EVALUATING INCREASING BLOCK PRICING AS A SUBSIDIZATION SCHEME IN THE ELECTRICITY RETAIL SECTOR: THE COLOMBIAN CASE

A Thesis in
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by
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ABSTRACT

Targeting of subsidies has been used by many policy makers in different countries as an attempt to ensure universal access to public utility services. This amounts to nonlinear pricing to achieve particular performance goals. Different subsidization schemes have been developed, and have also been augmented with cross-subsidies among customer classes i.e. residential, commercial and industrial. A variety of targeting mechanisms have been used to allocate the subsidies; the most popular ones being increasing block pricing (IBP), means-tested and geographically targeted subsidies. The Colombian subsidization scheme is particularly interesting because it combines cross-subsidization among customer classes with IBP and geographically targeted subsidies.

Under this scheme, residential customers are classified in one of six categories. Customers classified as part of the lower three categories received a subsidy on the first 200kWh of electricity consumed per month, while users in the upper two categories, along with industrial and commercial customers, pay a 20 percent tax on their monthly electricity consumption. Customers classified as part of class four pay the marginal price of electricity for all levels of consumption.

In theory, this household classification process is made such that the lower the household’s income, the lower its assigned category. However, in practice, households are being classified according to the neighborhood in which they are located and/or the observable characteristics of the household. The use of neighborhood characteristics results in the creation of subsidized zones, which can constitute an incentive for the migration of high income households to subsidized neighborhoods. Using households’ observable characteristics to identify high income households in poor neighborhoods can result in homeowners changing the
observable characteristics of their properties to make them look like those of poorer ones. Hence, the current subsidization scheme as it is being applied may result in subsidizing high income households at the expense of poorer ones, reducing the transfer to those at the bottom of the income distribution, and undermining the policy’s objective of universal access and wealth redistribution.

The objective of this study is to evaluate the effectiveness of this subsidization mechanism on targeting low income households. The importance of this study lies in the diagnosis of the problems associated with the currently used targeting method, and therefore constitutes an input for the improvement of the subsidization scheme. Evidence regarding the subsidization of high income households was obtained. I find that up to 50 percent of households were misclassified as part of class one when they actually belonged to the upper three quintiles of the income distribution. 61 percent of class two and 76 percent of class three households were misclassified. Additionally, I find that households classified as part of class one have a higher probability of exceeding the subsidized consumption level than households from classes two and three. The resulting marginal effects with respect to class four were 17.48 percent for class one, 12.71 percent for class two and 7.78% for class three. Household level income data is necessary to perform a better evaluation of the policy.
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1. Introduction

In 1994, the Colombian electricity retail sector moved from a subsidization system based exclusively on consumption levels to a more complex model that integrates a two-step increasing block pricing (IBP) with price discrimination according to households’ socioeconomic conditions. The objective of the new scheme was to ensure provision of utility services based on criteria of neutrality, solidarity, self-financing, redistribution, and socioeconomic efficiency. Under this policy, customers were divided into six categories, in theory, according to their income. Low income households were classified as part of the lower categories i.e. one, two and three while high income households were classified as part of the upper categories (five and six). The classification was intended to distinguish consumers in lower classes who needed subsidies from consumers in higher classes whose payments could be used to finance subsidies. Also it is important to note the subsidy is limited. They are granted only for consumption levels below a certain predefined quantity, which in this particular case is 200kWh/month.

The classification of households as a part of any of the six classes is carried out by each municipality. In practice, the criterion for classification has been based on the observable characteristics of neighborhoods and households rather than households’ income. This procedure can constitute either an incentive for household owners to worsen the observable characteristics of their property or an incentive for them to migrate to subsidized neighborhoods. This practice would result in high income households receiving subsidized electricity, impacting the effectiveness of the policy on targeting low income households.

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1 See Ley 142 de 1994-Ley de Servicios Públicos. Bogotá, Colombia.
The aim of this study is to assess the targeting effectiveness of the subsidization policy. In order to do this, I compute the probabilities that electricity consumption in households belonging to the three lower socioeconomic strata exceed the subsidized electricity threshold.

Conditional on the subsidies’ income effect and assuming that the subsidy threshold is high enough to cover basic electricity consumption, these probabilities constitute an indicator of high income households being classified as low income ones, a targeting error known as inclusion error. This methodology is based on the assumption that wealthier households consume more electricity than poorer ones (in other words, it is assumed that electricity is a normal good). Thus, if low inclusion errors are present, I would expect the probability of class three households consuming in the unsubsidized block to exceed that of households in class two and the same from class two to class one. If the opposite holds, it would be an indicator of errors in the households’ socioeconomic classification process.

Subsidies can constitute an incentive for low income households to consume more than high income ones. However, previous studies and the analysis of the data suggest that, on average, low income households consume less electricity and spend a higher share of their income on their electricity bill. Thus, the income effect of the subsidization scheme is not likely to be big enough to make households in lower classes have higher probabilities of consuming in the unsubsidized block than higher income households. However, with the purpose of isolating the subsidy income effect from the potential misclassification effect, I use a two-step least squares (2SLS) model to estimate the responsiveness of customers in the first three classes to changes in the subsidy amount.

In addition to the subsidy income effect, it is important to determine if the defined subsidized threshold is enough to cover the electricity consumed by basic appliances. This is
important because if the subsidized quantity is not enough, consumers will have to consume in the unsubsidized block even if that requires spending a high share of their income on electricity.

