\widetilde{\alpha}_i + \frac{\partial P_j}{\partial s_j}\right] s_j \\ \beta_{0,i} =& P_{e_j}e_i + \frac{\partial P_j}{\partial s_j}s_j \quad .\end{aligned} \tag{5}$$

Note that, unlike the conditions for other observable characteristics, the coefficient corresponding to the taste for size β_0 depends on the price and the consumption of electricity and therefore has an extra term that arises from the explicit way in which I model the complementarity between electricity consumption and the size of a house.

Using the structure from these utility-maximizing first-order conditions and the micro data on demographic variables from the ECV, I can recover household-level random taste coefficients. The estimation strategy followed to recover them and the estimation results are presented below.

4 Estimation Strategy

Following Bajari and Kahn (2005), I estimate this model in three stages. First, I estimate the housing hedonic regression to recover the implicit prices for different observable characteristics, and the valuation of the unobservable ones. In the second stage, I use the first-order conditions given by (5) to infer household-specific preference parameters. In the third stage, I regress these preference parameters on demographic variables to analyze the joint distribution of tastes and demographics.

4.1 Hedonic Price Equation

The first step consists of the estimation of a hedonic housing price equation. Hedonic models are based in the hypothesis that goods can be described as a bundle of characteristics, and are valued according to the utility obtained from each of these attributes. Therefore, the implicit prices faced by household i who chooses $j^*(i)$ can be estimated with:

$$P_j = \gamma_0 + \gamma_s s_j + \sum_k \gamma_k x_{jk} + \xi_j \quad . \tag{6}$$

The variables included in the vector of dwelling characteristics $X_j = (x_{j1}, \ldots, x_{jK})$ are described in full in the appendix.

The error term of the hedonic regression, ξ_j, is interpreted as the value of unobserved features. Hence, once I estimate equation (6), the value of the unobserved characteristics ξ_j can be calculated from the residual:

$$\widehat{\xi}_j = P_j - \widehat{\gamma}_0 - \widehat{\gamma}_s s_j - \sum_k \widehat{\gamma}_k x_{jk} \quad . \tag{7}$$

Here, I follow the standard hedonic assumption that the unobservable features are independent from the observable ones.

4.2 Application of the First-Order Conditions

The hedonic price equation described in the previous subsection implies that, in the particular case of dwelling size, the implicit marginal price is given by:

$$\frac{\partial P_j\left(s_j, X_j, \xi_j\right)}{\partial s_j} = \gamma_s \quad . \tag{8}$$

Therefore, given the first stage estimation of (6), I can estimate this price with

$$\frac{\partial \widehat{P}_j\left(s_j, X_j, \xi_j\right)}{\partial s_j} = \widehat{\gamma}_s \quad . \tag{9}$$

Replacing the coefficient in the utility-maximizing first-order condition described by equation (5), the estimator for the parameter characterizing the taste for size is given by

$$\widehat{\beta}_{0i} = \left[P_{e_j} e_i + \widehat{\gamma}_s s_j\right] \quad . \tag{10}$$

Recall that the expenditure in electricity, $P_{e_j} e_i$, and the dwelling size, s_j, are observed in the data.

4.3 Joint Distribution of Tastes and Demographics

Once I recover household-specific taste parameters in the second stage, I regress them on demographic variables in order to get the joint distribution of tastes for each particular housing attribute and household characteristic. For the specific case of electricity consumption and size, I estimate the model

$$\begin{aligned} \beta_{0i} &= f_\beta\left(d_i\right) + \eta_{\beta i} \qquad (11)\\ E\left[\eta_{\beta i} | d_i\right] &= 0 \end{aligned}$$

jointly with:

