

# Welfare implications of a tax on electricity consumption for Colombian households: why not to progressively discriminate the market?

Alejandro López-Vera<sup>1</sup>  
**Advisor:** Andrés Ramírez-Hassan<sup>2</sup>

<sup>1</sup> *Escuela de economía y finanzas, Universidad EAFIT, Medellín, Colombia. E-mail: calopezv@eafit.edu.co*

<sup>2</sup> *Escuela de economía y finanzas, Universidad EAFIT, Medellín, Colombia. E-mail: aramir21@eafit.edu.co*

Reception date of the manuscript: dd/02/2020

---

**Abstract**— This paper analyses the Colombian household utilities demand using the exact affine Stone index demand system to estimate the price and expenditure elasticities. We use this framework to analyze the welfare implications of a new tax on electricity demand of households in strata 4, 5 and 6 implemented to safe from drastic electricity disruptions the northwestern Colombian region. So, we propose a new progressive tax rule that minimizes welfare losses while maintaining the target of average tax revenues.

**Keywords**— Household utility demand, EASI Model, electricity taxes, welfare analysis.

**JEL**—D12, D60, Q41

---

**Resumen**— Este documento analiza la demanda de servicios públicos de los hogares colombianos utilizando el sistema de demanda exact affine Stone index para estimar las elasticidades precio y gasto. Utilizamos este marco para analizar las implicaciones de bienestar de un nuevo impuesto sobre la demanda de electricidad de los hogares en los estratos 4, 5 y 6 implementado para evitar drásticas interrupciones de la electricidad en la región noroeste de Colombia. Finalmente, proponemos un esquema progresivo alternativo de impuestos tal que se minimicen las pérdidas de bienestar manteniendo el objetivo de ingresos fiscales requeridos.

**Palabras clave**— Análisis de bienestar, Demanda de servicios públicos domiciliarios, Modelo EASI, Impuestos a la electricidad.

**JEL**—D12, D60, Q41

---

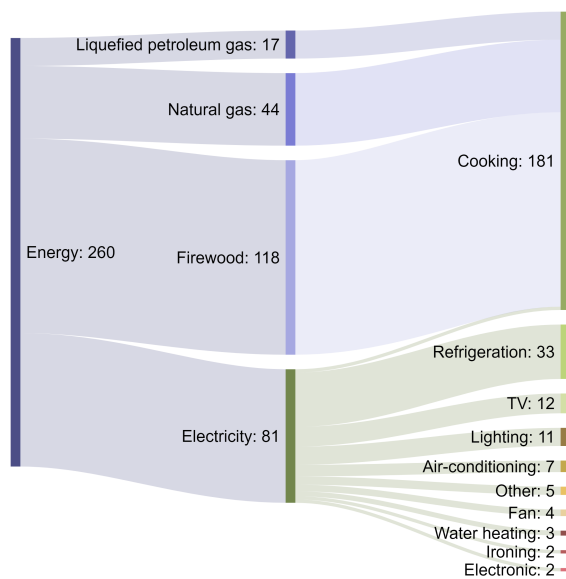
# 1. INTRODUCTION

Access to energy services is considered a prerequisite for human and economic development in modern society (Modi et al., 2006). Energy supply is an essential factor in people’s quality of life after water and air. In general, energy is necessary for the provision of services by the State, for use in production for the different economic sectors (Martínez, 2009), and domestic activities in households, making it a direct source of welfare for them (Medina and Morales, 2007; Ramírez and Londoño, 2008).

In Colombia, final energy consumption increased by 47% between 1990 to 2018, wherein this last year the residential sector had a 20% share with an energy demand of 260 Petajoules (UPME, 2019). Figure 1 characterizes the most used energies in the residential sector and its use, it is noted that the use of electricity is more diversified than other sources. In general, households use electricity for refrigeration, lighting, and television.

The demand for electricity has been growing in Colombia, according to XM, the administrator of the Colombian wholesale energy market, it is expected that for the period 2019 to 2033, the National Interconnected System (SIN) demand will grow 2.29% annually on average.

FIG. 1: ENERGY USE OF RESIDENTIAL SECTOR IN PETAJOULES



Source: Own Elaboration based on *plan energético nacional 2020-2050* (UPME, 2019)

From the supply side, Colombia’s energy matrix has been transformed. In 2018, the capacity of the SIN was composed of the hydraulic generation with a share of 68%, about 31% to thermal generation (13.3% with natural gas, 7.8% with liquid fuels and 9.5% with coal) and 1% to non-conventional renewable energy sources (NCRE): wind, solar, and biomass. These results reflect price policies oriented to decrease participation of diesel, and coverage policies geared to increase electric energy and gas.

Nowadays, one of the significant challenges is to integrate NCRE sources due to having variable costs close to zero and reducing risks in drought scenarios. Therefore, an institutional and regulatory framework that allows incorpo-

rating distributed energy resources and makes better use of technological advances is fundamental. It is expected that by 2031, NCRE sources will have participation between 13% and 18% of the Colombian electricity generation. For instance, Germany accounted for 36% of gross electricity consumption from renewable sources in 2018. Currently, the Ministry of Mines and Energy is working on the mission statement for energy transformation that includes a road map for these challenges.

Although electricity coverage index has increased by 20% over the past twenty years, reaching 97.02% in 2016, this still represents that nearly 2 million Colombians do not have this service, according to the Ministry of Mines and Energy. This reflects challenges in outreaching and servicing electricity despite the efforts that the government has been making with the *Plan Indicativo de Expansión de Cobertura de Energía Eléctrica* (PIEC).

We can see from Figure 1 that uses such as food refrigeration and lighting are essential for proper nutrition and optimal task performance. To ensure access to service, residential users from strata 1, 2, and 3 obtain a subsidy on the tariff applicable to subsistence consumption. The level of subsistence depends on whether the height of the municipality is above a threshold measured in meters above sea level, due to climatic conditions that affecting electricity consumption. On the other hand, households in strata 5 and 6 make contributions. These asymmetries in payment are reflected in prices (See Figure 2). Regarding expenditure, it seems that the demand factor associated implicitly with income levels (i.e. stratum) implies non-linear Engel curves. This has been recently recognized in demand system literature (Blundell et al., 2007).

To analyze the Colombian household utility demand for strata 4, 5 and 6, we specify a non-linear demand system composed of electricity, gas, water, and sewerage. This approach allows to have estimates of own-price and cross-price elasticities, analyze heterogeneous socio-demographic effects on demand, and make welfare calculations. The latter helps to analyze welfare implications of taxes. In particular, we use the equivalent variation to analyze the impact of an exogenous tax on electricity demand from households in strata 4, 5 and 6 that was proposed in the National Development Plan (PND, 2018) to avoid drastic electricity disruptions in the northwestern Colombian region.

This new tax is a flat tariff per kilowatt overall households. However, the microeconomic theory foundation suggests that welfare losses can be reduced if a progressive tax program on consumption is implemented. Therefore, we propose a new progressive taxation rule minimizing welfare losses but keeping average tax revenues under the baseline scenario (regressive tax rule).

This paper aims to contribute in two fronts: a rigorous analysis of the Colombian utility demand of strata 4, 5 and 6, and a welfare analysis due to a tax on electricity. To achieve these aims, we estimate an exact affine stone index (EASI) demand system proposed by Lewbel and Pendakur (2009). This approach allows us to take into account endogeneity between prices and budget shares, non-linearities in the aggregated price index and generate polynomial Engel curves. Additionally, price matrix with rank greater than two, and error terms that can be interpreted as unobserved preference heterogeneity. These features are not present in conventional

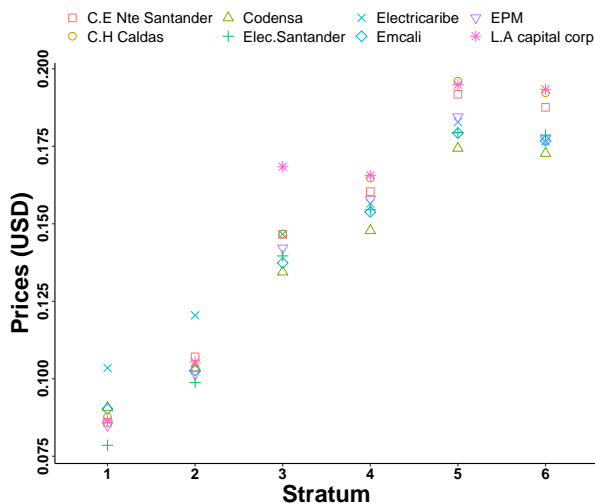
demand systems like the almost ideal demand system (Deaton and Muellbauer, 1980a) and its quadratic version (Blundell and Robin, 1999).

The paper is structured in six sections, including this introduction. Section 2 briefly describes the Colombian electricity market paying attention to the northwestern region. Section 3 presents the literature review. Section 4 shows the theoretical framework emphasizing in the EASI demand system. Section 5 shows estimation results and welfare analysis. Finally, we conclude this paper with a summary of the main findings and some policy recommendations.

## 2. THE COLOMBIAN ELECTRICITY MARKET

Agents in the Colombian energy market are responsible for producing, carrying, and selling energy to the end-user. They are classified into generators, transmitters, distributors, marketers, and one administrator, according to the role they play.

FIG. 2: ENERGY PRICES (KWH) BY COMPANIES



Own Elaboration, Source: Sistema Único de Información (SUI)

The Colombian energy market has both regulated and unregulated segments. The regulated market, is directly contracted and served by distribution companies, encompasses industrial, commercial, and residential users with energy demands of less than 55 MWh-month. In this market, the tariff structure is established by the regulatory agency *Comisión de Regulación de Energía y Gas* (CREG). Figure 2 shows average prices charged by the top ten energy companies to households differentiating by strata for the year 2017, the date on which the household survey used in this paper was completed. It can be seen that there is heterogeneity in the tariff charged to residential users.

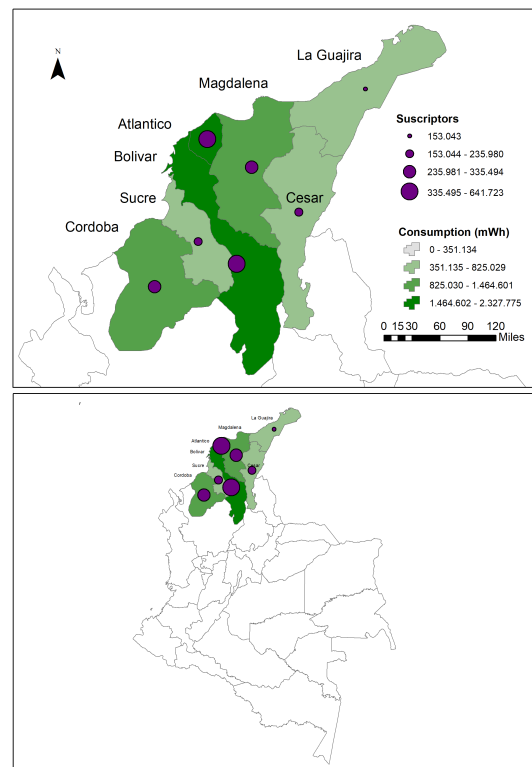
On the other hand, users with high energy consumption participate voluntarily in the Non-Regulated Market. An unregulated user is a consumer with energy demands greater than or equal to 55 MWh-month. Unlike the regulated one, the commercialization and generation price is freely agreed through a negotiation process between consumers and retailers.

In 2019, approximately 100 agents were dedicated to commercial activities of electricity in Colombia. Of these compa-

nies, *Electricaribe* is one of the largest companies providing regulated electricity service to about 2.7 million users on the Caribbean coast (northwestern Colombian region). In 2018 of the total national residential consumption (kWh), *Electricaribe* attended about one third of total users. Also, *Electricaribe* subscribers are mostly from lower strata, 60% from stratum 1, and 24% from stratum 2 (SUI, 2019). The above shows not only the relevance of this company in terms of the amount of demand it covers nationally, but also the type of users it serves. Figure 3 shows the consumption and the number of household users served by *Electricaribe* at a national level in 2019.

Given technical and financial problems that this company has presented, the Government, through the *Superintendencia de Servicios Públicos Domiciliarios* (SSPD), has been taking measures to ensure continuity of service to users. In November 2016 *Electricaribe* was intervened by the SSPD, to mitigate the financial crisis of the company, and the risk of suffering electricity disruptions. In particular, the National Development Plan 2018-2022, “*Pacto por Colombia, pacto por la equidad*”, the Government’s road map for a 4 years period came into effect. Articles 312 - 318 aims to face *Electricaribe* crisis from the following fronts; first, the Government will take care of the *Electricaribe* worker’s pensions. Second, there will be a new tariff regime to ensure efficient electricity service in *Electricaribe*’s market, and finally, Colombian electricity consumers classified in strata 4, 5 and 6, and non-residential will have to pay a tax of COP/kWh \$4 or USD 0,12 ¢/kWh.

FIG. 3: *Electricaribe* MARKET



Own Elaboration, Source: Sistema Único de Información (SUI)

This paper focuses on the latter measure, which came into effect on July 1, 2019. It will be adopted until December 31,

2022, seeking annual revenues of approximately \$160 billion to support financing, obligations, investments, and continuity of service.

### 3. LITERATURE REVIEW

In general, literature dedicated to the analysis of household utility demand is composed of a large amount of papers mainly motivated by topics like changes in fuel prices, efficient use, taxation, substitution between electricity and other energy, and reduction of gas emissions. In particular, residential energy demand has a different salient point according to [Kriström \(2009\)](#); generally quite price-inelastic but a response to income, variations due to non-price related factors such as; demographic factors (life-cycle and ethnic groups), host of exogenous factors, (i.e., temperature) and attitudes such as "feelings of obligation", importance of conservation" have been found to correlate with energy conservation behavior.

The study of energy demand constitutes a vast literature, even when restricting the analysis to the residential sector. Many authors study the residential electricity demand using aggregated data, i.e., [Donatos and Mergos \(1991\)](#); [Lin \(2003\)](#); [Narayan and Smyth \(2008\)](#); [Dergiades and Tsoulfidis \(2008\)](#); [Alberini and Filippini \(2011\)](#). However, studies using macroeconomic data suffer information loss since they cannot account for specific, individual determinants of energy use, this often impedes a more disaggregated analysis. This proposal belongs to the literature studying the micro determinants of energy demand using microeconomic data such that we represent the household's behavior more closely. The following literature review is framed in this context.

For a group of countries, [Lee and Chiu \(2011\)](#) and [Krishnamurthy and Kriström \(2015\)](#) study residential electricity demand in OECD countries. The previous work shows the nonlinear link between electricity consumption, real income, electricity price, and temperature. They show that electricity demand is less sensitive to changes in its price. When real income rises, electricity consumption rapidly increases, and evidence of a U-shaped relationship between electricity consumption and the temperature is supported. The latter paper provides evidence about strong price responsiveness, weak income responsiveness, and presence of non-price related factors, showing the importance of taking into account the heterogeneity of households and non-linearity in energy demand.