Analysis of the data shows that for the period of study, mean consumption of households in each of the six classes, is smaller than the subsidized threshold, and in the case of classes one and two, stays below the threshold even accounting for the standard deviation. Hence, the defined subsidized threshold is likely to be enough to cover households’ basic electricity consumption, and the proposed methodology is suitable for identifying potential misclassifications.

The main contribution of this project is the implementation of a discrete choice model and household level data for the evaluation of the targeting effectiveness of the subsidization policy. The identification of problems in the policy’s targeting mechanism constitutes an important input for the improvement of the scheme, directing more subsidies to those at the bottom of the income distribution and possibly leading to lower use of government resources to maintain the system. To the best of my knowledge, no previous study has used consumer-level data for the evaluation of Colombian electricity’s tariff structure using a discrete approach.

Results provide evidence of high inclusion errors. I find evidence that up to 50% of households were misclassified as part of class one when they actually belonged to the upper three quintiles of the income distribution. 61% of class two and 76% of class three households are likely to have been misclassified.

Additionally, I find that households in the first three classes respond to changes in the subsidy amount by cutting consumption by 1 percent and that households classified as part of class one have a higher probability of exceeding the subsidized consumption level than
households from classes two and three. The resulting probabilities with respect to class four were 17.48% for class one, 12.71% for class two and 7.78% for class three.

The rest of the document is organized as follows: Section 2 presents a review of the relevant literature. Section 3 presents a description of the Colombian electricity’s retail sector and an analysis of the policy at the national level. Section 4 develops the microeconomic model for the increasing block pricing tariff structure. Section 5 presents the data corresponding to the city of Manizales. Section 6 presents a non-parametric analysis of the policy. Section 7 explains the implemented econometric model. In section 8 the estimations are carried out and the results are analyzed and discussed. Section 9 concludes.
2. Literature Review

Most studies have focused largely on the estimation of the electricity demand functions under conditions introduced by the IBP tariff structure. In the Colombian case, the first attempt was carried out by Maddock et al. (1992). They estimate the price elasticity of electricity demand for the city of Medellin, solving a constrained maximization subject to a segmented budget set resulting from the rising block scheme of prices.

In the case of the United States, Agthe and Billings (1987) use individual household survey data from Tucson, Arizona to estimate a simultaneous equation model to determine the price elasticity of water demand for each income group. They find that under IBP higher income households not only use more water, but have lower elasticities of demand.

Olmstead et al. (2007) use data from 1,082 households from 11 urban areas in the United States and Canada. Using a D/C model, they obtained a price elasticity of demand of -0.59; a panel random-effects model produced an elasticity of -0.033. A prior study conducted by Hewitt and Hanemann in 1995 used a D/C model and obtained elasticities six times greater than those obtained by Olmstead et al. (2007). These mixed results illustrate the fact that more research is needed in order to determine the appropriate model specification in the presence of increasing block rate structures.

On the other hand, different studies have been conducted in order to evaluate the Colombian electricity subsidization scheme. Gomez-Lobo and Contreras (2003) performed an evaluation of the Colombian and Chilean subsidization schemes using a non-parametric analysis. They find that although there are high targeting errors in both the Chilean means-tested scheme and the Colombian geographically targeted scheme, the means-tested system is better able to identify low income households than the geographically targeted scheme.
Melendez (2008) uses data from the Colombian 2003 Quality of Life Survey to compute the share of average total households’ income that was being spent on electricity bills. The study concludes that households in the lower income quintile were spending more than 10.4% of their income on electricity, despite previous studies’ recommendations that this percentage should not exceed 9 percent of total income\(^2\). She also found that without subsidies, households in the two lower income quintiles would spend 16.1% and 10.4% of their total income on electricity, respectively.

Additionally, she observed that 80% of households belonging to the three upper quintiles of the income distribution were being subsidized, concluding that the targeting system was basically subsidizing every household in the country. In this analysis however, no econometric model was included to support the findings.

This study uses a methodology based on the Discrete/Continuous model developed by Hanemann (1995), but since the objective is to determine the conditional probabilities that consumers position their consumption in the unsubsidized part of the tariff structure, it only solves the discrete part using a Logit model.

\(^2\) The 9 percent limit in the share of total income spent on electricity was suggested by Foster et al. in their 2005 study of water and electricity markets in developing countries.
3. Colombian Electricity’s Retail Sector

The Colombian electricity’s retail sector is formed by 40 municipal utilities that simultaneously operate and maintain the distribution networks of the zones they serve. These municipal utilities buy power from the market and sell it to consumers according to the formula developed by the Gas and Energy Regulatory Commission (CREG) for each residential consumer class (see Table 1). In Colombia, households classified as class five or six pay an electricity price that is 20% higher than the market price. While consumers classified as part of classes three, two and one pay up to 15%, 40% and 50% less than the market price for the first 200 kWh of electricity they consumed, respectively.

Table 1. Tariff per residential class

<table>
<thead>
<tr>
<th>Socioeconomic Class</th>
<th>PRICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>= MP - 0.5MP</td>
</tr>
<tr>
<td>2</td>
<td>= MP - 0.4MP</td>
</tr>
<tr>
<td>3</td>
<td>= MP - 0.15MP</td>
</tr>
<tr>
<td>4</td>
<td>= MP</td>
</tr>
<tr>
<td>5, 6</td>
<td>= MP + 0.2MP</td>
</tr>
</tbody>
</table>

In the Colombian electricity market, 82.7% of the residential customers are currently classified as a part of the lowest three classes — 23% are classified as class one, 39.5% as class two, and 20.2% as class three. 4.2 percent of residential customers belong to classes five and six, with 2.8 percent in class five and 1.4 percent in class six. The number of households per residential class is presented in Table 2.