$$\widetilde{\alpha}_i = f_\alpha\left(d_i\right) + \eta_{\alpha i} \tag{12}$$

$$E\left[\eta_{\alpha i}|d_i\right] = 0 \ \ .$$

For these regressions, I replace the household-specific β_{0i} with their estimates obtained from equation (10), and I calculate the value for $\widetilde{\alpha}_i = \frac{e_i}{s_j}$ from the observed values of electricity consumption and dwelling size. In addition, I assume that the model for the joint distribution of demographic characteristics and tastes for size, which I assume to be correlated with the taste for electricity consumption, is linear, such that (11) and (12) can be rewritten:

$$\begin{aligned} \widehat{\beta}_{0i} &= \theta_{\beta 0} + \sum_s \theta_{\beta s} d_{si} + \eta_{\beta i} \\ \text{and,}& \\ \widetilde{\alpha}_i &= \theta_{\alpha 0} + \sum_s \theta_{\alpha s} d_{si} + \eta_{\alpha i} \end{aligned} \tag{13}$$

Once I estimate $\hat{\theta}$, residuals η_i can be interpreted as household-specific taste shocks.

5 Results

In this section, I present the model's estimates for Bogotá. Table 6 contains the results of the hedonic price regression—an OLS regression of the monthly rent (in logs) on observable characteristics of the dwelling. The full description of the explanatory variables included in the regression can be found in the appendix.

The estimated coefficients presented in this table suggest that the size of the house, the quality of walls and floors, and the availability of a garage or a parking space all have a positive and significant effect on the monthly rent. The dummy variables for the type of dwelling, house or apartment, are also significant and have the expected sign. The price is higher for these types of units than it is for units that rented room by room, where households share areas like the kitchen (the omitted category). This is also reflected by the negative coefficient for the *shared* variable. Living in an area that is subject to flooding, landslides, or similar natural risks has a negative effect on price. Dummy variables for each strata are highly significant and have the expected sign; rent is

Table 6: Hedonic Price Regression

Characteristics	Coefficient	Std. Error
House	0.17^{***}	0.0239
Apartment	0.23^{***}	0.0209
Shared	-0.23^{***}	0.0198
Walls	-0.06^{***}	0.0130
Floors	-0.10^{***}	0.00694
Rooms	0.19^{***}	0.0055
Garden	-0.03^{**}	0.0130
Lot	-0.04	0.0335
Garage	0.20^{***}	0.0188
Porch	-0.06^{***}	0.0162
Common Areas	0.05^{**}	0.0213
Topography	-0.08^{***}	0.0269
Pollution	-0.02	0.0134
Stratum 1	-1.08^{***}	0.0524
Stratum 2	-1.03^{***}	0.0463
Stratum 3	-0.77^{***}	0.0444
Stratum 4	-0.45^{***}	0.0458
Stratum 5	-0.26^{***}	0.0564
Constant	5.76^{***}	0.0540
N		$5,360$
Adjusted R^2		0.62

Notes: The dependent variable is the logarithm of the monthly rent, measured in thousands of Colombian pesos. ***, **, and * denote statistical significance at 1% or stricter, 5%, and 10%, respectively.

increasing with stratum. It is worth emphasizing that this positive effect is statistically significant even *after* I control for several observable characteristics. It is possible that these dummies are capturing features that are hard to quantify, like neighborhood quality. The access to common recreational areas, owning a lot, and the proximity to highly polluted areas has no statistically significant effect on the monthly rent. The dummies for having a garden or a porch both have negative, statistically significant coefficients.[14]

The results presented in Table 6 are estimated including all the observations in my sample for which I have the value of the monthly rent. However, as mentioned above, it is possible that some high-quality dwellings are classified in stratum 1 due to their special interest status, adding noise to the estimations. As a robustness check, I repeat the estimation of the hedonic price equation excluding all dwellings in stratum 1, and the estimated coefficients are very similar.[15]

With these results, the next steps are to recover individual preference parameters, and to estimate the effect of household demographic characteristics on tastes. Given the objective of the paper, I focus on β_{0i} and $\widetilde{\alpha}_i$, the coefficients related to the tastes for size and electricity consumption. As described in sections 4.2 and 4.3, I use the estimated value for $\hat{\gamma}_s$ presented in Table 6, and data on electricity consumption and dwelling size to recover $\hat{\beta}_{0i}$ for every household. The values for $\widetilde{\alpha}_i$ are calculated using data on size and electricity consumption.