Most studies in this field perform the analysis for a specific country and obtain different results according to methodology, covered period, data or motivation. For the United Kingdom, [Baker et al. \(1989\)](#) emphasizes the variation of the elasticities across the types of households, the theoretical budgeting model of the allocation of household expenditures. [Blundell and Robin \(1999\)](#) apply ILLE in two residential demand systems concluding that the distribution of price elasticities of QUAIDS model is more dispersed due to the presence of a quadratic term in expenditure. Meanwhile, [Jones and Lomas \(2015\)](#) focuses on relevant socioeconomic and dwelling characteristics determining high electricity demand. [Labandeira et al. \(2006\)](#) study Spanish residential spending on different goods, including electricity through a QUAIDS model. Among their results, it is worth mentioning that electricity is the most elastic in contrast to the price of

natural gas, recall that electricity is a normal good, and conclude that household composition also affects energy expenditure. [Labandeira et al. \(2012\)](#) calculates the elasticity between households and companies finding a more price inelastic energy demand by households. They show that elasticity diminishes as the level of per-capita income increases. For Germany, [Schulte and Heindl \(2017\)](#) and [Reaños and Wölfling \(2018\)](#), the latter uses the EASI methodology; they discover differences own-price elasticities between the effects of energy price changes on lower-income households compared to richer ones, the first ones suggesting stronger reactivity to price changes.

For other European countries, see [Nesbakken \(2001\)](#) and [Halvorsen and Larsen \(2001\)](#) for Norway. For Asian countries [Shi and Song \(2012\)](#) for China, [Yoo et al. \(2007\)](#) for Korea and [Filippini \(2004\)](#) and [Gundimeda and Köhlin \(2008\)](#) for India. Among papers that study residential electricity demand in the USA stand out [Silk and Joutz \(1997\)](#), who estimate an error correction model. [Lavín et al. \(2011\)](#) and [Woo et al. \(2018\)](#) study residential electricity and gas demand, they highlight that households have inelastic price elasticities of electricity and natural gas demand in the short and long term. In Latinamerica [Chang and Martinez-Chombo \(2003\)](#) for Mexico, [Schmidt and Lima \(2004\)](#); [Uhr et al. \(2019\)](#) for Brazil, [Garcia and Alvarado \(2018\)](#) for Peru and [González et al. \(2012\)](#) for Chile are some other studies. Interesting a Metadata analysis by [Espey and Espey \(2004\)](#) and [Labandeira et al. \(2016\)](#) about different products of energy.

Finally, in Colombia, different works such as [Barrientos et al. \(2012\)](#); [Barrientos and Martínez \(2017\)](#), and [Gil-Vera \(2017\)](#), have focused on forecasting energy demand. Among the papers that have been focused on the calculation of household elasticity are; [Medina and Morales \(2007\)](#) and [Pinzón \(2010\)](#) who methodologically use discrete continuous and block price estimation respectively, show a non-uniform distribution of the price elasticity of electricity in households. [Maddock et al. \(1992\)](#) estimates the demand for electricity in Medellín, finding different elasticities per stratum. [Cano et al. \(2011\)](#) examines Colombian's expenditure in daily need, including electricity consumption, they find that it is a normal good but inelastic to expenses, in line with [Acuña and Forero \(2013\)](#), who claim that energy for domestic use is a necessary commodity.

In general, when faced with changes in the electricity tariff, users reduce their energy consumption ([Zapata, 2011](#)) or the consumption of other goods to guarantee subsistence consumption ([Medina and Morales, 2007](#); [Ramírez and Londoño, 2008](#)), as it is considered an essential utility with a few substitutes ([Mendoza, 2010](#)).

Price and income demand elasticities for electricity of the papers mentioned above are reported in Table 1. About residential water consumption, the article by [Arbués et al. \(2003\)](#) presents a review of the literature on this topic and [Labandeira et al. \(2016\)](#) about natural gas.

Concerning the second topic of interest, welfare analysis, [Chipman and Moore \(1980\)](#) and [Mas-Colell et al. \(1995\)](#) showed that Equivalent Variation (EV) is generally the relevant measure for performing welfare analysis in a context in which different tariff policies are ordered. The EV is the amount of money the consumer receives, leaving it indifferent from accepting the change in price, i.e., the change in

**TABLE 1: LITERATURE REVIEW**

Authors	Country	Methodology	Own-Price Elasticity	Own-Income Elasticity
Baker et al. (1989)	Great Britain 1972-1983	Two-Stage	-0.75	0.13
Donatos & Mergos (1991)	Greece 1961-1986	Ridge Regression	SR: -0.21 LR: -0.58	SR: 0.53 LR: 1.50
Silk & Joutz (1997)	US 1949-1993	Error Correction	LR: -0.5	LR: 0.5
Blundell & Robin (1999)	UK 1974-1993	ILLE - QUAIDS	-0.75	0.13
Nesbakken (2001)	Norway 1971-1990	Discrete-continuous	SR: -0.55	SR: 0.13
Halvorsen & Larsen (2001)	Norway 1975-1994	Discrete-continuous	SR: -0.43 LR: -0.44	0.06 to 0.13
Chan & Martinez (2003)	Mexico 1985-2000	TVC Cointegrated	LR: -0.44	LR: 1.95
Lin (2003)	China 1985-2001	VECM		LR: 0.8
Filippini & Pachauri (2004)	India 1993-1994	Single Equation Approach	-0.29 to -0.51	0.60 to 0.64
Schmidt & Lima (2004)	Brazil 1980-2000	Error Correction	-0.15	1.10
Labandeira et al. (2006)	Spain 1985-1995	QUAIDS	-0.79	0.53 to 1.01
Medina & Morales (2007)	Colombia 2003	Discrete-continuous	-0.48	0,32
Yoo (2007)	Korea 2005	Bivariate/ Univariate	-0.24	0.06
Dergiades & Tsoulfidis (2008)	US 1965-2006	ARDL	LR: -1.06	LR: 0.28
Gundimeda & Köhlin (2008)	India 2008	LA-AIDS	-0.91 to -0.59	0.53 to 0.89
Pinzón (2010)	Colombia 2006-2010	Block Prices	-0.57 to 2.8	
Alberini & Filippini (2011)	US 1995-2007	LSDV - Blundell-Bond	SR: -0.08 to -0.15 LR: -0.45 to -0.75	
Ramírez et al. (2011)	Colombia 1968-2007	AIDS	-0.37	0.96
Lee & Chiu (2011)	24 OECD 1978 - 2004	Panel smooth transition (PST)	-0.23 to -0.06	0.08 to 1.68
Zapata (2011)	Colombia 2003-2010	ARIMA	-0.12	
González et al. (2012)	Chile 2006	Non-linear LS	-0.43 to -0.36	0,11
Labandeira et al. (2012)	Spain 2005-2007	Panel RE	-0.25	
Lavin & Hanemann (2011)	US 1993-1997	Discrete-continuous	-0.72 to -0.28	0.14
Shi et al. (2012)	China 2008-2009	Pooled	-2.47	0.05
Acuña et al. (2013)	Colombia 2000-2011	MCO BVARX	SR: -0,66 LR: -1,96	SR: 0.002 LR: 0.008
Hanemann et al. (2013)	Spain 2006-2008	Discrete-continuous Heckman (1979)	-0.13 to -0.14	0.23 to 0.39
Krishnamurthy & Kriström (2015)	11 OECD		-0.27 to -1.4	0.07 to 0.16
Galves et al. (2016)	Spain 2012	QUAIDS	-0.86	0,10
Schulte & Heindl (2017)	Germany 1993-2008	QUAIDS	-0.43	0.25 to 0.44
Garcia & Alvarado (2018)	Peru 2004-2014	AIDS - QUAIDS	-3.80 to -3.69	0.73
Tovar & Wölfing (2018)	Germany 2002-2012	EASI	-0.51 to -0.32	0.22 to 0.45
Woo (2018)	US 2001-2016	ITSUR	SR: -0.03 LR: -0.09	
Uhr et al. (2019)	Brazil 1998-2013	Quantile Regression	-0.46 to -0.56	0.20 to 0.32

wealth equivalent to the change in price in terms of its impact on welfare.

Previous intends to perform a welfare analysis may be based on simulating a cost-of-living associated with a change of price (i.e., a tax) for a particular good. Banks et al. (1997) for the United Kingdom , Lewbel and Pendakur (2009) for

Canada, and particularly for the change of price electricity, Medina and Morales (2007); Ramírez and Londoño (2008) for Colombia, Hanemann et al. (2013) for Spain, Schulte and Heindl (2017) and Reaños and Wölfing (2018) for Germany and Uhr et al. (2019) for Brazil.

## 4. THEORETICAL FRAMEWORK

The response of consumers to changes in prices of goods is instrumental for any ex-ante assessment of the welfare consequences of taxation. Demand models play an essential role in assessing changes in tax policies. In particular, the analysis of taxes on commodities, such as energy, requires precise specification of both price and revenue effects. In Colombia, for instance, [Medina and Morales \(2007\)](#) show that due to the inelasticity of demand for domestic services such as water and electricity, policies that affect their prices can significantly impact the welfare of the population.

Standard demand models did not provide an accurate adjustment of the behavior observed in all income groups due to analysis with aggregated variables or estimates of demand that take an average tariff for the household, even when the analysis has been done at the micro-level. Different works on consumer spending have found Engel curves that exhibit linear or quadratic behavior, while others are S-shaped ([Blundell et al., 2007](#)).

Typical parametric demand models cannot cover this variety of shapes and are limited by Gorman's type range restrictions. [Gorman \(1981\)](#) proved that for any exactly aggregable demand system with Marshallian form demands that are derived from utility maximization, the maximum possible rank of the matrix is three. Generalizing Gorman, [Lewbel \(1991\)](#) defined the rank of any demand system to be the dimension of the space spanned by its Engel curves. They show that the maximum possible rank of any demand system corresponding to any cost function is the number of goods in the system minus one. Finally, in most empirical demand models, the error term in the models cannot be interpreted as a random utility parameter representing unobserved consumer heterogeneity ([Brown and Walker, 1989](#); [Lewbel, 2001](#)).

EASI claims overcome these two limitations; demands are not constrained to have rank less than three, and the error term allows for an interpretation such as the unobserved heterogeneity of preferences in demand systems. Work with data at the micro-level, allowing the calculation of elasticities to vary according to household characteristics and allows error terms equal random utility parameters to account for unobserved preference heterogeneity. The above becomes vital given that if a consumer has a high unobserved preference parameter for good, he/she will allocate a large part of the budget. So, in the face of a price increase, this agent will be more affected than another, which links the income effect to the unobserved preference heterogeneity.

Following [Fisher et al. \(2001\)](#) demand systems can be classified into; *locally flexible* (i.e. Leontief ([Diewert, 1971](#)), Translog, ([Christensen et al., 1975](#)), Almost Ideal Demand System ([Deaton and Muellbauer, 1980a](#))), *globally regular*; Laurent system, ([Barnett, 1983, 1985](#)) and Quadratic Almost Ideal System, QUAIDS, ([Banks et al., 1997](#)) and *globally flexible* functional forms. These specifications have allowed multiple empirical applications and still forms the backbone of many empirical analyses in different fields. However, there are certain limitations due to non-fulfillment of properties of the economic theory, range restrictions, or inflexibility in some of these models.

Many of the above models use for the specification of the demand system the dual approach, which is an advantage be-

cause it allows the empirical generation of functional forms for Engel curves without the need to assume a specific functional form for the utility function. This procedure consists in minimizing the expenditure needed to reach a certain level of utility. In this way, all the information of the utility function that is relevant for the empirical analysis is contained in the cost function, empirical nesting information with economic theory (see [McFadden, 1978](#); [Diewert, 1971](#), for a formal demonstration). Additionally, It can be shown ([Deaton and Muellbauer, 1980b](#)) that Marshallian and Hicksian demand satisfy integrability properties, the value of the Marshallian and Hicksian demands is the total expenditure, and homogeneity, of zero degrees at prices and income. Hicksian demand presents symmetry properties, which guarantees consistency in consumer choice, and negativity reflected in the Slutsky matrix, which in economic terms means that demand for a good decreases (or at least remains constant) while increases its price. The EASI model follows the idea of the dual approach.

The choice of the demand model entirely determines the specification of income effects. In that sense, the AIDS demand system allows goods to be luxuries or necessities by accommodating Engel curves that are linearly increasing or decreasing. The QUAIDS model goes one step further by also accommodating quadratic relationships, and the EASI model allows higher degree polynomial Engel curves.

### 4.1. The EASI demand system

The EASI model is one of the most significant recent advancements in the toolbox of demand system estimation. It allows any polynomial shape of Engel curves, and the estimated error terms can be interpreted as random utility parameters accounting for unobserved preference heterogeneity. The EASI system can be estimated, based on expenditure and price data alone. No actual quantities are necessary. For more details, please refer to [Lewbel and Pendakur \(2009\)](#) and [Pendakur \(2009\)](#).

The methodology seeks to construct expenditure functions that have simple expressions for utility  $u$  in terms of observable variables,  $\mathbf{w}$ ,  $\mathbf{p}$ ,  $\mathbf{z}$  and  $x$ , budget shares, log prices, socioeconomic variables and log nominal expenditure, respectively. Given the implicit utility,  $y$ , and substituting  $y$  for  $u$  in the Hicksian demands obtains what we call implicit Marshallian demand functions. The expressions for the system are given by Equations (1) and (2).

$$y = u = \frac{x - \mathbf{p}'\mathbf{w} + \sum_{l=0}^L z_l \mathbf{p}'\mathbf{A}_l \mathbf{p}/2}{1 - \mathbf{p}'\mathbf{B}\mathbf{p}/2}. \quad (1)$$

The log nominal total expenditures  $x$  that faces the  $J$ -vector of log prices  $\mathbf{p}$ , assume that chooses a bundle of goods, described by the  $J$ -vector of budget shares  $\mathbf{w}$ , to maximize linear utility budget constrain. Finally,  $\mathbf{z}$  are the characteristics of the household,  $\mathbf{B}$  and  $\mathbf{A}$  are  $J \times J$  symmetric matrices.  $y$  has many of the properties of log real expenditures. It equals a cardinalization of utility  $u$ , it is affine in nominal expenditures  $x$ , and it equals  $x$  in the base period when all prices equal one (which is when log prices  $\mathbf{p}$  equal zero). Also, when  $\mathbf{B}$  is zero,  $y$  exactly equals the log of nominal expenditures deflated by the Stone price index.

So, the construction of the cost function allows us to have the following interpretation, the log cost or expenditure function is  $x = C(\mathbf{p}, u, \mathbf{z}, \varepsilon)$  which equals the minimum log-expenditure required for an individual with characteristics  $\mathbf{z}$ , to attain utility level  $u$  when facing log price  $\mathbf{p}$ . By Shephard's lemma, this cost function has Hicksian (compensated) budget shares:

$$\mathbf{w} = \sum_{r=0}^5 \mathbf{b}_r y^r + \mathbf{Cz} + \mathbf{Dz}y + \sum_{l=0}^L z_l A_l \mathbf{p} + \mathbf{Bp}y + \varepsilon, \quad (2)$$

where  $\mathbf{b}_r$  is the Engel curve terms,  $r=0,1,2,\dots,5$  specify budget shares as fifth-order polynomials in  $y$ . The terms  $\mathbf{C}$  and  $\mathbf{D}$  allow demographic characteristics to enter into budget shares through both intercept and slope terms on  $y$ . So, to make explicit the heterogeneous nature of preferences, observable and unobservable sources, is included an L-vector of observable demographic characteristics that affect preferences  $\mathbf{z}=(z_1, z_2, \dots, z_L)'$  and a J-vector of unobserved preference characteristics satisfying  $1_j' \varepsilon=0$ . Finally, compensated price effects governed by  $A_l$  and  $\mathbf{B}$ .

