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Abstract: This paper fills a gap in the literature on residential energy consumption in Brazil. We estimate price and income elasticities for residential electricity consumption using disaggregated data at household level for the São Paulo metropolitan area. Data were obtained from *Fundação Instituto de Pesquisas Econômicas* (Fipe), which has complete access to *Pesquisa de Orçamento Familiar (POF)*. Information about residential electricity consumption and household characteristics was available at two different periods, 1998 and 2008, which enabled us to adopt panel data estimation procedures. This study is the first to use Brazilian household level data on electricity consumption and a panel approach to estimate price and income elasticities. The results show that the price elasticity ranges from -0.26 to -0.64 and the income elasticity between 0.11 and 0.32. Controlling for a variety of fixed effects, household and family characteristics, price and income elasticities for the short-run are, approximately, -0.50, and 0.21.

Keywords: Electricity; Price elasticity; Income elasticity; Brazil; household data.

JEL Codes: C23; D12; Q41.

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1. Introduction

The electric power market is key to the growth and development of any economy. One of the most important issues in this area is to understand how the demand for residential energy changes when both the price of electricity and the income of consumers are varying (Dilaver and Hunt, 2011; Chang et al., 2014). The correct identification of the demand function parameters for residential energy consumption is relevant for the provision of estimates of future demand. An accurate estimation of price and income elasticities for residential electrical consumption serve as valuable inputs for policymakers and for electric companies in terms of investments in infrastructure, energy production, distribution structure, and profitability analysis (Medlock III and Soligo, 2001; Silk and Joutz, 1997; Beenstock et al., 1999; Chang et al., 2009; Nakajima and Hamori, 2010; Labandeira et al., 2017).

Although there are many publications regarding the energy sector in Brazil, there are few studies that estimate the price and income elasticities for the residential urban sector and even fewer that use some level of disaggregated data. This paper fills a gap in the literature on residential energy consumption in Brazil. We are the first to empirically estimate price and income elasticities for residential electricity consumption using disaggregated data at the household level. Household level data is more informative because we can monitor the consumers in different periods of time using a panel structure. It also allows us to control for household and family characteristics that might affect energy consumption, seasonality, and other unobservable characteristics by using fixed effects.

We use data from the *Pesquisa de Orçamento Familiar* (POF, or Household Budget Survey) which is conducted by the *Fundação Instituto de Pesquisa Econômica* (FIPE, or Economic Research Institute Foundation). The data collected by the POF survey is not entirely open to the public because it contains private information regarding the interviewed families. We had access to the complete sample and could obtain information about the household's energy consumption, family income, property details, among other variables. The sample covers residences in the metropolitan area of São Paulo and was available at two different periods, 1998-99 (POF98) and 2008-13 (POF08), which enabled us to adopt panel data estimation procedures and to control for a variety of fixed effects. In general terms, the estimated price elasticities range from -0.46 to -0.56, and the income elasticities range from 0.20 to 0.32. Therefore, our main contribution to empirical research is an accurate estimation of price and income elasticities for the residential electrical consumption for the São Paulo metropolitan area.

The remainder of this paper is organized as follows. The next section provides an overview of the residential electrical energy market in Brazil, followed by a brief empirical literature review in Section 3. Subsequently, in Section 4, the model specification and data are presented and discussed. Next, we present the empirical results with a robustness checks section. Finally, conclusions and political implications are discussed in section 6.

2. Production, distribution, price policies and residential energy consumption in Brazil

According to the Brazilian Energy Balance (MME, 2016), electricity generation in Brazil comes mainly from hydropower, corresponding to 64% of the domestic electricity supply. Other main sources are natural gas (12.9%), biomass (8%), oil sub-products, coal, and coal sub-products (9.3%). The Wind, solar and nuclear sources account for the remaining 5,91%. Public service plants are the largest producers, generating 83% of total capacity. Electricity consumption and generation have been growing since the 1970s, experiencing short periods of decline (as in the energy crises of 2001). The residential use of firewood and other indoor polluting energy sources have declined with the expansion of the electric system to rural locations. The Federal program *Luz Para Todos* (Light for All), launched in 2003, is the most famous initiative and aimed at bringing access to electricity, free of charge, to more than 10 million rural people living in vulnerable conditions (WEO, 2013). Besides these expansion and inclusion policies, the residential sector has experienced growth rates of 4.9% a year (from 2003 to 2012) mainly due to easy credit conditions for consumers with reflections over the sales of home electrical appliances (Villareal and Moreira, 2016; Achão and Schaeffer, 2009; WEO, 2013). In 2015 the residential electric consumption corresponded to 25% of the total market, the industrial sector is the main consumer, with 37.6% (MME, 2016). Although expected to continue growing in the upcoming years, when compared to developed countries, electricity consumption in Brazil is still very small (Villareal and Moreira, 2016).