Once household-specific parameters are recovered, I then analyze the interaction between tastes and socioeconomic characteristics. The demographic variables used for this stage are those described in Table 5, in the data section. Table 7 shows the results of OLS regressions of the taste parameters on these demographic variables.

The results presented in the first two columns of the table, corresponding to the joint coefficient β_0, suggest that wealth, household size, age of the head of the household, and ownership of different appliances, all have a positive and significant relationship with tastes for size and electricity consumption. On the contrary, marital status has a negative effect, while gender and education seem to have no effect on preferences for size and electricity consumption. Results for the *relative*

[14]Intuitively, both these variables are desirable features. One possible explanation for their negative effect on the paid rent is that they are costly to maintain, and a lower rent may be a way of compensating renters for incurring in these costs.

[15]The results of the estimation without dwellings classified in stratum 1 are available upon request.

taste between size and electricity consumption, measured with $\widetilde{\alpha}_i$, are presented in the last two columns of the table. The results suggest that wealth, age of the head of the household, and households with a male head seem to prefer size to electricity consumption, while bigger households, and those who have heads with higher education levels and more appliances seem to get higher utility from electricity consumption than from bigger houses. In this case, marital status has no significant effect on $\tilde{\alpha}$.[16]

Table 7: Joint Distribution of Tastes and Demographics

	β_0		$\tilde{\alpha}$	
	Coefficient	Std. Error	Coefficient	Std. Error
Expenditure	15.80^{***}	0.8238	13.88^{***}	1.6815
Size of Household	0.80^{***}	0.2873	-2.59^{***}	0.5864
Age	0.29^{***}	0.0340	0.21^{***}	0.0694
Male	0.91	1.1452	5.40^{**}	2.3374
Married	-2.01^{*}	1.1959	-1.12	2.4409
Education	0.38	1.0636	-4.86^{**}	2.1708
Appliances	1.36^{***}	0.2455	-2.57^{***}	0.5010
Constant	-101.32^{***}	5.1520	-24.32^{**}	10.5151
N		4,378		4,378
Adjusted R^2		0.25		0.02

Notes: The dependent variables are the household-specific taste coefficients, β_0 and $\tilde{\alpha}$. They are regressed on demographic characteristics. *Expenditure* is the logarithm of total monthly expenditure, measured in thousands of Colombian pesos. ***, **, and * denote statistical significance at 1% or stricter, 5%, and 10%, respectively.

[16] As mentioned before, some of the appliances included in my sample consume more electricity than others. Although I am using the number of appliances owned by the households for the estimations presented in Table 7 for exposition simplicity, I repeat these third-step estimations replacing the aggregate variable for individual dummies, and the estimated coefficients for all other demographic variables are qualitatively similar. These results are available upon request.

6 Analysis of the Effect of Subsidies

As stated in the introduction, the Colombian subsidy scheme may affect household choices. Given that the results presented in the previous section suggest that there is a significant effect of electricity consumption and dwelling size on household utility, I now proceed to analyze the effect that subsidies have on household choices, specifically on these two variables. To do so, I take a partial equilibrium approach and calculate the responses of different households to a potential change in electricity rates, keeping all other consumption choices and all marginal prices for housing characteristics constant.

With this subsidy scheme, different households pay a different price per unit of electricity. If I assume subsidies are eliminated, P_{e_j} will increase for households living in dwellings assigned to strata 1 to 3, will not change for those living in stratum 4, and will decrease for those living in strata 5 or 6. Now, let us analyze the problem for a household living in a dwelling classified in any of the lowest three strata. As stated above, utility maximization implies:

$$\widehat{\beta}_{0i} = \left[P_{e_j} e_i + \widehat{\gamma}_s s_j\right] \quad .$$

Since β_0 is a taste parameter, it should remain constant to price changes. Therefore, if P_{e_j} increases, an optimizing household will respond by decreasing the electricity consumption; depending on the cross-price elasticity, it will also adjust its dwelling size choice.