Lewbel and Pendakur (2009) shows under which conditions both random utility parameters and arbitrarily complicated Engel curves can be estimated. Finally, although  $y$  is endogenous (it depends on  $\mathbf{w}$ ), it can be instrumented (for example, by  $x$  and  $\mathbf{p}$ ). The intuition is that given the unobserved implicit utility  $y$ , the estimation can take the form of instrumental variables, using iterative linear three-stage least squares method (3SLS). The approach to estimating the EASI demand model impose additivity, homogeneity, and symmetry. The resulting EASI demand functions have the following properties:

- EASI budget share demand functions are, apart from the construction of  $y$ , completely linear in parameters, which facilitates estimation in models with many goods.
- EASI budget shares are linear in  $\mathbf{p}$  and are polynomials of any order in  $\mathbf{z}$  and  $y$ . They can also include interaction terms such as  $\mathbf{py}$ ,  $\mathbf{zy}$  and  $\mathbf{pz}$ , and contain other functions of  $\mathbf{z}$  and  $y$ .

Define semielasticities to be derivatives of budget shares  $\mathbf{w}$  with respect to log prices  $\mathbf{p}$ , implicit utility  $y$ , log nominal total expenditures  $x$ , and demographic characteristics (or other observed taste drivers)  $\mathbf{z}$ . The semielasticity of a budget share can be converted into an ordinary elasticity of budget share by dividing by that budget share. We provide semielasticities because they are easier to present algebraically. Hicksian price semielasticities (compensated) are:

$$\nabla_p w(\mathbf{p}, \mathbf{z}, y, \varepsilon) = \sum_{l=0}^L z_l A_l + \mathbf{B}y. \quad (3)$$

Semielasticities with respect to  $y$ , which can vary quite a bit as  $y$  changes, reflecting a high degree of Engel curve flexibility, are:

$$\nabla_y w(\mathbf{p}, \mathbf{z}, y, \varepsilon) = \sum_{r=0}^5 b_r r y^{r-1} + \mathbf{Dz} + \mathbf{Bp}. \quad (4)$$

Demographic semielasticities are given by:

$$\nabla_z w(\mathbf{p}, \mathbf{z}, y, \varepsilon) = \mathbf{c}_l + \mathbf{d}_l y + \mathbf{A}_l \mathbf{p}. \quad (5)$$

Cost functions with  $y$ , given by equation (1), have Marshallian demand functions implicitly given by:

$$\mathbf{w}(\mathbf{p}, x, \mathbf{z}, \varepsilon) = w \left( \mathbf{p}, \frac{x - \mathbf{p}' \mathbf{w} + \sum_{l=0}^L z_l \mathbf{p}' \mathbf{A}_l \mathbf{p} / 2}{1 - \mathbf{p}' \mathbf{B} \mathbf{p} / 2}, \mathbf{z}, \varepsilon \right). \quad (6)$$

Solving for the Marshallian semielasticity with respect to nominal expenditures  $x$  is

$$\nabla_x w(\mathbf{p}, x, \mathbf{z}, \varepsilon) = \left( I_j - \frac{\nabla_y w(\mathbf{p}, \mathbf{z}, y, \varepsilon) \mathbf{p}'}{1 - \mathbf{p}' \mathbf{B} \mathbf{p} / 2} \right)^{-1} \left( \frac{(1-x) \nabla_y w(\mathbf{p}, \mathbf{z}, y, \varepsilon) \mathbf{p}'}{1 - \mathbf{p}' \mathbf{B} \mathbf{p} / 2} \right). \quad (7)$$

Marshallian price elasticities are recovered from Hicksian  $\mathbf{p}$  elasticities (equation (3)) and the above Marshallian  $x$  elasticities using the Slutsky matrix.

$$\nabla_p w(\mathbf{p}, x, \mathbf{z}, \varepsilon) =$$

$$\nabla_p w(\mathbf{p}, \mathbf{z}, u, \varepsilon) - (\nabla_x w(\mathbf{p}, x, \mathbf{z}, \varepsilon)) w(\mathbf{p}, \mathbf{z}, y, \varepsilon). \quad (8)$$

Equations 7 and 8 allow to obtain Marshallian expenditure and price semielasticities. Own price (OPE) and expenditure elasticities (EE) are:

$$OPE_i = \nabla_p w(\mathbf{p}, x, \mathbf{z}, \varepsilon) \frac{1}{w_i} - 1 \quad (9)$$

$$EE_i = \nabla_x w(\mathbf{p}, x, \mathbf{z}, \varepsilon) \frac{1}{w_i} + 1 \quad (10)$$

We now show how to evaluate the effects of changing prices or other variables in EASI models, and we consider evaluating the cost to an individual of a price change. The estimated parameters from the demand system can be used to compute a metric for the maximum amount a consumer would be prepared to pay at the budget level  $x$  to avoid the change from  $\mathbf{p}^0$  to  $\mathbf{p}^1$ , the superscripts 0 and 1 denote prices  $\mathbf{p}$  before and after price change.

$$C(\mathbf{p}^1, u, \mathbf{z}, \varepsilon) - C(\mathbf{p}^0, u, \mathbf{z}, \varepsilon). \quad (11)$$

This measure is called equivalent variation (EV), and following Reaños and Wölfling (2018):

$$EV = x - \exp \left\{ \log(x) - \sum_{i=1}^I (\log(P_i^1 w_i^1) - \log(P_i^0 w_i^0)) + \frac{1}{2} \sum_{i=1}^I \sum_{j=1}^I a_{ij} [\log(P_i^1) \log(P_j^1) - \log(P_i^0) \log(P_j^0)] \right\}, \quad (12)$$

where  $P$  is the utility price in levels (no log).

## 5. ECONOMETRIC RESULTS

### 5.1. Data processing

From the *Encuesta Nacional de Presupuesto de los Hogares* (ENPH) - 2016, carried out by the Colombian national institute of statistics (*DANE*) between July 2016 - June 2017, households in strata 4, 5, and 6 were selected, which are those affected by the tax policy. So, from a total of 87,201 households, a sample of 5,838 is used. Each household was characterized as follows: gender and age of household head, highest level of education attained by any household member, number of people living in the household, and socio-economic score of household (strata from 1 to 6, low-low to high-high). Current expenditure is composed of monetary and non-monetary spending, meanwhile total expenditure by current and capital expenditure. Current and total income, as well as total expenditure on utilities (electricity, water, sewerage and gas) is also taken from this survey.

Equation 13 shows expenditure ( $E_{ismt}^u$ ) on utility  $u$  at household  $i$  in strata  $s$  with providers  $m$  at time  $t$ .

$$E_{ismt}^u = V_{ismt}^u + F_{smt}^u = \sum_{r=1}^R P_{rsmt}^u Q_{rismt}^u + F_{smt}^u, \quad (13)$$

so this expenditure is equal to payment for variable consumption ( $V$ ) plus fixed cost ( $F$ ). The former is equal to price at consumption range  $r$  times consumption in this range.

Electricity consumption does not have fixed cost, that is,  $F_{smt}^u = 0$ , and subsidies on consumption tariff (\$/kWh) depends on consumption ranges, which are given by subsistence consumption and municipality location above sea level (m.a.s.l). However, these details apply to strata 1, 2 and 3, as a consequence, it is not necessary to take them into account in our application. So, tariff depends just on stratum and electricity provider due to being a flat tariff. We use household municipality location to identify the most relevant provider in this area, and use to impute price.

Gas consumption does not have explicitly fixed costs for strata 4, 5 and 6, and there is not particular discrimination associated with m.a.s.l. We used same tariff imputation strategy as electricity. This information is available at *Sistema Único de Información* (SUI, [www.sui.gov.co](http://www.sui.gov.co)) and *Comisión de Regulación de Energía y Gas* (CREG, [www.creg.gov.co](http://www.creg.gov.co)).

On the other hand, water and sewerage have fixed charges which depends on regulated providers and strata. This information is available at *Sistema Único de Información* (SUI). Therefore, we obtain variable expenditure on water and sewerage subtracting fixed charges from total expenditure. We calculate variable utility expenditure shares, which are our dependent variables, as these are directly under household's control.

Water and sewerage average tariff per cubic meter depend also on m.a.s.l and household consumption level (basic, complementary and luxury). Resolution [Comisión de Regulación de Agua, CRA 750 de 2016](#) defines consumption ranges to classify consumption as basic, complementary and luxury depending on m.a.s.l. The first range is for municipalities with an average altitude below 1,000 m.a.s.l., the second for municipalities with an average altitude between 1,000 and 2,000 m.a.s.l., and finally the last range for municipalities with average altitude above 2,000 meters. A municipality in

a lower range can consume more cubic meters ( $m^3$ ) at lower consumption prices; so, prices associated with basic water consumption is up to 16  $m^3$ , 13  $m^3$  and 11  $m^3$  for municipalities in first, second and third m.a.s.l level, respectively. Prices at complementary level is between upper basic ranges and 32 $m^3$ , 26 $m^3$ , and 22 $m^3$ , respectively, and luxury prices apply to additional consumption.

We can deduce average water and sewerage tariff per using variable expenditure on these utilities, municipality location and strata from ENPH survey, consumption ranges from CRA, and provider marginal prices from SUI in conjunction with equation 13. Observe that average prices are weighted averages of marginal prices.

Due to households were surveyed in different months between 2016 and 2017, prices are expressed at June 2017 values. Then, all prices, expenditures, and fixed charges are expressed in dollars, as shown in Table 2 at the exchange rate of June 30, 2017, the month in which the survey ended.

### 5.2. Descriptive statistics

Table 2 shows descriptive statistics of household expenditure shares. We report proportion of zeros in the sample, where water has the lowest figure (3%), while sewerage has the highest (43%). It can be also seen that, on average, electricity share is the greatest (55%, followed by water (27%).<sup>1</sup>

Electricity has an average cost per unit of 0.17 USD/kWh. During the analysis period, Cartagena was the city with the lowest cost of the service 0.13 USD/kWh, while Montería had the highest at 0.27 USD/kWh. Sincelejo the city that has the highest charge per unit in water service, where average tariff is 0.67. Natural gas average price is 0.50, with Yopal and Neiva being the cities that paid a cheaper and higher price per unit of consumption, respectively.

TABLE 2: SUMMARY STATISTICS

Variable	Mean	Std. Dev.	Zero Shares	Min	Max
<b>Shares</b>					
Electricity	0.55	0.21	0.05		
Water	0.27	0.21	0.03		
Sewerage	0.06	0.09	0.43		
Natural Gas	0.11	0.11	0.18		
<b>Prices</b>					
Electricity(USD/kWh)	0.17	0.02		0.13 (Cartagena)	0.27 (Montería)
Water (USD/m <sup>3</sup> )	0.67	0.25		0.16 (Valledupar)	1.46 (Sincelejo)
Sewerage(USD/m <sup>3</sup> )	0.57	0.24		0.16 (Valledupar)	1.31 (Bogotá)
Natural Gas(USD/m <sup>3</sup> )	0.50	0.12		0.09 (Yopal)	0.95 (Neiva)

Prices are converted to dollars using the exchange rate of 30/06/2017, equivalent to 1 USD = \$3,038.26. Source: Superintendencia Financiera de Colombia

Table 3 presents the descriptive statistics of the households. Demographic variables were chosen according to literature review mentioned in Section 3 and data availability. Likewise, the expenditure in dollars is shown, which is in line with the descriptive statistics of the expenditure shares mentioned in the previous table.

On average, the head of household is a person over 50 years old; however, there is a heterogeneity of households according to the dispersion presented by this variable. As for the participation of women as head of household, they repre-

<sup>1</sup>We omit shares equal to 0 for the latter figures to avoid distortions.

sent 40%. On average, the size of the households is composed of three members, but the sample included households up to 10 members. By analyzing the composition by socio-economic strata, stratum 4 households have the highest participation in the sample with 67%, while strata 5 and 6 have a share of 22% and 11%, respectively.

The most educated person in the household, not necessarily the head of the household, has an undergraduate degree, representing 40%, followed by households with a graduate degree with 28% and then households with a vocational education (15%). Households were also categorized by the altitude in which they were located, for the reasons described previously. It is shown that 40% of the households live in cities with an altitude above sea level of less than 1,000 meters. They are followed by households living in cities with an altitude between 1,000 and 2,000 meters above sea level, whose participation in the sample corresponds to 30%. Finally, the variables associated with aggregate expenditure, expenditure on utilities, and household income are described.

Table 3 also has expenditure on each utility. The first part is the total utilities, on average, total expenditure on services is 76.8 USD per month, showing a significant dispersion of 57.7 USD. The variable expenditure on utilities, that is, expenditure after deduction of the fixed charge, represents the largest share of total expenditure on utilities. It can be seen that the service for which households pay the most is electricity. The average total household income is USD 2,055 per month, which takes into account capital income as opposed to current income. The average total expenditure is USD 1,569. It is worth noting the high dispersion that exists in total income and expenditure. Table 17 in the Appendix shows previous information by strata. There, we can see a high heterogeneity among strata.

TABLE 3: DEMOGRAPHIC STATISTICS

Variable	Mean	Std. Dev.	Min.	Max.
Age Head of household	55.02	15.92	17	99
*Gender Head of household	0.59	0.41	0	1
Members	2.83	1.39	1	10
<b>Stratum (Dummy Variable)</b>				
Stratum 4	0.67	0.47	0	1
Stratum 5	0.22	0.42	0	1
Stratum 6	0.11	0.31	0	1
<b>Education (Dummy Variable)</b>				
Elementary school	0.05	0.22	0	1
High School	0.15	0.36	0	1
Vocational	0.12	0.33	0	1
Undergraduate	0.40	0.49	0	1
Postgraduate	0.28	0.45	0	1
<b>Altitude</b>				
Below 1,000 m.a.s.l	0.44	0.5	0	1
Between 1,000 and 2,000 m.a.s.l	0.31	0.46	0	1
More than 2,000 m.a.s.l	0.25	0.43	0	1
<b>Expenditure statistics (USD)</b>				
Total expenditure in utilities	76.83	57.7	0.85	1027.16
Variable Expenditure in utilities	72.16	57.3	0.85	1,022.21
Expenditure in electricity	41.06	41.95	0	564.05
Expenditure in water	19.61	25.34	0	1,006.13
Expenditure in sewerage	3.94	6.74	0	115.77
Expenditure in gas	7.54	8.30	0	162.4
Fixed Cost	5.7	2.08	2.86	17.09
Fixed cost water	2.96	1.33	1.12	9.82
Fixed cost sewerage	1.79	0.81	0.48	5.77
Fixed cost gas	0.95	0.26	0.34	1.67
Total Income	2,055	2,297.29	0	50,483.64
Current income	1,709.03	1,958.29	0	43,278.74
Total Expenditure	1,569.95	1,842.7	98.87	62,399.57
Current Expenditure	1,110.18	1,125.18	24.54	50,915.87

\*Gender=1 if is a Male

To check the unconditional difference between strata regarding utilities consumption patterns, Table 4 shows average difference tests for the three strata, comparing both the consumption shares in each of the services and the prices per unit. Statistically significant differences are observed except for gas consumption. The difference is generally statistically significant at 0.01.