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3 Source: Sistema Único de Información (SUI).
Table 2.
Number of households per residential class in 2011

<table>
<thead>
<tr>
<th>Socioeconomic Class</th>
<th>Number of Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,470,927</td>
</tr>
<tr>
<td>2</td>
<td>3,256,428</td>
</tr>
<tr>
<td>3</td>
<td>1,662,351</td>
</tr>
<tr>
<td>4</td>
<td>498,856</td>
</tr>
<tr>
<td>5</td>
<td>235,020</td>
</tr>
<tr>
<td>6</td>
<td>120,235</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8,243,817</strong></td>
</tr>
</tbody>
</table>

From Table 2, it can be concluded that in order to have a self-financing system, 355,255 residential users or 4.2 percent of the total number of households, would have to subsidize 7,389,706 residential customers or 82.7% of the total number of households. That is, each household from classes five and six would have to subsidize 21 households from classes one, two and three. However, if we add contributions from the industrial and commercial sectors, the number of households to be subsidized by each customer in classes five and six is reduced to six (see Table 3).

According to the CREG, electricity demand for classes one, two and three makes 75% of total demand in the market. This implies that the contributions made by consumers in classes five and six are almost negligible when divided by the total number of customers in the subsidized classes. Table 3 presents contributions and subsidies from 2003 to 2011.
From Table 3, the average yearly deficit from 2003 to 2011 was US$121 million; on average, the government paid 33% of the total subsidies allocated throughout this nine year period. This means that for the policy to be self-financing, contributions made by the upper socioeconomic classes and the industrial and commercial customers will have to rise significantly. Alternatively, the increasing block pricing tariff structure for customers in classes one, two and three could be modified either by lowering the basic consumption being subsidized or by decreasing the percentage of the total electricity bill that can be subsidized. It can also be
observed in table 3 that contributions from the commercial and industrial sectors make almost 88% of total contributions.

According to the results obtained by Melendez (2008), lowering the subsidized threshold defined by the block pricing policy would excessively hurt consumers in the lowest socioeconomic class and would hardly result in enough revenues for the system to be self-financing. From table 3 it can be inferred that in order to avoid the use of government resources, contributions from the residential sector would have to be at least five times greater. This means that households from classes five and six would have to pay at least two times the market value for the electricity they consume, a potentially difficult strategy to implement⁴.

From these results, it seems very challenging to change the tariff structure of the market in order to avoid the use of government resources without excessively affecting the welfare of consumers. The improvement of the targeting system appears to be the most promising mechanism for decreasing the fiscal cost of the Colombian subsidization scheme. This gives more relevance to the findings of this study because if the study finds evidence of high inclusion errors, the classification scheme could be a major area for policy improvement. This improvement can mean better targeted households leading to potential reductions in the use of government resources and higher transfers for those with lower incomes.

⁴ It is worth noting that the increase in the contribution that customers from classes five and six would have to make is related to how responsive they are to electricity prices. i.e. the lower the price elasticity of this customers, the higher the contribution they would have to make.
4. Microeconomic Model

The implementation of increasing block pricing (IBP) in the electricity’s retail market results in a tariff structure where average and marginal prices differ from each other due to the introduction of intra-marginal prices. This result in a piece-wise budget constrain that rotates around the kink as marginal price increases (see figure 1).

The fact that marginal and average prices are not equal to each other makes it more difficult to specify the price variable. In the case where all levels of electricity consumption are uniformly priced, the price variable can be defined as total electricity revenue divided by total electricity consumption; this gives the average price that in that case would be the same as marginal price. However, under IBP, such an approach would not account for variations in the intra-marginal and/or marginal prices of electricity, resulting in excessive estimates of the price elasticity of demand (Billings and Agthe 1980). Similarly, the use of marginal price as the only price variable ignores any variation in the intra-marginal price, producing wrong estimates of the price elasticity of demand.

To solve this problem, Nordin (1976) proposed including the product of the difference between the marginal and intra-marginal prices and consumption in the first block as the variable that accounts for the changes in the intra-marginal prices. In the case of IBP this variable represents the implicit transfer that consumers receive for the units consumed in the intra-marginal block. However, mixed results have been obtained by including the difference variable, this is mostly because of its size when compared with the magnitude of total income and consumers’ lack of information on rate structures and billing procedures (Nieswiadomy 1989). In this study I will use marginal price, intra-marginal price and the difference variable as the variables for the specification of the electricity’s demand function.
The IBP structure faced by electricity consumers in the Colombian market is shown in Figure 1. Customers receive a transfer (subsidy) given by the area ABCP, for the first $E$ KWh consumed and pay the marginal price for any additional consumption. Figure 1 also shows the budget constraint, which in this case is formed by two segments representing the reduction in consumer’s purchasing power caused by the increase in the electricity price of unsubsidized consumption. The equilibrium quantity and price for a demand curve D are also shown in the figure.

![Figure 1: Electricity’s Tariff Structure under IBP.](image)

Figure 2 presents the scenario of subsequent increments in the electricity’s marginal price. In this case, as marginal price goes up so does the implicit transfer received by consumers. But when marginal price rises, consumers react by cutting their electricity consumption, making the budget constraint line rotate inwards around the kink as marginal price increases.
Figure 2. Increments on Electricity’s Marginal Price.