In this particular setting, the first-order utility-maximization conditions imply that the Marshallian demands for electricity and size are:

$$s_j^* = \frac{\beta_{0i}}{\left[\widetilde{\alpha}_i P_{e_j} + \gamma_s\right]} \tag{14}$$

and

$$e_i^* = \frac{\beta_{0i}}{\left[P_{e_j} + \widetilde{\alpha}_i^{-1} \gamma_s\right]} \quad . \tag{15}$$

Therefore, the price elasticity of demand for electricity and the cross-price elasticity of demand for size are both given by

$$\epsilon_e^p = \epsilon_{e,s} = \frac{-\widetilde{\alpha}_i P_e}{\left[\widetilde{\alpha}_i P_{e_j} + \gamma_s\right]} \quad . \tag{16}$$

These elasticities being equal to each other is a direct result of the first component of the utility function being a Leontief function.

Since $\widetilde{\alpha}$ and γ_s are positive, (16) implies that the value of the price elasticity of demand for electricity is less than one (in absolute value) for all households. Then, if there is an increase in P_e, the reduction in the consumption of electricity will be smaller in percentage terms, leading to an overall increase in electricity expenditure. So, for the preference parameter β_0 to remain constant, a household will need to adjust its house size choice as well. Taking the price of an extra room as given, an optimizing household will change its choice of dwelling size according to (16).

Notice that both the price elasticity of demand for electricity, and the cross-price elasticity of demand for size, depend upon the value of $\tilde{\alpha}$. Therefore, the response to a price change will be different across households. For example, for a typical household living in stratum 2, in a house with 2 bedrooms, and consuming 114 kWh of electricity per month, the elimination of the 40% subsidy will lead this household to consume 99 kWh of electricity per month and demand a house with 1.7 rooms. Table 8 shows the estimated results for the median household in each stratum. These numbers illustrate how would typical households react to the elimination of the cross-subsidy scheme. These results suggest that households who are eligible to receive subsidies choose bigger dwellings than the ones they would choose in the absence of subsidies. In contrast, those households that are taxed opt for units smaller than what they would otherwise choose.

The findings presented in Table 8 and discussed above, however, should not be generalized. First and foremost, the numbers presented in Table 8 were calculated assuming that the size of a dwelling is a continuous variable. But, as stated in section 3, in the case of discrete variables as the number of rooms, the model predicts thresholds that determine parameter ranges for which each option would be optimal. Therefore, a change in the price of electricity may not lead *all* households to alter their dwelling size choice, since it is possible that, even with the new rates, their current choice is the optimal one. And, even if it is optimal for any given household to chose

Table 8: Predicted Responses to Price Changes by Median Households

	e	S	Subsidy	ϵ_e	$\epsilon_{e,s}$	New e	New S
Stratum 1	106	2	50%	−0.15	−0.15	90	1.7
Stratum 2	114	2	40%	−0.20	−0.20	99	1.7
Stratum 3	140	3	15%	−0.15	−0.15	136	2.9
Stratum 4	194	4	0%	−0.10	−0.10	194	4.0
Stratum 5	202	4	−20%	−0.10	−0.10	205	4.1
Stratum 6	305	4	−20%	−0.08	−0.08	309	4.1

a dwelling of a different size, if moving costs are positive these could prevent the household from moving to a unit with their optimal number of rooms. Second, as mentioned above, I estimate the model using data for renters, and it is possible that households who own the dwelling they inhabit exhibit a different behavior. And third, these numbers are the result of a partial equilibrium analysis. In a general equilibrium setting, one would need to take into account the changes in the implicit prices for all features. This is particularly relevant for the marginal price of rooms, since the number of additional rooms demanded by households whose electricity rate would decrease if subsidies were eliminated would probably be smaller than those liberated by households who would face a rate increase — while less than 10% of households live in strata 5 and 6, more than 80% of households live in the lowest three strata. The change in the marginal price of rooms could be significant: in the housing market the short run supply is highly inelastic, so shifts in demand will be reflected in price changes before enough small dwellings can be constructed.