TABLE 4: T-TEST SHARES AND PRICES

Variable	Diff	t statistics
<b>Stratum 4 - 5</b>		
Electricity	0.0943***	(14.53)
Water	-0.0645***	(-9.85)
Sewerage	-0.0233***	(-8.53)
Natural Gas	-0.0065	(-1.84)
Electricity(USD/kWh)	-0.0252***	(-66.06)
Water(USD/m <sup>3</sup> )	-0.3210***	(-58.72)
Sewerage(USD/m <sup>3</sup> )	-0.3130***	(-57.85)
Natural Gas(USD/m <sup>3</sup> )	-0.1030***	(-27.51)
<b>N</b>	<b>5,194</b>	
<b>Stratum 4 - 6</b>		
Electricity	0.0384***	(4.65)
Water	-0.0306***	(-3.85)
Sewerage	-0.00673	(-1.93)
Natural Gas	-0.0011	(-0.24)
Electricity(USD/kWh)	-0.0161***	(-32.17)
Water(USD/m <sup>3</sup> )	-0.4750***	(-71.43)
Sewerage(USD/m <sup>3</sup> )	-0.3930***	(-57.97)
Natural Gas(USD/m <sup>3</sup> )	-0.1050***	(-20.68)
<b>N</b>	<b>4,542</b>	
<b>Stratum 5 - 6</b>		
Electricity	-0.0558***	(-5.30)
Water	0.0339**	(2.97)
Sewerage	0.0166***	(3.54)
Natural Gas	0.0054	(1.01)
Electricity(USD/kWh)	0.0090***	(14.53)
Water(USD/m <sup>3</sup> )	-0.1550***	(-14.50)
Sewerage(USD/m <sup>3</sup> )	-0.0798***	(-7.38)
Natural Gas(USD/m <sup>3</sup> )	-0.0016	(-0.36)
<b>N</b>	<b>1,940</b>	

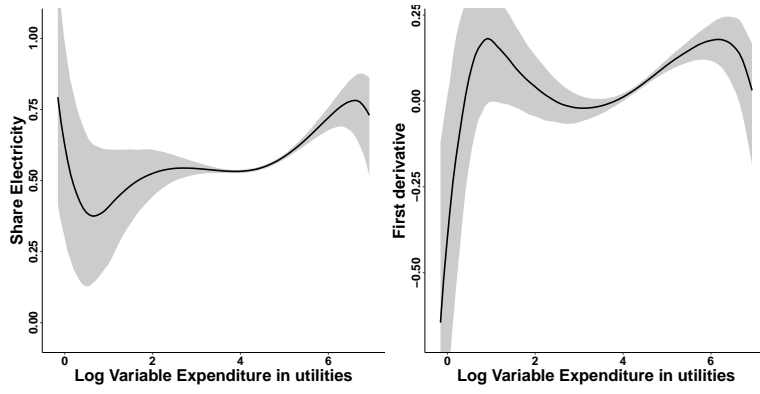
Ho: diff=0

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

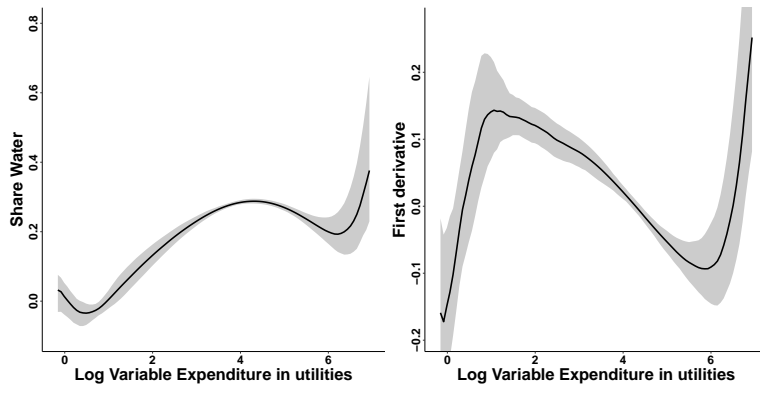
It is observed that in stratum 4, the participation of electricity expenditure is greater than in stratum 5, while for other services it is higher in stratum 5. In terms of unit prices, stratum 5 faces higher prices in all utilities compared to stratum 4. When comparing stratum 4 with stratum 6, the same pattern is observed as in the previous group. However, the magnitude of the differences in prices is more considerable, except for electricity, while the difference in shares is less. Finally, when comparing households in strata 5 and 6, the participation of water, gas and sewerage services is statistically greater in stratum 5 than in stratum 6; however, the opposite is true for the share of electricity. In turn, unit prices are higher in stratum 6, except for electricity.

Figure 4 shows the relationship between the shares associated with each utility and the logarithm of expenditure, the left column is an approximation of the Engel curve using a Kernel estimator. A substantial heterogeneity can be observed for all services, particularly for electricity and water

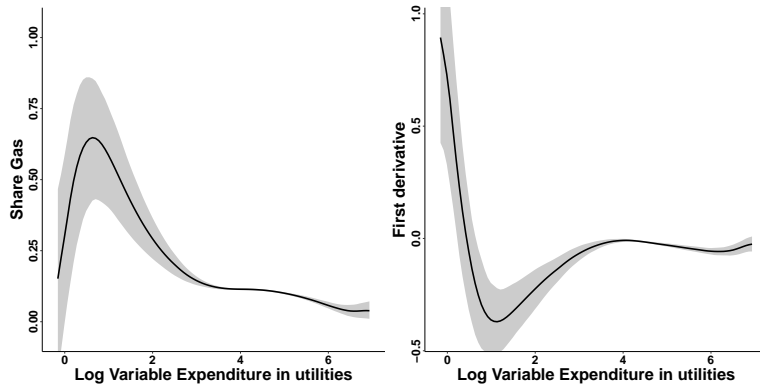
**FIG. 4: SHARE ELECTRICITY-LOG EXPENDITURE**



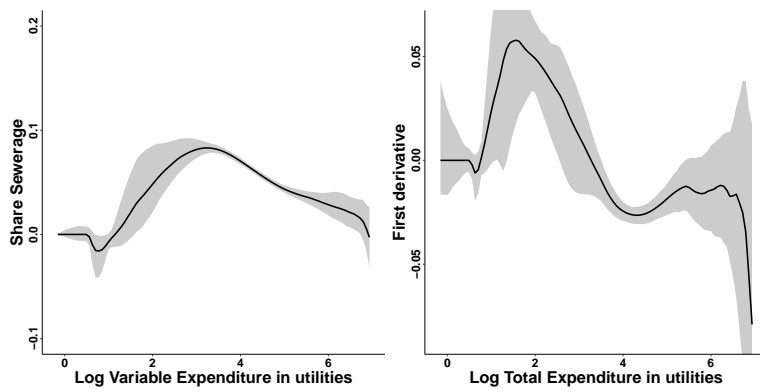
**FIG. 5: SHARE WATER-LOG EXPENDITURE**



**FIG. 6: SHARE GAS-LOG EXPENDITURE**



**FIG. 7: SHARE SEWERAGE-LOG EXPENDITURE**



services where households with a higher expenditure show a higher consumption of these two services, reinforcing the idea that both goods are normal, and given the characteristics of these goods as a basic need for households. The right column shows the rate of change associated with each service. From this figure, it seems that Engel curves are non-linear, and exhibits polynomial orders greater than 2.

**TABLE 5:** T-TEST TEST SOCIOECONOMIC VARIABLES

Variable	Diff	t statistics
<b>Stratum 4 - 5</b>		
Age H.h	-2.53***	(-4.97)
Members	0.19***	(4.41)
Total utilities expenditure	-18.56***	(-12.63)
Variable expenditure in utilities	-16.37***	(-11.17)
Expenditure in electricity	-1.91	(-1.70)
Expenditure in water	-10.01***	(-15.88)
Expenditure in sewerage	-2.39***	(-13.13)
Expenditure in gas	-2.05***	(-8.27)
Fixed Cost	-2.62***	(-55.81)
Fixed cost water	-1.45***	(-42.73)
Fixed cost sewerage	-0.97***	(-50.84)
Fixed cost gas	-0.20***	(-28.24)
Total Income	-834.40***	(-12.99)
Current income	-686.3***	(-12.65)
Total Expenditure	-735.5***	(-13.34)
Current Expenditure	-486.1***	(-14.50)
<b>N</b>	<b>5,194</b>	
<b>Stratum 4 - 6</b>		
Age H.h	-4.36***	(-6.53)
Members	0.15**	(2.60)
Total utilities expenditure	-60.15***	(-25.88)
Variable expenditure in utilities	-57.33***	(-24.71)
Expenditure in electricity	-31.13***	(-17.90)
Expenditure in water	-17.71***	(-17.44)
Expenditure in sewerage	-3.26***	(-12.57)
Expenditure in gas	-5.23***	(-15.74)
Fixed Cost	-3.59***	(-61.80)
Fixed cost water	-1.88***	(-46.32)
Fixed cost sewerage	-1.40***	(-57.50)
Fixed cost gas	-0.31***	(-32.38)
Total Income	-2,067.3***	(-23.09)
Current income	-1,685.5***	(-21.26)
Total Expenditure	-1,363.9***	(-22.97)
Current Expenditure	-843.9***	(-23.96)
<b>N</b>	<b>4,542</b>	
<b>Stratum 5 - 6</b>		
Age H.h	-1.829*	(-2.38)
Members	-0.0416	(-0.65)
Total utilities expenditure	-41.59***	(-11.88)
Variable expenditure in utilities	-40.96***	(-11.71)
Expenditure in electricity	-29.22***	(-11.40)
Expenditure in water	-7.69***	(-4.50)
Expenditure in sewerage	-0.86	(-1.88)
Expenditure in gas	-3.18***	(-6.80)
Fixed Cost	-0.97***	(-10.21)
Fixed cost water	-0.44***	(-6.19)
Fixed cost sewerage	-0.43***	(-12.44)
Fixed cost gas	-0.10***	(-9.65)
Total Income	-1,232.9***	(-9.09)
Current income	-999.2***	(-8.87)
Total Expenditure	-628.4***	(-5.07)
Current Expenditure	-357.8***	(-4.65)
<b>N</b>	<b>1,940</b>	

Ho: diff=0

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

**TABLE 6:**  $\chi^2$  TEST DEMOGRAPHIC VARIABLES

Variable	$\chi^2$	Pr	df
Gender H.h	8.54	0.014	2
Education	190.05	0.0000	8
<b>N</b>	<b>5,838</b>		

Ho: equal proportions

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Table 5 shows mean difference tests by stratum for socioeconomic variables. Significant differences are found for all combinations of variables by stratum, except for expenditure on electricity for stratum 4 - 5 and expenditure on sewerage for stratum 5 - 6. So, it seems that there are remarkable statistically significant differences between households.

Table 6 performs a joint chi-square test for the demographic variables that are categories showing that there are statistically significant differences. This reflects the joint difference that exists both by level of education and by gender.

### 5.3. Estimation results

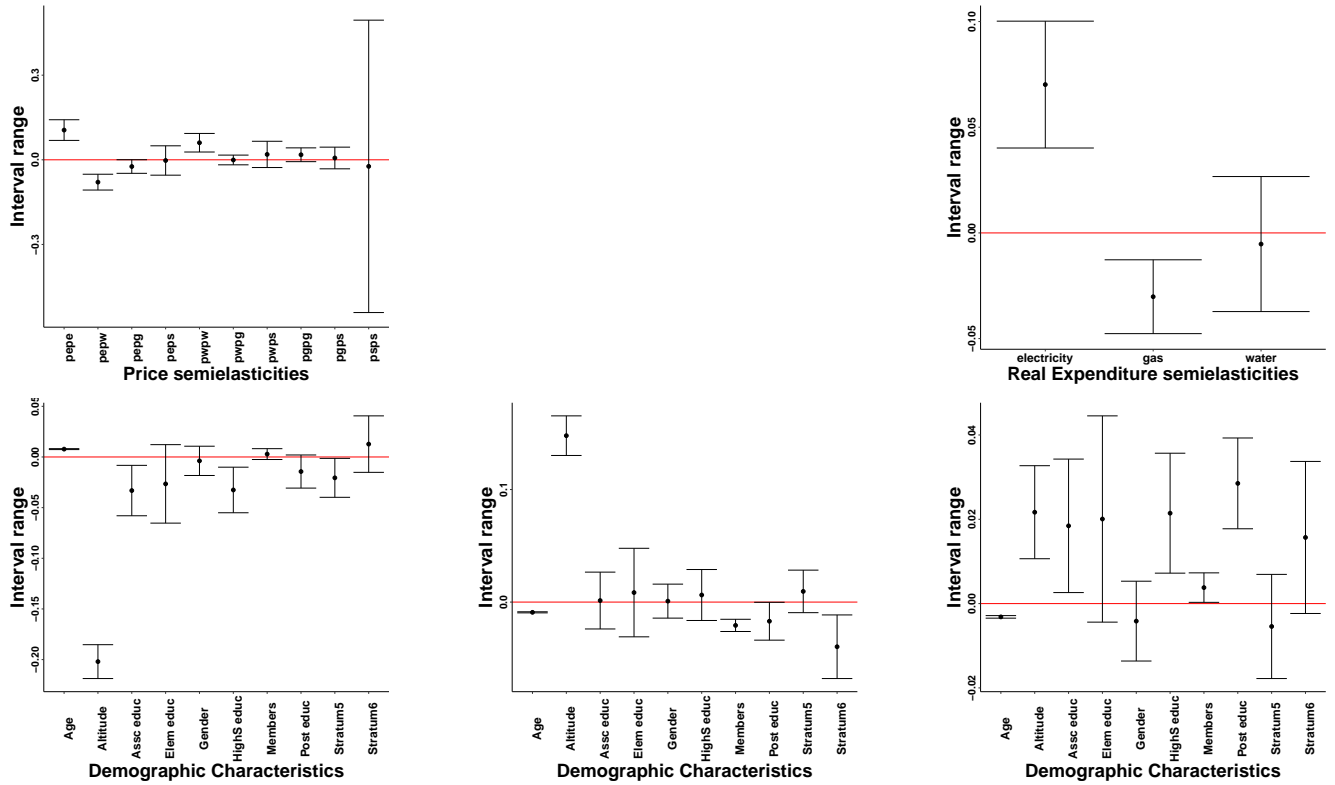
Table 7, and Figure 8, summarizes the information for the representative household, which is based on descriptive statistics in previous section. The representative household has 3 members, living in stratum 4, household head is a 55 years-old male, the highest education level at household is undergraduate, and it is located at an altitude less than 1,000 m.a.s.l

Figure 8 displays own-price and cross-price semielasticities. Observe that four out of ten are significant at 5% level, electricity has three of them. The own-price semielasticity of demand for the representative household was 0.10 for electricity, 0.06 for the water, and 0.01 for gas. The coefficients associated with the semielasticities of electricity and water are statistically significant. The above implies that an electricity price increase of 10 per cent would be associated with a budget share 1 percentage points higher in this utility compensating by expenditure effects. Some cross-price effects are statistically significant, which may reveal presence of some substitution effect. As an illustration, the electricity budget share compensated water cross-price semi-elasticity is -0.079, implying that an increase in the price of the water is associated with a statistically significant decrease in the budget share for electricity. While these two services are of primary importance to households, they tend to offset. The rightmost block of Table 7 gives compensated price semi-elasticities mentioned above.

The **S** matrix, normalizes the Slutsky matrix for prices and expenditure, and is related to the compensated semi-elasticity matrix, by  $\mathbf{S} = \mathbf{\Gamma} + \mathbf{w}\mathbf{w}' - \mathbf{W}$ , where  $\mathbf{\Gamma}$  is 3, and  $\mathbf{W} = \text{diag}(\mathbf{w})$ . The values of the own-price Slutsky terms are reported in the second column of Table 7. Concavity of expenditure function is satisfied if and only if **S** is negative semi-definite (see Pollak and Wales, 1995). A glance at this column reveals that own-price Slutsky terms are all negative, and statistically significant, showing normal goods. The **S** matrix is negative semi-definite, implying that the expenditure function is weakly concave at this point in the data.

The leftmost column of Table 7 contains estimated own-price elements of **B**, which show the magnitudes of the interaction between own-prices and total expenditures in utilities.