Figure 3 shows the case in which intra-marginal prices increases. In this situation, the transfer received by consumers goes down until the point where all consumption is priced uniformly. Under this scenario, as the subsidy goes down, electricity consumption also goes down, to the point where the budget constraint is completely linear.

The figures describing the different scenarios demonstrate that under IBP, consumers’ budget constraints are strictly convex. And consumption levels can be described by the unique point of tangency between the indifference map and the convex budget set. This means that the observed consumption levels are strictly preferred to all other feasible points of consumption and consequently the utility maximization problem has a unique solution (Hausman 1986).
The households’ utility maximization problem can be divided into two parts. The first is continuous choice problem in which consumers maximize their utility according to the selected block or budget subset to which they limit their consumption. The second is a discrete choice problem in which consumers select their consumption set \( k \), which is the same as the consumption block, and in the case of a two-step IBP tariff structure, takes values 1 or 2, setting the price to be pay and the subsidized threshold. The solution to this problem is a bundle \( x \in k \) that tells us where consumers position their consumption.

The increasing two blocks tariff structure that households faced in the Colombian electricity market can be written as:

\[
C(x_{kn}) = \sum_{k=1}^{K} (MP_{kn} \cdot x_{kn}) + FC \quad [1]
\]

Where \( C(x_{kn}) \) is household’s \( n \) cost function, \( x_{kn} \) is household’s \( n \) electricity consumption in block \( k \), \( MP_{kn} \) is household \( n \) marginal price for block \( k \) and \( FC \) is fixed electricity charge.
Assuming a single price for all consumption levels of other goods, the piece-wise linear budget constraint resulting from the IBP structure can be written as:

\[ C(x_{kn}) + \sum_{j=2}^{J} P_j x_{jn} \leq I_n \quad [2] \]

Where \( I_n \) is household \( n \) income, \( P_j \) is the price of all other goods, and \( x_{jn} \) is household \( n \) consumption of good \( j \).

Then, the continuous utility maximization problem can be defined as:

\[ \text{max} \ U_{kn}(x_{kn}; \varphi) \quad \text{s. t.} \quad x_{kn} \leq k \quad [3] \]

Where \( U_{kn} \) is the \( n \)th household’s expected utility resulting from choosing block \( k \) and \( \varphi \) represents the unknown parameters of the utility function.

The solution to this maximization problem is a set of conditional demand functions of the form:

\[ x^*_n(MP_{kn}, I_n, FC, \varphi), n = 1, \ldots, m \quad [4] \]

Thus, the conditional indirect utility function can be written as:

\[ V^*_{kn}(MP_{kn}, I_n, FC, \varphi) \equiv \]

\[ \equiv U_{kn}[x^*_1(MP_{kn}, I_n, FC, \varphi), x^*_2(MP_{kn}, I_n, FC, \varphi), \ldots, x^*_K(MP_{kn}, I_n, FC, \varphi); \varphi] \quad [5] \]
And the discrete choice problem can be defined as:

\[ \sup \{ V_{1n}^*(MP_{kn}, I_n, FC, \varphi), V_{2n}^*(MP_{kn}, I_n, FC, \varphi), \ldots, V_{Kn}^*(MP_{kn}, I_n, FC, \varphi) \} \]  [6]

The solution to this problem is a vector of discrete choice indices given by:

\[ \delta_{kn} = \begin{cases} 1 & \text{if } V_{kn}^*(\cdot) \geq V_{jn}^*(\cdot) \forall j = 1, \ldots, K \\ 0 & \text{otherwise} \end{cases} \]  [7]

Since the budget set is strictly convex, the discrete choice problem has a unique solution.

The conditional demand functions are related to the unconditional demand function by the expression:

\[ x_{kn}(MP_{kn}, I_n, FC, \varphi) = \sum_{k=1}^{K} \delta_{kn}(\cdot) x_{kn}^*(\cdot) \]  [8]

Since the aim of this project is the computation of the probabilities of households consuming in the unsubsidized block, I am only interested in solving the discrete choice problem. Solving the continuous problem would produce the electricity demand functions whose calculation is out of the reach of this project.

In the sections to follow, I will estimate the errors in the classification process (inclusion and exclusion errors), carrying out a non-parametric analysis using the data on household level income and household class reported in the National Quality of Life Survey. This analysis will produce evidence of the presence or absence of error in the household classification process at
the national level. Subsequently, and in order to obtain stronger evidence of the presence or absence of classification errors, I will use data on household level electricity consumption and electricity prices to perform a parametric analysis in order to estimate the probability that household in the first three socio-economic classes exceed the electricity’s subsidized consumption. Conditional on the subsidies’ income effect, and assuming that the subsidy threshold is high enough to cover basic electricity consumption, these probabilities constitute an indicator of high income households being classified as low income ones, a targeting error known as inclusion error.

This methodology is based on the assumption that wealthier households consume more electricity than poorer ones (i.e. electricity is assumed to be a normal good). Thus, if low inclusion errors are present, I would expect the probability of class three households consuming in the unsubsidized block to exceed that of households in class two and the same from class two to class one. If the opposite holds, it would be an indicator of errors in the households’ socioeconomic classification process.