7 Conclusion

In this paper I present a model of demand for housing, that explicitly takes into account the consumption of electricity and its complementarity with dwelling size, and I use the results to analyze the effect of the Colombian cross-subsidies to public utilities on the housing market. I estimate the model using household-level data from the 2003 Colombian Living Standards Survey. Following the three-step procedure proposed by Bajari and Kahn (2005), I recover the structural taste coefficients and the willingness to pay for specific housing characteristics.

My findings suggest that wealthier, larger households, and those whose head is older, has higher education and/or is married, tend to choose bigger dwellings and consume more electricity. These variables also help explain whether this is a result of a relatively stronger preference for size or for electricity consumption. With respect to the effect of subsidies on the housing market, the solution to the proposed utility maximization problem implies that a change in electricity prices will affect not only the consumption of electricity, but also size choice. Subsidized households seem to choose bigger dwellings than they would if they were to pay full price for all their electricity consumption, while those who are taxed choose smaller ones.

While these results support the hypothesis that the subsidy scheme is distorting the housing market, it is important to note that they come from a hypothetical scenario in which size is assumed to be a continuous variable. In practice, with households being forced to choose a discrete number of rooms for their dwellings, it is possible that some of them would opt to keep their dwelling size unchanged if subsidies were eliminated.

To fully characterize the housing market in Bogotá, future work needs to be done. One important extension would be to estimate the effects of subsidies in the context of a general equilibrium model. Also, both the utility function parameters and the implicit prices that result from the hedonic equation could be estimated using non-parametric methods. In the case of the utility function, this would allow for a more flexible relationship between electricity consumption and the different dwelling characteristics. In the case of the hedonic price, this would allow us to have a local estimation that would probably yield more accurate results. Finally, it is important to extend this model to include home owners. Presumably owners have different tastes than renters, and the estimations presented in this paper do not account for these differences. It will be interesting to see if demographic differences between these two groups result in different tastes.

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Appendix

Variables from the ECV included in the vector of dwelling characteristics, X_j.

House:
Binary variable equal to 1 if the household lives in a house.

Apartment:
Binary variable equal to 1 if the household lives in an apartment.

Shared:
Binary variable equal to 1 if the dwelling is shared with other households.

Walls:
Main material of external walls. The value is decreasing with quality and ranges from 1 to 8, where 1 corresponds to brick, stone or polished wood walls, and 8 to zinc, plastic, or cloth walls.

Floors:
Main material of floors. The value is decreasing with quality and ranges from 1 to 6, where 1 corresponds to granite or polished and varnished wood, and 6 to soil or sand. 3, the most common category across dwellings with a share of 60%, corresponds to tile, vinyl, brick or polished wood.

Rooms:
Number of rooms, excluding bathrooms and kitchen.

Garden:
Binary variable equal to 1 if the dwelling has a garden.

Lot:
Binary variable equal to 1 if the dwelling has a lot.

Garage:
Binary variable equal to 1 if the dwelling has a garage or a parking space.

Porch:
Binary variable equal to 1 if the dwelling has a terraced roof.

Common Areas:
Binary variable equal to 1 if the dwelling has access to common property areas.

Topography:
Binary variable equal to 1 if the dwelling is in an area with topographic problems, such as being subject to flooding, river overflows, landslides, or geological failures in general.

Pollution:
Binary variable equal to 1 if the dwelling is in an area with high pollution, due to its proximity to

industrial areas, airports and/or bus terminals, waste dumps, big markets, black water pipes, or high-tension electricity cables.

Stratum 1-Stratum 6:
Binary variables equal to 1 if the dwelling is classified in the corresponding stratum.