**FIG. 8:** COMPENSATED PRICE, REAL EXPENDITURE, AND DEMOGRAPHIC SEMIELASTICITIES: ELECTRICITY, WATER AND GAS



**TABLE 7:** COMPENSATED PRICE EFFECTS: EVALUATED FOR REFERENCE TYPE WITH MEDIAN EXPENDITURE AT BASE PRICES

	Own-Price B element	Own-Price Slutsky element	Electricity	Water	Gas
Electricity	0.0545** (0.0176)	-0.2499*** (0.0187)	0.1054*** (0.0187)		
Water	0.0277 (0.0163)	-0.1786*** (0.0168)	-0.0792*** (0.0143)	0.0605*** (0.0168)	
Gas	-0.0033 (0.0107)	-0.1275*** (0.0125)	-0.0238* (0.0102)	-0.0005 (0.0088)	0.0179 (0.0125)

Standard error are in parenthesis, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

**TABLE 8:** COMPENSATED REAL EXPENDITURE SEMIELASTICITIES

Electricity	Water	Gas
0.0701*** (0.0153)	-0.0053 (0.0163)	-0.0302*** (0.0089)

Standard error are in parenthesis, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

**TABLE 9:** COMPENSATED SEMIELASTICITIES RESPECT TO DEMOGRAPHICS VARIABLES

	Members	Age	Gender	Stratum 5	Stratum 6	Elementary School	High School	Associate degree	Postgraduate	>1,000 m.a.s.l
Electricity	0.0029 (0.0027)	0.0078*** (0.0002)	-0.0038 (0.0074)	-0.0206* (0.0098)	0.0127 (0.0142)	-0.0266 (0.0198)	-0.0326** (0.0115)	-0.0332** (0.0127)	-0.0144 (0.0083)	-0.202*** (0.0085)
Water	-0.0207*** (0.0028)	-0.0091*** (0.0002)	0.0008 (0.0077)	0.0095 (0.0096)	-0.0397** (0.0144)	0.0085 (0.0201)	0.0063 (0.0116)	0.0014 (0.0129)	-0.017 (0.0086)	0.1479*** (0.009)
Gas	0.0038* (0.0018)	-0.0032*** (0.0002)	-0.0042 (0.0048)	-0.0054 (0.0063)	0.0157*** (0.0092)	0.0201 (0.0125)	0.0214** (0.0073)	0.0184* (0.0081)	0.0285*** (0.0055)	0.0217*** (0.0056)

Standard error are in parenthesis, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

These parameters allow to assess whether or not compensated semi-elasticities are the same for high and low spending households. Electricity own-price compensated semi-elasticity coefficient estimate on  $y$  is 0.054 and it is statis-

tically significant. We compare electricity own-price compensated semi-elasticity for a representative household at the 10<sup>th</sup> percentile of expenditure ( $x = -1.098$ ) versus a household at the 85<sup>th</sup> percentile of expenditure ( $x = 0.28$ ). Re-

member that electricity own-price semielasticity at the median expenditure ( $x = 0$ ) is 0,105. Based on the Slutsky equation, we use expenditure and semielasticity values in **B** to make a comparison. At the 10<sup>th</sup> percentile, we have  $-0.105 - 1.098 * 0.054 = -0.164$ , in contrast, at the 85<sup>th</sup> percentile  $-0.105 + 0.28 * 0.054 = -0.089$ . Also, corresponding own-price electricity terms in **S** are  $-0.068$  at the 10<sup>th</sup> percentile, and  $-0.052$  at the 85<sup>th</sup> percentile, both are statistically significant negative; however, the magnitude of the results is similar. These results suggest a slight difference in substitution effects of households for different amounts of expenditure, that is, households with lower expenditure levels substitute a few more than households with higher levels in the face of an increase in electricity price. Similar degree of substitutability between households may be due electricity is a normal good that has no close substitutes.

Table 8 shows real expenditure semielasticities where electricity and gas semielasticities are statistically significant. This tells that a real expenditure increase of 10 per cent would be associated with a budget share of 0.70 percentage points higher for electricity. This can be associated with the fact that expenditure increases in utilities at these socioeconomic levels are more associated with electricity, for instance, more use of electric appliances, than water and gas.

Demographic semielasticities are shown in Table 9 and intended to capture observable preferences related to demand. For electricity, household head age, the altitude of the municipality, highest education level at household, and belong to stratum 5 are statistically significant for the representative household. For instance, municipalities at higher altitudes above sea level proportionally expend less in electricity than municipalities at less altitude. Variations in water shares are statistically associated with household size, and altitude. Gas is statistically associated with household size, household head age, education level, and altitude.

The exercise was also performed for a household with other characteristics. For this purpose, the representative household for each stratum was taken. For those living in stratum 4, the representative household has three members, the head of the household is a 54 year-old male, the highest educational degree at household is undergraduate, and it is located at an altitude of less than 1,000 m.a.s.l. For those who live in stratum 5, the representative household has two members, the head of the household is a 56 years-old male, the maximum education level is undergraduate, and the dwelling is located at an altitude higher than 1,000 m.a.s.l. Finally, the representative household of stratum 6 has three members, is at an altitude higher than 1,000 m.a.s.l., the head of the household is a 60 year-old male, and the highest education level is postgraduate.

Figure 9 shows coefficient estimates for these representative households. This figure allows to see a high heterogeneity. Tables 19 - 27 in Appendix have coefficients estimates and standard errors.

We get two main conclusions from studying price effects. First, elasticity estimates reflect a high level of heterogeneity between representative households for different socioeconomic strata. Second, substitution effects do not differ much when we carry out analysis for different percentiles of the real expenditure once controlling for strata.

Tables 10 and 11 show Marshallian expenditure elasticities. These are categorized by stratum, and by quartiles of household total expenditure and total income. In general, it can be seen that all three goods are normal. It is observed that for electricity, the values oscillate between 0.91 and 1. So for every 1% increase in utility expenditure, electricity demand increases between 0.91% and 1%. Although these results confirm that electricity is a basic necessity, it is believed that the results with high values are due to the segment of households analyzed, since high-income households have access to more and different goods that are intensive in electricity consumption.

Water expenditure elasticities greater than one are observed, this does not indicate that for households, water is a luxury good because it has elasticities greater than one, since the relationship is not with income increase. What this indicates is that as utility expenditure increases, expenditure on water consumption increases more than proportionally. This makes sense if we frame it in the *SPPD* report that shows that strata 4, 5, and 6 are those with the highest water consumption, up to 50% more than the lower strata.

Natural expenditure elasticity is the smallest, it is positive, but less than 1, reflecting that it is a necessary good. 10% increase in utility expenditure implies gas increases between 4.9% and 8.2%. Tables 12 and 13 show Marshallian price elasticities results. Negative expected signs are observed for all utilities.

Analyzing information by quartiles, price elasticity is between  $-0.72$  and  $-0.64$ . This means inelastic demand for strata 4, 5, and 6. It is observed that at lower utility expenditure, households are less sensitive to changes in prices controlling for strata.

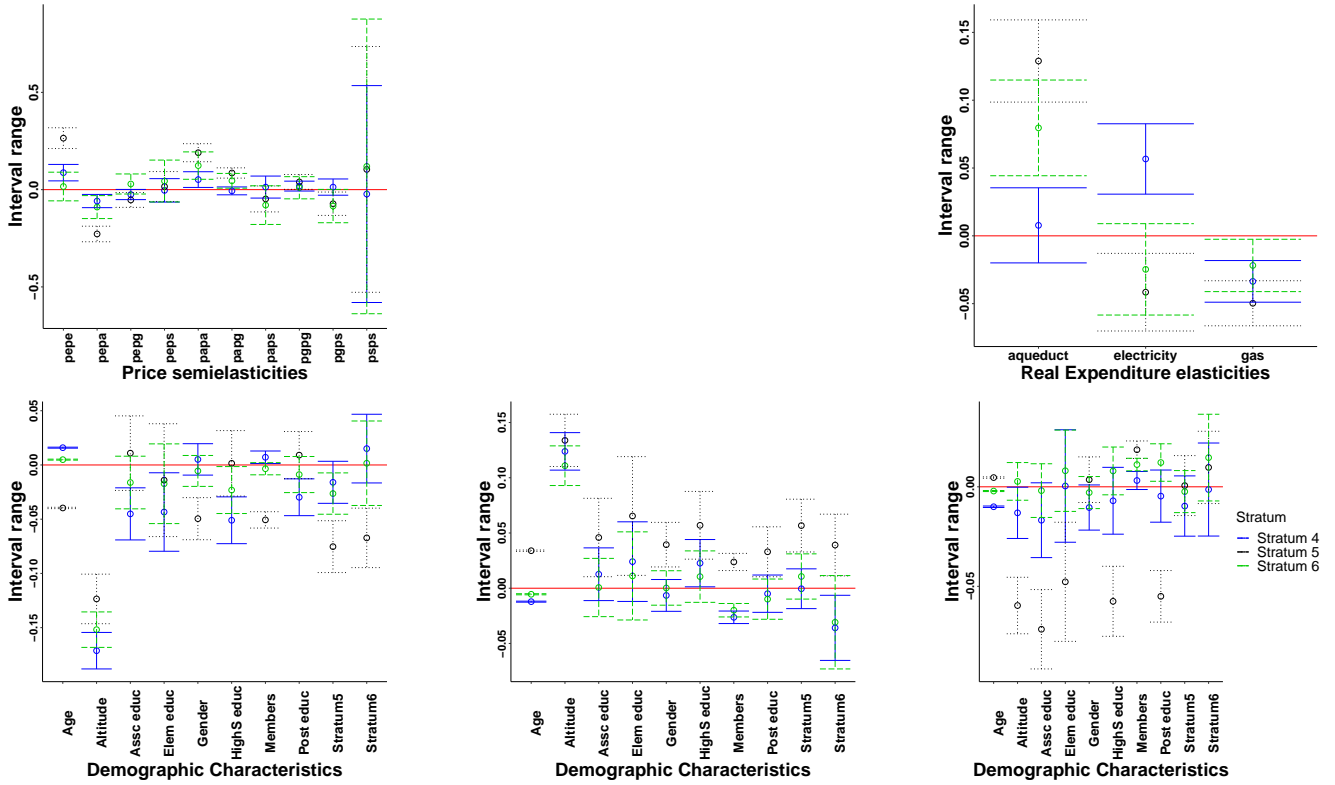
Water is the most inelastic of the three public services, this is due to lacking substitutes. Elasticity tends to be similar when moving between quartiles ranging between  $-0.55$  and  $-0.36$ .

Natural gas results indicate price elasticity between  $-0.72$  and  $-0.67$ , showing that this service is inelastic. In Colombia, most of the gas use is cooking with not near substitute at least buying an electricity device.

Electricity results are in line with those obtained for other countries by authors such as Baker et al. (1989); Blundell and Robin (1999); Labandeira et al. (2006); Lavín et al. (2011); Krishnamurthy and Kríström (2015); Galvez et al. (2016), additionally with Reaños and Wölfing (2018) who use the EASI model methodology.

When we compare the results for Colombia, we see that the results of electricity price elasticity are higher in absolute value than those found by Cano et al. (2011). They estimate an elasticity for the category where electricity is found of  $-0.37$ . Ramírez and Londoño (2008), perform a disaggregated analysis at the stratum level, finding for strata 4, 5, and 6, long-term price elasticities of  $-0.96$   $-1.05$   $-0.78$  and short-term of up to  $-0.66$ ,  $-0.82$ ,  $-0.66$  respectively for each stratum, respectively. Maddock et al. (1992), for the strata 3-4 of  $-0.50$  and 5-6 of  $-0.79$ , both papers are consistent with the results obtained here. Previous literature also reports results of the income or expenditure elasticity of electricity, when compared with ours, the results are higher than those previously reported. When analyzing the rest of the public services, a work for Colombia that integrates two of these, water and

**FIG. 9:** COMPENSATED PRICE, REAL EXPENDITURE, AND DEMOGRAPHIC SEMIELASTICITIES: ELECTRICITY, WATER AND GAS BY STRATUM



**TABLE 10:** UNCOMPENSATED EXPENDITURE ELASTICITIES

Category	Electricity	Water	Gas
Complete	0.9791	1.3339	0.6441
Stratum 4	1.0021	1.2710	0.6995
Stratum 5	0.9112	1.5238	0.4946
Stratum 6	0.9782	1.3280	0.6156

**TABLE 11:** UNCOMPENSATED EXPENDITURE ELASTICITIES BY QUANTILES FOR INCOME AND EXPENDITURE TYPE

	Total Income	Current income	Total expenditure	Current expenditure
<b>Electricity</b>				
1st Quartile	0.9473	0.9500	0.9541	0.9587
2nd Quartile	0.9790	0.9774	0.9754	0.9676
3rd Quartile	0.9890	0.9895	1.0019	0.9954
4th Quartile	1.0011	0.9996	0.9850	0.9948
<b>Water</b>				
1st Quartile	1.3966	1.4052	1.4183	1.3972
2nd Quartile	1.3568	1.3281	1.3073	1.3285
3rd Quartile	1.3004	1.3131	1.2716	1.2839
4th Quartile	1.2818	1.2891	1.3383	1.3259
<b>Gas</b>				
1st Quartile	0.7926	0.7625	0.8201	0.7715
2nd Quartile	0.7147	0.7122	0.6441	0.6808
3rd Quartile	0.5670	0.5889	0.5644	0.5456
4th Quartile	0.5019	0.5127	0.5478	0.5784

**TABLE 12: UNCOMPENSATED OWN PRICE ELASTICITIES**

Category	Electricity	Water	Gas
Complete	-0.7029	-0.4550	-0.7033
Stratum 4	-0.7295	-0.4138	-0.7103
Stratum 5	-0.6494	-0.5575	-0.6733
Stratum 6	-0.6555	-0.4917	-0.7203

**TABLE 13: UNCOMPENSATED OWN PRICE ELASTICITY BY QUANTILES FOR INCOME AND EXPENDITURE TYPE**

	Total Income	Current income	Total expenditure	Current expenditure
<b>Electricity</b>				
1st Quartile	-0.6844	-0.6860	-0.7011	-0.7041
2nd Quartile	-0.7024	-0.7073	-0.7039	-0.7058
3rd Quartile	-0.7199	-0.7154	-0.7201	-0.7095
4th Quartile	-0.7051	-0.7031	-0.6867	-0.6923
<b>Water</b>				
1st Quartile	-0.4013	-0.4085	-0.4157	-0.3691
2nd Quartile	-0.4300	-0.4093	-0.4135	-0.4577
3rd Quartile	-0.4951	-0.4968	-0.4800	-0.4694
4th Quartile	-0.4935	-0.5052	-0.5107	-0.5237
<b>Gas</b>				
1st Quartile	-0.7301	-0.7101	-0.7132	-0.7121
2nd Quartile	-0.7117	-0.7205	-0.7116	-0.7076
3rd Quartile	-0.6782	-0.6866	-0.7053	-0.6955
4th Quartile	-0.6929	-0.6958	-0.6829	-0.6978

electricity, is that of [Medina and Morales \(2007\)](#) who finds a price elasticity for electricity of -0.45, and the price elasticity of water demand is -0.23, both results show less elastic than those found in here. Since not much evidence is found for Colombia on the elasticity of goods such as gas and water, the results are compared with other countries. A generality is that given the condition of necessary good, and without a close water substitute, this good tends to be inelastic. [Florax et al. \(2003\)](#) carried out a meta-analysis of price and income elasticities of residential water demand covering the period from 1963 to 1998 in which they analyzed studies for different countries, under different methodologies, and found that distribution of income elasticities has a mean of 0.43 and price elasticity of -0.41.