The non-parametric analysis will allow me to quantify the inclusion and exclusion errors in the system, while the parametric analysis will give me stronger evidence of the presence/absence of these errors by producing the conditional probabilities of households positioning their consumption in the unsubsidized part of the tariff structure.
5. Data

Monthly electricity consumption data for each household in the city of Manizales, Colombia, for 2011 was obtained from the *Superintendencia de Servicios Públicos*\(^5\), which is the institution in charge of the regulation of public utilities. Additionally, I gathered data on monthly electricity retail price for each of the six household classes for 2011, from the *Sistema Único de Información* (SUI), which maintains aggregated data related to the Colombian electricity and other utility services. Descriptive statistics for the dataset are provided in Table 4.

### Table 4
Descriptive statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
<th>Mean</th>
<th>Std. Dev</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(MP_{1n})</td>
<td>Marginal Price Block 1</td>
<td>USD$/kWh</td>
<td>0.189</td>
<td>0.013</td>
<td>0.177</td>
<td>0.246</td>
</tr>
<tr>
<td>(MP_{2n})</td>
<td>Marginal Price Block 2</td>
<td>USD$/kWh</td>
<td>0.204</td>
<td>0.008</td>
<td>0.199</td>
<td>0.246</td>
</tr>
<tr>
<td><em>Con1</em></td>
<td>Consumption Class 1</td>
<td>kWh</td>
<td>91.76</td>
<td>71.78</td>
<td>1</td>
<td>1860</td>
</tr>
<tr>
<td><em>Con2</em></td>
<td>Consumption Class 2</td>
<td>kWh</td>
<td>105.57</td>
<td>84.40</td>
<td>1</td>
<td>5809</td>
</tr>
<tr>
<td><em>Con3</em></td>
<td>Consumption Class 3</td>
<td>kWh</td>
<td>125.33</td>
<td>91.52</td>
<td>1</td>
<td>4635</td>
</tr>
<tr>
<td><em>Con4</em></td>
<td>Consumption Class 4</td>
<td>kWh</td>
<td>138.05</td>
<td>122.92</td>
<td>1</td>
<td>4224</td>
</tr>
<tr>
<td><em>Con5</em></td>
<td>Consumption Class 5</td>
<td>kWh</td>
<td>147.03</td>
<td>156.52</td>
<td>1</td>
<td>4020</td>
</tr>
<tr>
<td><em>Con6</em></td>
<td>Consumption Class 6</td>
<td>kWh</td>
<td>162.24</td>
<td>146.75</td>
<td>1</td>
<td>6019</td>
</tr>
</tbody>
</table>

\(^5\) The data comprise household level consumption of 360,000 customers served by a single utility, *Hidroeléctrica de Caldas*. 
The marginal prices of block 1 ($MP_{1n}$) faced by consumers in classes one, two and three are computed as the difference between marginal price of block 2 ($MP_{2n}$) and the division of total subsidy per class per month and total subsidized consumption per class per month (see equation 9).

$$MP_{1n} = MP_{2n} - \frac{Monthly\ Subsidy}{Monthly\ Subsidized\ Consumption} \quad [9]$$

The electricity marginal price of block 2 for classes one through three is equal to the marginal price paid by class four, while the marginal price for classes five and six equals the marginal price for class four plus a 20% tax. Finally, electricity consumption by class is also included.

Average national income by class was obtained from the *Colombian National Department of Statistics* (DANE). The most recent available data on households’ income, access to public services and other relevant variables was collected in 2011, when information from a national sample of 23,140 households was gathered via a door-to-door survey known as the *National Quality of Life Survey*.

Average electricity consumption below and above the subsidy threshold and average block prices are presented in Table 5.

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6 The information collected by the *National Quality of Life Survey* is publicly available and can be consulted at: www.dane.gov.co.
<table>
<thead>
<tr>
<th>Class</th>
<th>$x_n \leq 200$</th>
<th>$x_n &gt; 200$</th>
<th>$MP_{1n}$ [USD$]$</th>
<th>$MP_{2n}$ [USD$]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>79.12</td>
<td>275.04</td>
<td>0.179</td>
<td>0.203</td>
</tr>
<tr>
<td>2</td>
<td>87.93</td>
<td>285.46</td>
<td>0.184</td>
<td>0.203</td>
</tr>
<tr>
<td>3</td>
<td>101.28</td>
<td>286.67</td>
<td>0.193</td>
<td>0.203</td>
</tr>
<tr>
<td>4</td>
<td>104.25</td>
<td>309.25</td>
<td>0.203</td>
<td>0.203</td>
</tr>
<tr>
<td>5</td>
<td>99.28</td>
<td>350.40</td>
<td>0.243</td>
<td>0.243</td>
</tr>
<tr>
<td>6</td>
<td>105.96</td>
<td>322.90</td>
<td>0.243</td>
<td>0.243</td>
</tr>
</tbody>
</table>
6. Non-Parametric Analysis

A non-parametric analysis can be carried out using the aggregate income data from the *National Quality of Life Survey* and the household level consumption data from the *SUI*. With this information, average electricity bills can be computed as:

\[
\text{Ave. Electricity Bill} = \text{Consumption}_{b1} \cdot \text{IMP} + \text{Consumption}_{b2} \cdot MP \quad [9]
\]

Table 6 presents the computed average electricity bills and the percentage of monthly average income that households in different classes spend on electricity.