Other authors such as [Martinez-Espineira \(2004\)](#) find a short-term price elasticity equal to -0.10 for Spain and -0.50 in the long term, while the [Galvez et al. \(2016\)](#) find a price elasticity of -0.75 for the same country. [Ruijs et al. \(2008\)](#) for Brazil between -0.46 and -0.50 and [Schleich and Hillenbrand \(2009\)](#) for Germany between -0.24 and -0.75. With the above, the results found in this work are similar to the evidence found in the literature for other countries.

Finally, for natural gas, [Blundell and Robin \(1999\)](#) use a QUAIDS, finding price elasticities up to -0.42 and income elasticities between 0.58 and 0.74 depending on the quartile evaluated. [Labandeira et al. \(2016\)](#), under a meta-analysis, show short-term price elasticity results for the European Union between -0.92 and 0.28, a fairly wide range, and calculate an average elasticity of -0.26. [Burke and Yang \(2016\)](#) used national-level data for a sample of 44 countries to estimate the price and income elasticities. They present separate

estimates for final natural gas demand by households obtain estimates between -0.13 and -1.44 according to specification. The income elasticity point estimates are between 0.58 and greater than 1. Finally, for Colombia, *UPME* considers different moments and measures established by the government, finding differences in price elasticity of households that oscillate in absolute value between 0.3 and 1.8 between 2015 and 2017.

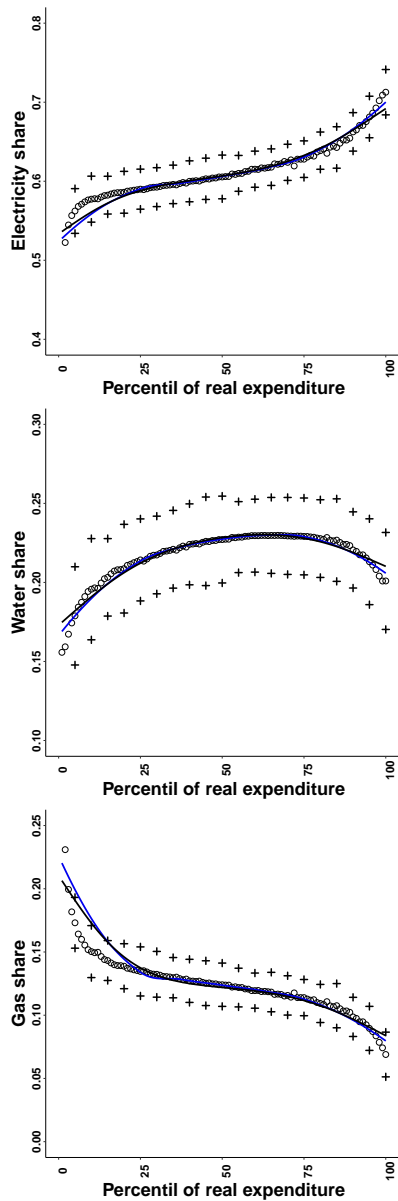
In general, it is observed that reported results of price elasticities are in the ranges shown by the literature for different countries, and for Colombia, the main differences are in expenditure or income elasticities.

We show conditional Engel curves in [Figure 10](#). These curves are only for the representative household, that is, a household with three members, household head is a 55 year-old male with a professional education level, the household is located in a city with an altitude lower than 1,000 m.a.s.l, and the socioeconomic stratum is 4. So, at these base prices we obtain the Engel curve given by  $\mathbf{w} = \sum_{r=0}^5 \mathbf{b}_r x^r + \mathbf{Cz} + \mathbf{Dz}x + \varepsilon$ , where  $\mathbf{Cz}$  and  $\mathbf{Dz}x$  capture interaction given by differences between demographic characteristics and  $y$ . For the representative household  $\mathbf{w} = \sum_{r=0}^5 \mathbf{b}_r x^r$ , we assume unobserved heterogeneity  $\varepsilon = 0$ . Baseline period Engel curves for households with different values of unobserved heterogeneity are identical except for being vertically shifted by  $e$ . Results are reported to take the median into quartiles, and the curves are plotted using a local smoothing regression (blue) and spline smooth (black).

It is observed that all three sets of estimates lie within the pointwise confidence intervals of the exact model estimates, Engel curves for the representative household present appa-

rent curvatures for all public utilities. The above is supported by the statistical significance of different polynomial terms in the electricity, water and gas equations. It can be seen that the Engel curve has a positive slope, for water and electricity, given that they are normal goods, as shown in the previous analysis, and all have a positive elasticity with respect to variable expenditure on utilities. Natural gas is a service that presents a decreasing part of the expenditure as it increases.

FIG. 10: ENGEL CURVES - REPRESENTATIVE AGENT



Predicted electricity and water expenditure monotonically increase with variable expenditure, as shown by the analysis of the expenditure elasticities by quartiles for these services. Electricity Engel curve has a steeper slope than water. For this last service, we can see a tendency to increase in expenditure that stabilizes at the highest segments finding evidence of an inverse U-shaped mild relationship. Although natural gas increases when expenditure increases, it is shown that there is a large decrease in their budget weight as we move to higher deciles. Everything else constant, expenditure on electricity, water and natural gas tend to represent in households

at the lower decile 52, 20 and 15 per cent of their budgets, respectively.

This is relevant because Engel curves shapes enable more informed decisions to be made to minimize welfare losses associated with price increases. In particular, although it is not the object of study of this paper, it is of special analysis in the structure of subsidies and contributions that are given to households of low strata.

#### 5.4. Welfare Analysis

We perform welfare analysis based on the equivalent variation from our sample. Equivalent variation tells how much money should be taken from the household at the original price to have an equivalent effect on his/her welfare as the price rise. We use the equation 12. However, we do not know  $w_i^1$ ; this value is calculated using the definition of elasticity obtaining  $w_i^1 = w_0 * (1 + \epsilon^w \Delta \%P)$ , where  $\epsilon^w$  is the Marshallian price elasticity respect to the share, which is calculated using equation 8, and  $\Delta \%P$  is the percentual change in prices, prices are in levels.

The equivalent variation is different for each household since while households from the same stratum located in the same municipality have the same prices, they generally experience differences in  $x$ ,  $w^1$ , and  $w^0$ . Households that have a higher expenditure experience a more significant equivalent variation, so money that should be withdrawn to these households at the original price is higher. To avoid distortions, we omit households that have shares equal to zero; so, the sample becomes 4,404. Table 14 shows descriptive information of the calculation of the equivalent variation (mean, standard deviation, minimum and maximum) by strata, and as a proportion of other variables.

Equivalent variation is 0.77 dollars on average, and it is increasing with strata. When the information is analyzed as a proportion of expenses on utilities and total household expenses, the highest is associated with stratum 4. Figure 11 shows scatter plots regarding these figures. We observe a high level of heterogeneity with expenditures displaying increasing order according to strata.

TABLE 14: EQUIVALENT VARIATION

	Mean	Std. Desv	Min	Max
<b>EV (€)</b>				
Complete	\$77.55	\$62.29	\$2.91	\$1456.60
Stratum 4	\$68.47	\$46.43	\$2.91	\$799.06
Stratum 5	\$79.78	\$57.23	\$9.19	\$632.43
Stratum 6	\$123.72	\$109.48	\$14.35	\$1456.60
<b>EV/TU (%)</b>				
Complete	0.94 %	0.20 %	0.17 %	4.59 %
Stratum 4	0.97 %	0.19 %	0.17 %	4.59 %
Stratum 5	0.88 %	0.21 %	0.25 %	3.95 %
Stratum 6	0.95 %	0.17 %	0.49 %	1.84 %
<b>EV/TE (%)</b>				
Complete	0.06 %	0.05 %	0 %	0.54 %
Stratum 4	0.07 %	0.05 %	0 %	0.54 %
Stratum 5	0.05 %	0.04 %	0 %	0.39 %
Stratum 6	0.06 %	0.04 %	0 %	0.24 %

EV: Equivalent Variation, TU: Total Utilities, TE: Total expenditure

FIG. 11: WELFARE ANALYSIS

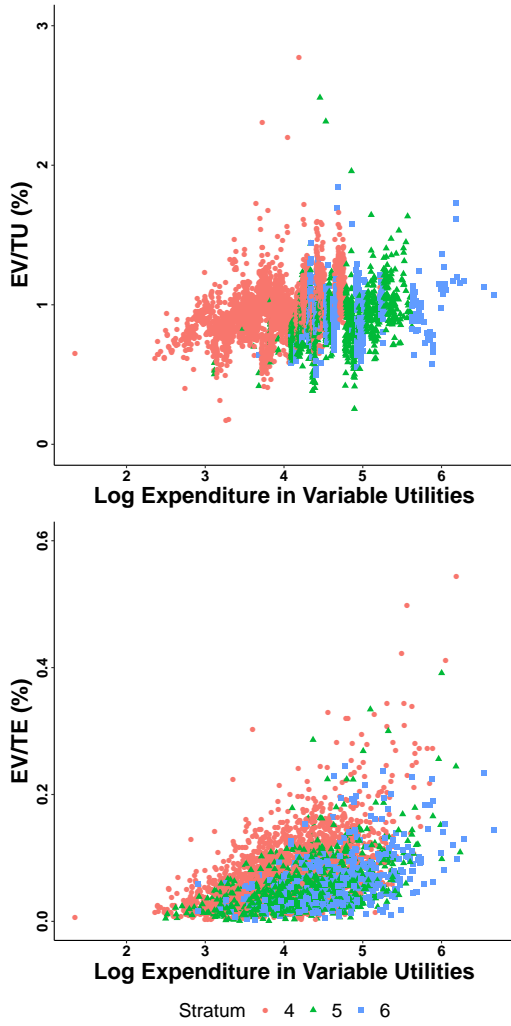


FIG. 12: EV, EXPENDITURE AND  $\Delta$  PRICES

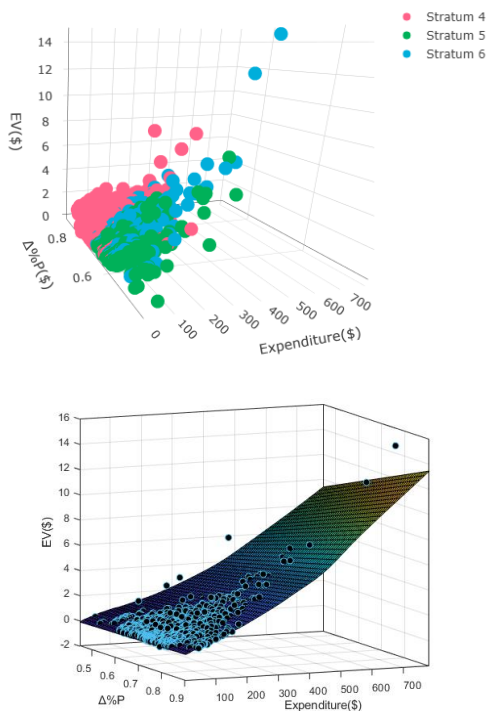


Figure 12 shows a perspective that allows us to relate: the equivalent variation, the change in price, and the expenditure for each of the households. The top panel will enable us to illustrate the global effect on the distribution of these households, showing that the equivalent variation is increasing for the expenditure. We observe that there are households in stratum 4 experiencing similar or greater variation than those in higher strata.

The bottom panel is a lowess approximation represented by the plan, where the points are the households. An increasing trend is observed as the level of expenditure increases. It reinforces the idea that changes in price may represent a different equivalent variation because average prices per stratum are different even for the same level of expenditure.

### 5.5. Alternative Scenario

Now we present some exercises where we try to obtain differential taxation rules by stratum such that tax income under the base scenario is achieved but minimizing social welfare losses. However, we should take into account that the concept of social welfare is dubious, given the Arrow's impossibility theorem (Arrow, 1950). The main issue here is how to weight individual equivalent variations. Despite this warning, we try to propose some "sensible" alternative scenarios under progressive tax rules.

Table 15 shows the information required to perform these alternative scenarios. The initial quantities ( $Q^0$ ) and the number of subscribers are taken from the SUI in June 2019. The new quantities ( $Q^1$ ) are calculated using elasticity definition, the relationship  $Q_1 = Q^0 * (1 + \epsilon^m \Delta \%P)$ , where  $\epsilon^m$  is the demand Marshallian price elasticity (Table 13). Table 15 also shows the target population; urban and regulated households belonging to strata 4, 5, and 6. The final quantities  $Q^1$ , the value of the tax, and the number of users allow an estimate of how much will be collected monthly. The SSPD estimated to collect per household between \$ 0.27 (\$800 COP) and \$ 0.43 (\$1,300 COP) monthly according to stratum. Assuming that the number of subscribers remains constant, \$15.4 billion will be collected over the 42 months of the tax.

TABLE 15: USERS AND COLLECT MONTHLY

	$Q^0$	$Q^1$	Users	Collect (Thousand \$)
Complete			1,600,323	367.54
Stratum 4	164.04	163.13	999,654	195.69
Stratum 5	199.09	198.24	380,812	90.59
Stratum 6	309.40	308.02	219,857	81.26

The representative household for each stratum is constructed based on the description in Session 5 and the descriptive statistics taking the median. Representative agents are chosen because taxes are charged by stratum and not by households.

The base scenario has an even price increase equal to USD 0.0012, which implies an average percentage change in the prices equal to 0.76%, 0.65%, and 0.68% for stratum 4, 5, and 6, respectively. So, we propose to solve the program 14, that is, minimize the social loss (sum of total representative equivalent variations) such that total tax income is same, but percentage variations are increasing with strata ( $\theta_4 < \theta_5 < \theta_6$ ),  $P_k^1 = P_k^0 * (1 + \theta_k)$ .

$$\begin{aligned}
& \underset{\theta_k}{\operatorname{argmin}} = \\
& \sum_{k \in \{4,5,6\}} \left\{ x_k - \exp \left\{ \log(x_k) - \sum_{i=1}^I (\log(P_{ik}^0 * (1 + \theta_k) w_{ik}^1) \right. \right. \\
& \left. \left. - \log(P_{ik}^0 w_{ik}^0)) + \frac{1}{2} \sum_{i=1}^I \sum_{j=1}^I a_{ij} [\log(P_{ik}^1 * (1 + \theta_k)) \log(P_{jk}^1) \right. \right. \\
& \left. \left. - \log(P_{ik}^0) \log(P_{jk}^0)] \right\} \right\} \times Users_k.
\end{aligned} \tag{14}$$

$$s.t \quad \theta_4 < \theta_5 < \theta_6$$

$$\sum_{i=1}^k P_k^1 * Q_k^1 * Users_k = \$369,40$$

Table 16 shows additional scenarios raised. Since we are working with representative households, the welfare results are not comparable with those from Table 11, but we can compare them to each other. The budget constraint is guaranteed by having the same number of households per stratum and the same total collection, not necessarily the same collection per stratum.

The left column shows the scenario in which a price increase is made in the way the tax was implemented. The EV value for each representative household expressed in cents ( $\text{¢}$ ) is \$61.25, \$69.47, and \$97.17 for stratum 4, 5, and 6. It is observed that stratum 4 is the one that presents the highest percentage increase and the highest welfare loss as a percentage of total utility expenses (1.09%). This stratum also represents the main proportion of total tax income (\$195.69 thousand, more than 50%, see Table 15).