<table>
<thead>
<tr>
<th>Class</th>
<th>Electricity Bill [USD$]</th>
<th>%Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16.60</td>
<td>10.0%</td>
</tr>
<tr>
<td>2</td>
<td>19.57</td>
<td>7.5%</td>
</tr>
<tr>
<td>3</td>
<td>24.27</td>
<td>5.0%</td>
</tr>
<tr>
<td>4</td>
<td>27.98</td>
<td>3.2%</td>
</tr>
<tr>
<td>5</td>
<td>35.74</td>
<td>2.6%</td>
</tr>
<tr>
<td>6</td>
<td>39.44</td>
<td>3.6%</td>
</tr>
</tbody>
</table>

As it was expected, the average electricity bill increases as class increases. The increase in electricity bills with class can be explained by recognizing that generally households with higher incomes consume more than poorer households i.e. electricity has the characteristics of a normal good (see Agthe and Billings 1987).
An additional conclusion that can be made from Table 6 is that class one households are spending on average 10% of their total monthly income paying for their electricity bill. This value is similar to the one obtained by Melendez (2008), and exceeds the limit of 9 percent defined by Foster (2005) for developing nations, suggesting that poorer households might have not been receiving enough subsidies to pay for the service.

On the other hand, class three households are spending on average 5.0 percent of their income on electricity, meaning that they might be receiving more subsidies than they need. If subsidies were not given to consumers from class three, they would spend on average 5.2 percent of their income on electricity, still lower than the 9 percent limit defined by Foster. Even though this may look like a failure of the subsidization policy, it is not because the policy was not designed on the premise that households would only spend certain among of their monthly income on electricity. Instead, it was designed with the purpose of subsidizing up to 50%, 40% and 15% of the electricity bill for households in classes one, two and three respectively. As a consequence, since higher income households consume more electricity than lower income ones, the individual subsidies for households in class three can exceed those for households in classes one and two. To see if this was the case, I used the data on monthly subsidies per class and number of household per class, to compute monthly subsidies per household per class. This information is presented in Table 7.
From Table 7, it can be concluded that the amount of the monthly subsidy received by households in classes one and two is bigger than that received by households in class three. So in this sense, the policy is being effective at giving more subsidies to customers in the lower classes.

It can also be observed in Table 7 that as at the national level, total subsidies in the city are exceeding total contributions from residential customers by more than six times. Consequently, contributions from the commercial and industrial sectors and taxes collected for other purposes have been used to finance the policy.

Now let’s use the income data to examine whether the municipalities’ classification method has been effective at classifying poorer households as part of the first three classes and richer households as part of the upper two classes. In order to carry out this analysis, I divided monthly income in five quintiles, and located each household in its corresponding quintile and assigned class. The result is presented in Table 8.
Municipalities can make two types of errors when classifying households as a part of one of the six socioeconomic classes. The first one is classifying a high income household as part of the three lower socio-economic classes; this error is known as inclusion error and results in the subsidization of electricity consumption of high income households. The second error is classifying a low income household as part of the three higher classes; this error is known as exclusion error and results in poor households not only no receiving their subsidies, but also paying a tax on top of the marginal price, spending a high share of their income on electricity bills.

An index of inclusion errors can be defined as:

\[
Inclusion\ error_{Ci} = \frac{\sum_{u=3}^{5} Q_{iu}}{\sum_{u=1}^{5} Q_{iu}} \text{ for } Ci = C1, C2 \text{ and } C3 \ [10]
\]
Where $Q_{iu}$ is the number of households in class $i$ and quintile $u$. Note that the inclusion error only makes sense for households classified as part of the first three classes. Using a similar expression, an index of exclusion errors can be defined as:

$$Exclusion \ error_{ci} = \frac{\sum_{u=1}^{2} Q_{iu}}{\sum_{u=1}^{5} Q_{iu}} \text{ for } C_i = C4, C5 \text{ and } C6 \quad [11]$$

Note that the exclusion error index is defined only for households classified as part of the three upper classes. The obtained inclusion and exclusion error index are presented in Table 9.

**Table 9**  
Inclusion and exclusion errors per class

<table>
<thead>
<tr>
<th>Households Class</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inclusion Errors</strong></td>
<td>0.50</td>
<td>0.61</td>
<td>0.76</td>
<td>0.28</td>
<td>0.19</td>
<td>0.26</td>
</tr>
<tr>
<td><strong>Exclusion Errors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

According to the obtained inclusion errors, 50 percent of households classified as part of class one actually belong to upper income classes. This value is extremely high and basically means that the method being used by municipalities is not working and subsidies are being granted to households that do not need them. Higher inclusion errors are found for classes two and three. This problem results in reductions on the amount of individual subsidies given to households with incomes in the lower two quintiles and undermines the policy objective of wealth redistribution.
On the other hand, the obtained exclusion errors suggest that on average, 25 percent of the households classified as part of classes four, five and six, belong to low income classes and should be receiving subsidies but instead, they are paying a tax for the electricity they consume. Since this analysis was carried out using average national income per class, the obtained results are just a first approximation and can be far from the real values of inclusion and exclusion errors. In order to obtain stronger evidence of the presence of inclusion errors, the conditional probabilities that households in the subsidized classes position their consumption in the unsubsidized block are compute in the following section.

7. Parametric Analysis

7.1. Econometric Model

Assuming that $V_{kn}$ is linear in its parameters, the indirect utility function of household $n$ positioning its electricity consumption on block two (unsubsidized block) is given by:

$$V_{2n} = \beta_0 + \beta_1 \cdot MP_{1n} + \beta_2 \cdot MP_{2n} + \sum_{j=3}^{6} (\beta_j \cdot C_n) + \epsilon_n \quad [13]$$

Where $C_n$ is household class (taking class four as the reference class) and $\epsilon_n$ is household’s $n$ disturbance term. The disturbance term accounts for all relevant variables that may be left out of the model or are measured inaccurately.

The expression on [10] can be rewritten as:

$$V_{2n} = Z_{2n} + \epsilon_n \quad [15]$$

Where, $Z_{2n} = \beta_0 + \beta_1 \cdot MP_{1n} + \beta_2 \cdot MP_{2n} + \sum_{j=3}^{6} (\beta_j \cdot C_n)$
Hence, the probability of household \( n \) positioning its consumption on block two is given by:

\[
\Pr(x_n > 200\text{kWh}) = \Pr(U_{2n} > U_{1n}) \quad [16]
\]

Or

\[
\Pr(x_n > 200\text{kWh}) = \Pr(V_{2n} + \varepsilon_{2n} > V_{1n} + \varepsilon_{1n}) = \Pr(\varepsilon_{1n} - \varepsilon_{2n} < V_{2n} - V_{1n}) \quad [17]
\]

Alternatively the expression on [17] can be rewritten as:

\[
\Pr(x_n > 200\text{kWh}) = \Pr(Z_{kn} + \varepsilon_n > 200\text{kWh}) = \Pr(\varepsilon_n < 200\text{kWh} - Z_{kn}) \quad [18]
\]

Thus, the likelihood function for the sample is given by:

\[
L = [\Pr(x_n \leq 200\text{kWh})]^{\delta_{kn}} \cdot [\Pr(x_n > 200\text{kWh})]^{1-\delta_{kn}} \quad [19]
\]

Or

\[
L = [\Pr(\varepsilon_n \leq 200\text{kWh} - Z_{kn})]^{\delta_{kn}} \cdot [\Pr(\varepsilon_n > 200\text{kWh} - Z_{kn})]^{1-\delta_{kn}} \quad [20]
\]

And under a binomial Logit model, the probabilities become:

\[
\Pr(x_n \leq 200\text{kWh}) = \Lambda(200\text{kWh} - Z_{kn}) = \frac{1}{1 + \exp(Z_{kn} - 200\text{kWh})} \quad [21]
\]

And

\[
\Pr(V_{kn} = 1) = 1 - \Lambda(200\text{kWh} - Z_{kn}) = 1 - \frac{1}{1 + \exp(Z_{kn} - 200\text{kWh})} \quad [22]
\]
Then, the likelihood function can be specified as:

\[ L = [\Lambda(200\text{kWh} - Z_{kn})]^\delta_{kn} \cdot [1 - \Lambda(200\text{kWh} - Z_{kn})]^{1 - \delta_{kn}} \quad [23] \]

Or

\[ L = [1/(1 + \exp(Z_{kn} - 200\text{kWh}))]^\delta_{kn} \cdot [1 - 1/(1 + \exp(Z_{kn} - 200\text{kWh}))]^{1 - \delta_{kn}} \quad [24] \]

The parameters of the model can be estimated by maximizing the above likelihood function. Once the parameters are estimated, the probabilities of households exceeding the subsidize consumption can be computed using the derived formulas.

7.2. Estimation and Results

Before computing the probabilities that households in the first three classes position their consumption in the unsubsidized block, it is useful to obtain measures of their responsiveness to changes in electricity prices and subsidy amount. Under an increasing block pricing tariff structure, the average price paid by households is positively related to electricity consumption. And due to this relationship, it is necessary to include a price equation in the model in order to identify the demand relationship (see Wilder 1975). In order to do this, I will use a log-log two step least square model (2SLS) with monthly precipitation (pp) as the instrument for price. Since I am using a log-log model, the obtained coefficients will be equal to the elasticities of demand of each of the explanatory variables. The model to estimate can be written as:

\[ \text{Approximately 70}\% \text{ of the electricity generated in Colombia comes from hydroelectric plants hence; precipitation levels constitute a good instrument for electricity prices.} \]
\begin{align*}
\ln Price_n &= \alpha_0 + \alpha_1 \cdot \ln Q_n + \alpha_2 \cdot \ln pp + \nu \quad [26] \\
\ln Q_n &= \beta_0 + \beta_1 \cdot \ln Price_n + \beta_2 \cdot \ln dif_n + \epsilon \quad [25]
\end{align*}

Where \( \text{dif} \) is the difference between marginal and intra-marginal prices multiplied by subsidized quantity. The subsidized quantity is equal to total household consumption within the subsidized block.

The subsidy elasticity will give us an idea of the virtual transfer’s income effect. If the subsidies given to households in the lower categories have a higher income effect in lower classes, I expect the subsidy elasticity to be bigger for lower classes. If I find the opposite trend, that would mean that subsidies are having a smaller effect on households belonging to lower categories. The obtained estimates are presented in Table 9.

**Table 10**

<table>
<thead>
<tr>
<th></th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ln(Price)</td>
<td>-0.91368***</td>
<td>-0.95136***</td>
<td>-5.7287***</td>
</tr>
<tr>
<td></td>
<td>(0.03644)</td>
<td>(0.02781)</td>
<td>(0.7341)</td>
</tr>
<tr>
<td>Ln(dif)</td>
<td>1.0306***</td>
<td>1.0420***</td>
<td>1.1001***</td>
</tr>
<tr>
<td></td>
<td>(0.0004)</td>
<td>(0.0003)</td>
<td>(0.0007)</td>
</tr>
</tbody>
</table>

Note: Coefficients reported; standard errors in parentheses. Significance levels: *10% **5% ***1%

The obtained estimates are of the expected sign. The price elasticity of demand goes up as we move from class one to class three, meaning that class three customers should be more responsive to changes in electricity prices than class two and class one customers. Three possible mechanisms may be motivating this result. The income effect of the subsidy might be bigger for
the lower classes, so they have a higher incentive to consume unsubsidized electricity. Alternatively, the higher income households might have more flexibility in adjusting their consumption because they have more non-essential and/or luxury appliances; customers with these appliances can choose whether to use them or not according to the price of electricity. Finally, misclassification of households might have resulted in high income households being classified as a part of the lower classes, resulting in households in lower classes being more inelastic to changes in marginal price, and consequently having a higher likelihood of consuming unsubsidized electricity.