In the alternative scenario, we propose percentage increases according to strata,  $\theta_4 < \theta_5 < \theta_6$ , but same total tax income. The result is  $\theta_4 = 0,70\%$ ,  $\theta_5 = 0,71\%$  and  $\theta_6 = 0,72\%$ . It can be seen that these values are lower than the initial value for  $\theta_4$  but higher for the other two strata as expected.

As a consequence, the collection is lower in stratum 4 and higher in the others; the total welfare loss decreases. Decreasing for stratum 4, but increasing for strata 5 and 6. When analyzing the EV/TU ratio, a reduction in this proportion is observed for stratum 4 such that household welfare losses as total utility expenses percentage are very similar among strata. It seems that our alternative scenario establishes a better “social situation” under a progressive tax rule.

Although the collection of the tax implies a reduction in the welfare of households in strata 4, 5 and 6, there is the benefit that users served by Electricaribe, in the vast majority of strata 1, 2 and 3, will benefit from a better electricity service that mitigates problems like interruptions, rationing, among others<sup>2</sup>. Frequent electricity interruptions and rationing force users to consume less than the optimal amount according to their preferences and established tariffs. In goods such as public services, particularly electricity, welfare losses depend not only on the amount of energy not consumed during the

<sup>2</sup>UPME (2015) shows that interruption costs in the residential sector vary by stratum and hour and that on average households willingness to pay to avoid a one-hour cut on weekdays is USD 0.11.

supply cut but also on the moment when the service is interrupted due to the peak-load demand. Given the difficulty of the user to cover himself against this risk, minimizing the option of welfare losses in users is essential.

TABLE 16: ALTERNATIVE SCENARIO

		Baseline	Alternative
<b>Complete</b>	Total EV (\$)*	1,090.46	1,086.66
	$\Delta_{TEV}$		-3.80
	collection (\$)*	367.54	367.54
<b>Stratum 4</b>	$\theta_4$ (%)	0.76	0.70
	Prices ( $\text{¢}$ )	15.94	15.93
	$\Delta_P$		-0.01
	EV by Household ( $\text{¢}$ )	61.25	57.90
	Total EV (\$)*	612.28	578.83
	$\Delta_{TEV}$		-33.42
<b>Stratum 5</b>	EV/TU (%)	1.09	1.03
	collection (\$)*	196.78	181.80
	$\theta_5$ (%)	0.65	0.71
	Prices ( $\text{¢}$ )	18.59	18.60
	$\Delta_P$		0.01
	EV by Household ( $\text{¢}$ )	69.47	74.51
<b>Stratum 6</b>	Total EV (\$)*	264.54	283.75
	$\Delta_{TEV}$		19.21
	EV/TU (%)	0.98	1.05
	collection (\$)*	90.98	99.38
	$\theta_6$ (%)	0.68	0.72
	Prices ( $\text{¢}$ )	17.74	17.75
<b>Stratum 6</b>	$\Delta_P$		0.01
	EV by Household ( $\text{¢}$ )	97.17	101.90
	Total EV (\$)*	213.64	224.04
	$\Delta_{TEV}$		10.4
	EV/TU (%)	1.00	1.05
	collection (\$)*	81.63	86.36

\*In thousands

## 6. CONCLUSIONS

To the best of our knowledge, we are the first to have empirically examined an EASI model for Colombia, making an application to the retail market households of strata 4, 5, and 6. The results are broadly in line with previous empirical studies both for Colombia and for other countries confirming that goods such as electricity, water, and gas are inelastic goods, that is, these are considered necessary goods regardless of the stratum being analyzed. Although, we show that in this application Engel curves are polynomials of degree higher than 2; therefore, the EASI model is a necessary choice.

The analysis of taxes on public services, such as electricity, requires accurate and precise price effects estimates. So, using micro-level data avoids biases due to aggregation and allows to find heterogeneous responses of consumers to price changes according to their characteristics and expenditure levels, among other things. In particular, *Ex ante* tax analysis is critical to infer welfare implications. We show through a simple optimization program based on reliable estimates that “better social” solutions can be achieved. The economic intuition is basic: discriminate consumers according to a progressive tax rule on consumption. Our empirical exercise shows that it is possible to reduce welfare losses by keeping the same tax incomes, that is, keeping the same welfare gains for beneficiaries of the tax collection.

Future research should analyze welfare gains associated with avoiding power outage or/and poor quality service. This is particularly relevant as welfare losses are approximately

three times tax collections. So, welfare gains using tax income should compensate welfare losses. In our application, it is well known that electricity quality service provided by *Electricaribe* has caused damage to electric devices affecting the most social vulnerable population. So, it would be interesting to obtain the welfare social balance between welfare gains improving electricity quality service versus welfare losses due to broad national taxes.

## REFERENCES

- [1] Acuña, O. A. E., a. G. A. V. and Forero, R. A. (2013). "Elasticidades de demanda por electricidad e impactos macroeconómicos del precio de la energía eléctrica en Colombia." *Revista de Métodos Cuantitativos para la Economía y la Empresa*, 16:216–249.
- [2] Alberini, A. and Filippini, M. (2011). "Response of residential electricity demand to price: The effect of measurement error." *Energy Economics*, 33(5):889–895.
- [3] Arbués, F., Garcia-Valiñas, M. , and Martínez-Españeira, R. (2003). "Estimation of residential water demand: a state-of-the-art review." *The Journal of Socio-Economics*, 32(1):81–102.
- [4] Arrow, K. J. (1950). "A Difficulty in the Concept of Social Welfare". *Journal of Political Economy*, 58(4):328–346.
- [5] Baker, P., Blundell, R., and Micklewright, J. (1989). "Modelling household energy expenditures using micro-data." *The Economic Journal*, 99(397):720–738.
- [6] Banks, J., Blundell, R., and Lewbel, A. (1997). "Transcendental logarithmic utility functions". *Review of Economics and statistics*, 79(4):527–539.
- [7] Barnett, W. A. (1983). "New indices of money supply and the flexible Laurent demand system". *Journal of Business Economic Statistics*, 1(1):7–23.
- [8] Barnett, W. A. (1985). "The minflex-Laurent translog flexible functional form". *Journal of Econometrics*, 30(1-2):33–44.
- [9] Barrientos, J. and Martínez, M. T. (2017). "Análisis de los fundamentales del precio de la energía eléctrica: evidencia empírica para Colombia." *Economía del Caribe*, 19:33–59.
- [10] Barrientos, J., Rodas, E., Velilla, E., Lopera, M., and Villada, F. (2012). "Modelo para el pronóstico del precio de la energía eléctrica en Colombia." *Lecturas de Economía*, 77:91–127.
- [11] Blundell, R., Chen, X., and Kristensen, D. (2007). "Semi-nonparametric IV estimation of shape-invariant Engel curves". *Econometrica*, 75(6):1613–1669.
- [12] Blundell, R. and Robin, J. M. (1999). "Estimation in large and disaggregated demand systems: An estimator for conditionally linear systems." *Journal of Applied Econometrics*, 14(3):209–232.
- [13] Brown, B. and Walker, M. (1989). "The Random Utility Hypothesis and Inference in Demand Systems". *Econometrica*, 57(4):815–829.
- [14] Burke, P. and Yang, H. (2016). "The price and income elasticities of natural gas demand: International evidence". *Energy Economics*, 59:466–474.
- [15] Cano, D. L., Zapata, E. L., and Hassan, A. R. (2011). "Un sistema casi ideal de demanda para el gasto en Colombia: Una estimación utilizando el método generalizado de los momentos en el período 1968-2007". *Ecos de Economía: A Latin American Journal of Applied Economics*, 15(32):39–58.
- [16] Chang, Y. and Martínez-Chombo, E. (2003). "Electricity demand analysis using cointegration and error-correction models with time varying parameters: The Mexican case." *Rice University, Department of Economics*.
- [17] Chipman, J. S. and Moore, J. C. (1980). "Compensating variation, consumer's surplus, and welfare." *The American Economic Review*, 70(5):933–949.
- [18] Christensen, L. R., Jorgenson, D. W., and Lau, L. J. (1975). "Transcendental logarithmic utility functions". *The American Economic Review*, 65(3):367–383.
- [19] Deaton, A. and Muellbauer, J. (1980a). "An almost ideal demand system". *The American Economic Review*, 70(3):312–326.
- [20] Deaton, A. and Muellbauer, J. (1980b). "Economics and consumer behavior". *Cambridge university press*.
- [21] Dergiades, T. and Tsoulfidis, L. (2008). "Estimating residential demand for electricity in the United States, 1965–2006." *Energy Economics*, 30(5):2722–2739.
- [22] Diewert, W. (1971). "An application of the Shephard duality theorem: A generalized Leontief production function". *Journal of political economy*, 79(3):481–507.
- [23] Donatos, G. S. and Mergos, G. J. (1991). "Residential demand for electricity: the case of Greece". *Energy Economics*, 13(1):41–47.
- [24] Espey, J. A. and Espey, M. (2004). "Turning on the lights: A meta-analysis of residential electricity demand elasticities." *Journal of Agricultural and Applied Economics*, 36(1):65–81.
- [25] Filippini, M., . P. S. (2004). "Elasticities of electricity demand in urban Indian households." *Energy Policy*, 32(3):429–436.

- [26] Fisher, D., Fleissig, A. R., and Serletis, A. (2001). "An empirical comparison of flexible demand system functional forms". *Journal of Applied Econometrics*, 16(1):59–80.
- [27] Florax, R., de Groot, H. L., Nijkamp, P., and Dalhuisen, J. (2003). "Price and income elasticities of residential water demand: A meta-analysis". *Land Economics*, 79:292–308.
- [28] Galvez, P., Mariel, P., and Hoyos, D. (2016). "Application of the quads model to the residential energy demand in Spain." *Revista de Economía Aplicada*, 24(72):87–108.
- [29] García, J. M. and Alvarado, A. (2018). "Estimación de elasticidades de demanda de bienes y servicios en Perú mediante los métodos AIDS y QUAIDS." *University Library of Munich, Germany*.
- [30] Gil-Vera, V. (2017). "Pronóstico de la demanda mensual de electricidad con series de tiempo." *Revista EIA*, 13(26):111–120.
- [31] González, A., C. A., Plottier, M. C., and Saavedra, E. H. (2012). "La demanda residencial de energía eléctrica en Chile." *Economía chilena*, 15(3).
- [32] Gorman, W. (1981). "Some Engel Curves in Essays in the Theory and Measurement of Consumer Behaviour in Honor of Sir Richard Stone". *Cambridge: Cambridge University Press*.
- [33] Gundimeda, H. and Köhlin, G. (2008). "Fuel demand elasticities for energy and environmental policies: Indian sample survey evidence." *Energy Economics*, 30(2):517–546.
- [34] Halvorsen, B. and Larsen, B. M. (2001). "The flexibility of household electricity demand over time." *Resource and Energy Economics*, 23(1):1–18.
- [35] Hanemann, M., Labandeira, X., Labeaga, J. M., and López-Otero, X. (2013). "Energy demand for heating: short run and long run." *Economics for Energy Working Paper*, 7.
- [36] Jones, R. V. and Lomas, K. J. (2015). "Determinants of high electrical energy demand in UK homes: Socio-economic and dwelling characteristics." *Energy and Buildings*, 101:24–34.
- [37] Krishnamurthy, C. K. B. and Kriström, B. (2015). "A cross-country analysis of residential electricity demand in 11 OECD-countries". *Resource and Energy Economics*, 39:68–88.
- [38] Kriström, B. (2009). "Household Behaviour and Environmental Policy: Residential Demand for Renewable Energy. In". *Paper for OECD Conference by Environment Directorate*.
- [39] Labandeira, X., Labeaga, J. M., and López-Otero, X. (2012). "Estimation of elasticity price of electricity with incomplete information." *Energy Economics*, 34(3):627–633.
- [40] Labandeira, X., Labeaga, J. M., and López-Otero, X. (2016). "Un metaanálisis sobre la elasticidad precio de la demanda de energía en España y la Unión Europea." *Papeles de Energía*, 2:65–93.
- [41] Labandeira, X., Labeaga, J. M., and Rodríguez, M. (2006). "A residential energy demand system for Spain." *The Energy Journal*, 27(2).
- [42] Lavín, F. V., Dale, L., Hanemann, M., and Moezzi, M. (2011). "The impact of price on residential demand for electricity and natural gas." *Climatic change*, 109(1):171–189.
- [43] Lee, C. C. and Chiu, Y. B. (2011). "Electricity demand elasticities and temperature: Evidence from panel smooth transition regression with instrumental variable approach." *Energy Economics*, 33(5):896–902.
- [44] Lewbel, A. (1991). "The Rank of Demand Systems: Theory and Non-parametric Estimation". *Econometrica*, 59(3):711–30.
- [45] Lewbel, A. (2001). "Demand Systems with and without Errors." *American Economic Review*, 91(3):616–618.
- [46] Lewbel, A. and Pendakur, K. (2009). "Tricks with Hicks: The EASI demand system". *American Economic Review*, 99(3):827–63.
- [47] Lin, B. O. (2003). "Electricity demand in the People's Republic of China: investment requirement and environmental impact." *Asian Development Bank*.
- [48] Maddock, R., Castano, E., and Vella, F. (1992). "Estimating Electricity Demand: The Cost of Linearising the Budget Constraint". *The Review of Economics and Statistics*, 74(2):350–354.
- [49] Martínez-Espineira, R. (2004). "An Estimation of Residential Water Demand Using Co-integration and Error Correction Techniques".
- [50] Martínez, C. I. P. (2009). "Energy efficiency developments in the manufacturing industries of Germany and Colombia, 1998–2005". *Energy for Sustainable Development*, 13(3):189–201.
- [51] Mas-Colell, A., Whinston, M., and Green, J. R. (1995). *Microeconomic theory*. Oxford university press., New York.
- [52] McFadden, D. (1978). "Duality of production, cost, and profit functions". *Production Economics: A Dual Approach to Theory and Applications*, 1:1–110.
- [53] Medina, C. and Morales, L. (2007). "Demanda por servicios públicos domiciliarios en Colombia y subsidios: implicaciones sobre el bienestar". *Borradores de Economía*, (467).
- [54] Mendoza, J. (2010). "Estimación de la demanda de energía eléctrica de la empresa Electricaribe SA de la ciudad de Santa Marta, durante el período comprendido entre 1998-2006." .
- [55] Modi, V., McDade, S., Lallement, D., and Saghir, J. (2006). "Energy and the millennium development goals. Technical Report. Energy Sector Management Assistance Programme, United Nations Development Programme, UN Millennium Project, and World Bank, New York".
- [56] Narayan, P. K. and Smyth, R. (2008). "Energy consumption and real GDP in G7 countries: new evidence from panel cointegration with structural breaks". *Energy Economics*, 30(5):2231–2341.
- [57] Nesbakken, R. (2001). "Energy consumption for space heating: a discrete-continuous approach." *Scandinavian Journal of Economics*, 103(1):165–184.
- [58] Pendakur, K. (2009). "EASI made easier". *Quantifying Consumer Preferences*.
- [59] Pinzón, I. (2010). "Estimación de funciones de consumo de energía eléctrica para clientes residenciales en Bogotá." .
- [60] PND (2018). *Plan Nacional de Desarrollo*.
- [61] Pollak, R. and Wales, T. J. (1995). *Demand System Specification and Estimation*. Oxford University Press.
- [62] Ramírez, A. and Londoño, E. (2008). "Implicaciones de bienestar en el sector residencial de la unificación tarifaria en el servicio de electricidad en el departamento de Antioquia". *Ecós de Economía*, 13(28):1–45.
- [63] Reaños, M. A. T. and Wölfing, N. M. (2018). "Household energy prices and inequality: Evidence from German microdata based on the EASI demand system." *Energy Economics*, 70:84–97.
- [64] Ruijs, A., Zimmermann, A., and Berg, M. (2008). "Demand and distributional effects of water pricing policies". *Ecological Economics*, 66:506–516.
- [65] Schleich, J. and Hillenbrand, T. (2009). "Determinants of residential water demand in Germany". *Ecological Economics*, 68:1756–1769.
- [66] Schmidt, C. A. J. and Lima, M. A. (2004). "A demanda por energia elétrica no Brasil." *Revista brasileira de economia*, 58(1):68–98.
- [67] Schulte, I. and Heindl, P. (2017). "Price and income elasticities of residential energy demand in Germany." *Energy Policy*, 102:512–528.
- [68] Shi, G., Z. X. and Song, F. (2012). "Estimating elasticity for residential electricity demand in China." *The Scientific World Journal*.
- [69] Silk, J. I. and Joutz, F. L. (1997). "Short and long-run elasticities in US residential electricity demand: a co-integration approach." *Energy Economics*, 19(4):493–513.
- [70] Uhr, D. D. A. P., Chagas, A. L. S., and Uhr, J. G. Z. (2019). "Estimation of elasticities for electricity demand in Brazilian households and policy implications." *Energy policy*, 129:69–79.
- [71] UPME (2015). *Desarrollo de una metodología para determinar los costos de racionamiento de los sectores de electricidad y gas natural*.
- [72] UPME (2019). *Plan Energético Nacional 2020–2050*.
- [73] Woo, C. K., Liu, Y., Zarnikau, J., Shiu, A., Luo, X., and Kahrl, F. (2018). "Price elasticities of retail energy demands in the United States: New evidence from a panel of monthly data for 2001–2016." *Applied energy*, 222:460–474.
- [74] Yoo, S. H., Lee, J. S., and Kwak, S. J. (2007). "Estimation of residential electricity demand function in Seoul by correction for sample selection bias." *Energy Policy*, 35(11):5702–5707.
- [75] Zapata, J. (2011). "Impacto del PIB, del gas natural y de los precios de la electricidad, en el Consumo de Energía Eléctrica en Colombia." .