The subsidy elasticity is slightly higher for customers in higher classes. This indicates that by a small difference, customers in class three value subsidies more than customers in classes one and two. Thus, according to this result, the income effect of subsidies is not considerably affecting households’ consumption levels.

Having found evidence of the subsidy income effect on each class, I used the Logit model developed in equation [13] to estimate the probabilities that households in the different classes position their consumption in the unsubsidized block. The obtained estimates are presented in Table 11.

As it can be observed in this table, electricity prices have a really small marginal effect on the binary variable for electricity consumption. This means that at the margin, changes in marginal and/or intra-marginal electricity prices will have no effect on households’ consumption. On the other hand, households in classes one, two and three have a probability of exceeding the subsidized quantity of 17.48%, 12.17% and 7.78% respectively with respect to class four. This result suggests the presence of inclusion errors. If not inclusion errors were present, the probabilities of consuming in the second block would be expected to increase as we go from
lower to higher classes. For households in classes five and six, the obtained estimates indicate that on average, consumers in these classes are using less electricity than consumers in class four.

**Table 11**
Binomial Logit model marginal effects

\[ y = \Pr(\text{Consumption}) \ (\text{predict})=0.1033 \]

<table>
<thead>
<tr>
<th>Marginal Effects</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MP₁</td>
<td>0.0048***</td>
</tr>
<tr>
<td>(0.0006)</td>
<td></td>
</tr>
<tr>
<td>MP₂</td>
<td>-0.0039***</td>
</tr>
<tr>
<td>(0.0006)</td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
<td>0.1748***</td>
</tr>
<tr>
<td>(0.0522)</td>
<td></td>
</tr>
<tr>
<td>Class 2</td>
<td>0.1271***</td>
</tr>
<tr>
<td>(0.0282)</td>
<td></td>
</tr>
<tr>
<td>Class 3</td>
<td>0.0778***</td>
</tr>
<tr>
<td>(0.0153)</td>
<td></td>
</tr>
<tr>
<td>Class 5</td>
<td>-0.0470***</td>
</tr>
<tr>
<td>(0.0035)</td>
<td></td>
</tr>
<tr>
<td>Class 6</td>
<td>-0.0210***</td>
</tr>
<tr>
<td>(0.0049)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Marginal effects reported; standard errors in parentheses. Significance levels: *10% **5% ***1%

The fact that inclusion errors are taking place means that some households with incomes belonging to the higher quintiles of the income distribution have been mistakenly labeled as a part of the subsidized classes. This problem could have been originated by the lack of a means-tested procedure that would allow municipalities to better identify poor households or, could be a result of the municipalities’ reliance on neighborhood and households’ observable characteristics for the classification of households.
The lower intra-marginal prices perceive by consumers in lower classes may also be influencing the probabilities of households positioning their consumption in the higher block. However, the obtained subsidy elasticities suggest that inclusion errors and not subsidy levels are motivating higher probabilities of consuming in the unsubsidized block in lower classes.
8. Conclusions

In this study, the effectiveness of the Colombian electricity’s subsidization policy on targeting the poor was evaluated. Using a discrete choice model and disaggregated electricity’s consumption data for the city of Manizales, Colombia, evidence regarding the presence of inclusion errors was obtained.

Using aggregated national income per class and number of customers per class for the city of Manizales, I obtained inclusion errors of 50% for households classified as a part of class one, 61% for households in class two and 76% for households in class three. These inclusion errors are extremely high and suggest that the municipalities’ targeting method is poorly classifying households into socioeconomic classes. As a result, subsidies might have been granted to customers that do not need them.

In order to obtain stronger evidence of the presence of inclusion errors, I computed the probabilities that households in the subsidized classes position their consumption in the unsubsidized block. I obtained probabilities of 17.48% for households labeled as part of class one, 12.71% for households in class two and 7.78% for households in class three. Since for normal goods, high income households normally have higher levels of consumption than low income ones, this result provides additional evidence of the presence of high inclusion errors.

The findings of this study are in line with those obtained by Gomez-Lobo (2003) and Melendez (2008). The first policy implication of these findings is that although geographically targeted subsidies are easier to implement than means-tested targeting schemes, their adoption results in the subsidization of almost every household in the region where they are implemented. Thus, the Colombian electricity subsidization policy should use a means-tested targeting scheme.
Additionally, according to the obtained evidence, subsidies should only be given to households classified as part of classes one and two.

Household level income data is necessary to perform a more accurate evaluation of targeting effectiveness of the subsidization policy. The obtained results might have been produced by the absence of household level income data on the econometric model or by under-reported income by the households that participated in the National Quality of Life Survey.
References


Meléndez, Subsidios al consumo de los servicios públicos: reflexiones a partir del caso colombiano, Perspectivas, Vol. 6, No 1, Junio 2008.