## 7. ANEXOS

**TABLE 18: SUMMARY STATISTICS BY STRATUM**

**TABLE 17: DEMOGRAPHIC STATISTICS BY STRATUM**

Variable	Mean	Std. Dev.	Min.	Max.	N	
<b>Stratum 4</b>						
Age H.h	54.01	15.78	17	97	3,898	
Gender H.h	0.58	0.49	0	1		
Members	2.89	1.43	1	10		
<b>Education</b>						
Elementary school	0.06	0.24	0	1		
High School	0.17	0.38	0	1		
Associate Degree	0.14	0.35	0	1		
Undergraduate	0.38	0.49	0	1		
Postgraduate	0.24	0.43	0	1		
<b>Altitude</b>						
Below 1,000 m.a.s.l	0.48	0.5	0	1		
Between 1,000 and 2,000 m.a.s.l	0.26	0.44	0	1		
More than 2,000 m.a.s.l	0.26	0.44	0	1		
<b>Expenditure statistics (USD)</b>						
Total expenditure in utilities	66.07	42.75	0.85	527.06		
Variable expenditure in services	62.2	42.61	0.85	524.25		
Expenditure in electricity	37.2	33.03	0	494.27		
Expenditure in water	15.44	16.62	0	262.01		
Expenditure in sewerage	3.05	4.55	0	57.38		
Expenditure in gas	6.51	7.21	0	126.18		
Fixed cost	4.72	1.24	2.86	9.54		
Fixed cost water	2.43	0.86	1.12	4.77		
Fixed cost sewerage	1.42	0.55	0.48	4.33		
Fixed cost gas	0.87	0.23	0.34	1.39		
Total income	1,641.73	1,812.99	0	43,415.44		
Current income	1,370.74	1,603.77	0	43,278.74		
Total expenditure	1,256.22	1,208.71	98.87	27,951.5		
Current expenditure	909.17	703.29	24.54	13,101.27		
<b>Stratum 5</b>						
Age H.h	56.55	16.29	18	99		1,296
Gender H.h	0.58	0.49	0	1		
Members	2.7	1.31	1	8		
<b>Education</b>						
Elementary school	0.04	0.19	0	1		
High School	0.11	0.32	0	1		
Associate Degree	0.09	0.28	0	1		
Undergraduate	0.43	0.49	0	1		
Postgraduate	0.33	0.47	0	1		
<b>Altitude</b>						
Below 1,000 m.a.s.l	0.3	0.46	0	1		
Between 1,000 and 2,000 m.a.s.l	0.48	0.5	0	1		
More than 2,000 m.a.s.l	0.22	0.41	0	1		
<b>Expenditure statistics (USD)</b>						
Total expenditure in utilities	84.63	54	2.79	517.12		
Variable expenditure in services	78.57	53.96	1.87	511.07		
Expenditure in electricity	39.11	40.72	0	409.87		
Expenditure in water	25.45	26.81	0	244.86		
Expenditure in sewerage	5.45	8.21	0	74.71		
Expenditure in gas	8.56	9.13	0	162.4		
Fixed cost	7.34	1.99	4.5	13.26		
Fixed cost water	3.88	1.49	1.99	8.57		
Fixed cost sewerage	2.39	0.72	1.12	5.34		
Fixed cost gas	1.07	0.23	0.41	1.67		
Total income	2476.12	2490.68	0	50483.64		
Current income	2057.06	1934.45	0	23157.89		
Total expenditure	1991.72	2729.49	180.88	62399.57		
Current expenditure	1395.28	1701.44	82.14	50915.87		
<b>Stratum 6</b>						
Age H.h	58.38	15.21	20	97		644
Gender H.h	0.64	0.48	0	1		
Members	2.74	1.33	1	8		
<b>Education</b>						
Elementary school	0.03	0.16	0	1		
High School	0.1	0.30	0	1		
Associate Degree	0.05	0.23	0	1		
Undergraduate	0.41	0.49	0	1		
Postgraduate	0.41	0.49	0	1		
<b>Altitude</b>						
Below 1,000 m.a.s.l	0.47	0.5	0	1		
Between 1,000 and 2,000 m.a.s.l	0.27	0.44	0	1		
More than 2,000 m.a.s.l	0.26	0.44	0	1		
<b>Expenditure statistics (USD)</b>						
Total expenditure in utilities	126.22	100.04	12.91	1027.16		
Total expenditure in services	119.53	100.03	6.58	1022.21		
Expenditure in electricity	68.33	71.97	0	564.05		
Expenditure in water	33.15	48.48	0	1006.13		
Expenditure in sewerage	6.31	11.68	0	115.77		
Expenditure in gas	11.74	10.76	0	106.26		
Fixed cost	8.31	1.96	4.61	17.09		
Fixed cost water	4.31	1.39	2.05	9.82		
Fixed cost sewerage	2.82	0.71	1.16	5.77		
Fixed cost gas	1.18	0.23	0.58	1.5		
Total Income	3709	3370.54	0	29297.36		
Current income	3056.26	2988.55	0	27970.19		
Total Expenditure	2620.11	2214.77	136.7	26177.15		
Current Expenditure	1753.08	1357.22	119.6	10446.89		

Variable	Mean	Std. Dev.	Zero Shares		
<b>Shares</b>					
<b>Stratum 4</b>					
Electricity	0.58	0.19			
Water	0.25	0.18			
Sewerage	0.06	0.08			
Natural Gas	0.11	0.11			
<b>Stratum 5</b>					
Electricity	0.48	0.23			
Water	0.32	0.25			
Sewerage	0.08	0.10			
Natural Gas	0.12	0.12			
<b>Stratum 6</b>					
Electricity	0.54	0.20			
Water	0.29	0.20			
Sewerage	0.07	0.09			
Natural Gas	0.11	0.10			
Prices			N	Min	Max
<b>Stratum 4</b>					
Electricity(USD/kWh)	0.16	0.01	3,898	0.13	0.20
Water(USD/m3 )	0.55	0.15		0.16	0.91
Sewerage(USD/m3)	0.46	0.15		0.16	1.05
Natural Gas(USD/m3)	0.47	0.12		0.09	0.87
<b>Stratum 5</b>					
Electricity(USD/kWh)	0.19	0.01	1,296	0.16	0.27
Water(USD/m3 )	0.87	0.23		0.23	1.39
Sewerage(USD/m3)	0.77	0.22		0.24	1.23
Natural Gas(USD/m3)	0.57	0.09		0.23	0.95
<b>Stratum 6</b>					
Electricity(USD/kWh)	0.18	0.01	644	0.15	0.22
Water(USD/m3 )	1.02	0.21		0.25	1.46
Sewerage(USD/m3)	0.85	0.22		0.38	1.31
Natural Gas(USD/m3)	0.57	0.09		0.36	0.85

Prices are converted to dollars using the exchange rate of 30/06/2017, equivalent to 1 USD = \$3,038.26 . **Source:** Superintendencia Financiera de Colombia

**TABLE 19: COMPENSATED PRICE EFFECTS, EVALUATED FOR REPRESENTATIVE HOUSEHOLD: STRATUM 4**

	Own-Price B element	Own-Price Slutsky element	Electricity	Water	Gas
Electricity	0.0545** (0.0176)	-0.1580*** (0.0216)	0.0874*** (0.0216)		
Water	-0.0670 (0.0138)	-0.1314*** (0.0206)	-0.0586*** (0.0174)	0.0517* (0.0206)	
Gas	0.0070 (0.0107)	-0.0907*** (0.0130)	-0.0251 (0.0134)	-0.0063 (0.01030)	0.0183 (0.0130)

Standard error are in parenthesis, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

**TABLE 20: COMPENSATED PRICE EFFECTS, EVALUATED FOR REPRESENTATIVE HOUSEHOLD: STRATUM 5**

	Own-Price B element	Own-Price Slutsky element	Electricity	Water	Gas
Electricity	0.0545** (0.0176)	0.0476 (0.0273)	0.2648*** (0.0273)		
Water	-0.0670 (0.0138)	-0.0596* (0.0237)	-0.2279*** (0.0204)	0.1900*** (0.0237)	
Gas	0.0070 (0.0107)	-0.0642*** (0.0195)	-0.053 (0.0195)	0.0857*** (0.0135)	0.0397* (0.0195)

Standard error are in parenthesis, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

**TABLE 21: COMPENSATED PRICE EFFECTS, EVALUATED FOR REPRESENTATIVE HOUSEHOLD: STRATUM 6**

	Own-Price B element	Own-Price Slutsky element	Electricity	Water	Gas
Electricity	0.0545** (0.0176)	-0.2330*** (0.0376)	0.0161 (0.0376)		
Water	-0.0670 (0.0138)	-0.0847** (0.0359)	-0.0896** (0.0301)	0.1237*** (0.0359)	
Gas	0.0070 (0.0107)	-0.1372*** (0.0291)	0.0291 (0.0263)	0.0455* (0.0193)	0.0098 (0.0291)

Standard error are in parenthesis, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

**TABLE 22: REAL EXPENDITURE SEMIELASTICITIES: STRATUM 4**

Electricity	Water	Gas
0.0567*** (0.0132)	0.0077 (0.0141)	-0.0336*** (0.0078)

Standard error are in parenthesis, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

**TABLE 23: REAL EXPENDITURE SEMIELASTICITIES: STRATUM 5**

Electricity	Water	Gas
-0.0415** (0.0146)	0.1289*** (0.0155)	-0.0497*** (0.0085)

Standard error are in parenthesis, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

**TABLE 24: REAL EXPENDITURE SEMIELASTICITIES: STRATUM 6**

Electricity	Water	Gas
-0.0247 (0.0172)	0.0796*** (0.0180)	-0.0218* (0.0098)

Standard error are in parenthesis \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

**TABLE 25: DEMOGRAPHIC SEMIELASTICITIES: STRATUM 4**

	Members	Age	Gender	Stratum 5	Stratum 6	Elementary School	High School	Associate degree	Postgraduate	>1,000 m.a.s.l
Electricity	0.0071* (0.0029)	0.0159*** (0.0002)	0.0051 (0.0074)	-0.0160 (0.0099)	0.0151 (0.0162)	-0.0434* (0.0185)	-0.0510*** (0.0110)	-0.0451*** (0.0123)	-0.0298*** (0.0087)	-0.1712*** (0.0086)
Water	-0.0263*** (0.0029)	-0.0122*** (0.0002)	-0.0065 (0.0073)	-0.0005 (0.0092)	-0.0359* (0.0150)	0.0241 (0.0184)	0.0227 (0.0109)	0.0127 (0.0122)	-0.0049 (0.0086)	0.1239*** (0.0087)
Gas	0.0032 (0.0023)	-0.0100 (0.0002)	-0.0104 (0.0058)	-0.0097 (0.0077)	-0.0014 (0.0119)	0.0004 (0.0144)	-0.0070 (0.0086)	-0.0168 (0.0096)	-0.0047 (0.0067)	-0.0131 (0.0066)

Standard error are in parenthesis, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

**TABLE 26: DEMOGRAPHIC SEMIELASTICITIES: STRATUM 5**

	Members	Age	Gender	Stratum 5	Stratum 6	Elementary School	High School	Associate degree	Postgraduate	>1,000 m.a.s.l
Electricity	-0.0506*** (0.0039)	-0.0396*** (0.0003)	-0.0495*** (0.0099)	-0.0753*** (0.0122)	-0.0672*** (0.0140)	-0.0140 (0.0265)	0.0015 (0.0154)	0.0109 (0.0175)	0.0091 (0.0111)	-0.1235*** (0.0117)
Water	0.0238*** (0.0040)	0.0340*** (0.0003)	0.0394*** (0.0103)	0.0567*** (0.0122)	0.0391** (0.0143)	0.0654* (0.0274)	0.0569*** (0.0156)	0.0459** (0.0181)	0.0330** (0.0115)	0.1338*** (0.0121)
Gas	0.0186*** (0.0022)	0.0046*** (0.0002)	0.0036 (0.0059)	0.0006 (0.0077)	0.0097 (0.0093)	-0.0477** (0.0153)	-0.0575*** (0.0090)	-0.0716*** (0.0102)	-0.0550*** (0.0066)	-0.0597*** (0.0072)

Standard error are in parenthesis, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

**TABLE 27: DEMOGRAPHIC SEMIELASTICITIES: STRATUM 6**

	Members	Age	Gender	Stratum 5	Stratum 6	Elementary School	High School	Associate degree	Postgraduate	>1,000 m.a.s.l
Electricity	-0.0035 (0.0029)	0.0049*** (0.0002)	-0.0055 (0.0073)	-0.0264** (0.0097)	0.0016 (0.0199)	-0.0173 (0.0187)	-0.0231* (0.0110)	-0.0162 (0.0124)	-0.0088 (0.0085)	-0.1519*** (0.0083)
Water	-0.0199*** (0.0031)	-0.0055*** (0.0003)	0.0002 (0.0080)	0.0106 (0.0104)	-0.0308 (0.0216)	0.0111 (0.0203)	0.0105 (0.0119)	0.0006 (0.0135)	-0.0099 (0.0093)	0.1109*** (0.0092)
Gas	0.0112*** (0.0016)	-0.0021*** (0.0001)	-0.0029 (0.0041)	-0.0024 (0.0054)	0.0147 (0.0111)	0.0081 (0.0104)	0.0080 (0.0061)	-0.0019 (0.0069)	0.0122* (0.0048)	0.0027 (0.0048)

Standard error are in parenthesis, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$