With regards to household electricity prices, the majority of consumers face flat rates, that is, retail prices are fixed and defined by ANEEL (National Agency for Electric Energy). Created in 1997, ANEEL is responsible for regulating and supervising the power sector and energy prices and for boosting efficiency advances in the generation and distribution of energy (WEO, 2013; ANEEL, 2008). The main players in the sector are the energy generating companies, that produce the energy; the transmission companies, responsible for transporting energy from the point of generation to the consumer centers; and the distribution companies, which take energy to the home of the consumer. The costs of generation (31.33%), transmission (6.25%) and distribution (28.98%) are included in the final consumer's bill, plus taxes and charges at different levels of government (33.45%)[1]. Energy tariffs for the electric sector are revised every 4-5 years (obeying regulatory periods for concessions' contracts) to establish a new plateau for prices and are also adjusted annually in accordance with inflation rates and other distribution costs (Corton et al., 2016; ANEEL, 2008). Following these rules, from 2003 to 2007, residential electricity prices had a real increase of 32% (ANEEL, 2008).

Until 1993, energy prices were uniform for the entire territory. Federal Law 8.631 ended this model and the tariff became fixed by concession area: a geographic territory where each distribution company is contractually obliged to supply electricity, which may or may not coincide with the limits of the federative units (a single state can have more than one concession area and, therefore, more than one energy tariff). Thus, according to ANEEL (2008), energy tariffs reflect the peculiarities of each region, such as the number of consumers, the size of the

[1] Data considering the Brazilian mean tariff for 2007 (ANEEL, 2008).

consumer market or the distribution network, state and local taxes, among other factors. Additionally, in Brazil, the electricity tariff is calculated according to consumption classes: residential; industrial; commercial and services; rural; public power; street lighting; public service, and own consumption. Each class has a distinct tariff structure, according to the peculiarities of energy consumption and power demand.

Regarding residential consumers, energy prices vary according to the type of residential connection: whether in single-phase, two-phase or three-phase circuits. There are also low income and indigenous groups that receive substantial energy subsidies. The Social Energy Tariff was created in 2002 by the Federal Law 10.438 and it is intended to give a discount to the energy bill of low-income consumers in different categories of consumption with the objective of expanding and democratizing the access to electricity. Federal Law 12.212/2010 and Decree 7.583/2011, defined the socio-economic criteria[2] for receiving the benefit and stipulated the discounts[3]. Prior to that, ANEEL was the responsible for the direct regulation of the abatement[4].

3. Brief empirical literature review

Several international studies seek to estimate the price and income elasticities for the residential electricity consumption. However, the literature for Brazil is still relatively scarce (Uhr et al., 2017). In this section, we present a short review of the empirical studies for the field.

3.1 International literature

The international empirical literature is rich, mainly at the country level (e.g., Table 1) but also for regional applications (Zhang et al., 2017; Gomez et al., 2013; Hosoe and Akiyama, 2009).

Table 1 – Empirical Studies for abroad and calculated elasticities

Author	Period	Country	Method	Short Run		Long Run	
				Price (-)	Income	Price (-)	Income
Labandeira et al. (2017)	-	Meta-analis.	GLS/FE	0.22/0.21	-	0.58/0.61	-
Schulte & Heindl (2017)	1993-08	Germany	QES	0.43-0.50	0.40-0.41	-	-
Wang & Mogi (2017)	1989-14	Japan	TVP	0.46-0.68	0.86-1.59	-	-
Sun & Ouyang (2016)	2013	China	AIDSM	0.39	0.62	-	-
Okajima & Okajima (2013)	1990-07	Japan	GMM	0.40	-	0.49	-
Zhou & Teng (2013)	2007-09	China	OLS	0.35-0.50	0.14-0.33	-	-
Arthur et al. (2012)	2002-03	Mozambic	Deaton's	0.49-0.66	0.52-0.69	-	-
Alberini & Filippini (2011)	1995-07	USA	GMM	0.08-0.15	-	0.45-0.75	-
Filippini (2011)	2000-06	Swiss	LSDV	0.65-0.84	-	1.27-2.26	-
Halicioglu (2007)	1968-05	Turkey	ARDL	0.33	-	0.52	-
Filippini & Pachauri (2004)	1993-94	India	OLS	0.29-0.51	0.60-0.64	-	-
Nesbakken (1999)	90/93/95	Norway	C.S.	0.24-0.53	-	-	-

Notes: Labandeira et al. (2017) use uses meta-analysis to identify the main factors affecting short and long terms price and income elasticities for different countries. He also presents an interesting literature review.

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[2] Socioeconomic criteria are: The family must be enrolled in the Federal Government's Single Registry for Social Programs, with monthly family per capita income less than or equal to half a national minimum wage, or to have among its member's someone receiving continued social assistance.

[3] Up to 30 kWh/month, 65% discount; between 31 kWh/month and 100 kWh/month, 40% discount; between 101 kWh/month and 220 kWh/month, 10% discount.

[4] Until 2010, the reductions in the light bill varied between 10% and 65% with an automatic discount for residences with consumption below 80 kWh monthly. Between 80 kWh and 220 kWh, households with a per capita family income of up to R $ 120.00 were entitled to the benefit.

Table 1 presents selected empirical studies that seek to identify the price and/or income elasticities for household electricity demand, for the short and long terms or both. Calculated elasticities are shown at the end of the table. It should be noted that the identification of price elasticities receives more attention in the literature than the estimation of income elasticities. Table 1 also depicts data location, the period of analysis, and employed methodology for each selected study.

3.2 Brazilian literature

Although there are many publications regarding the energy sector in Brazil[5], there are few studies that estimate price and income elasticities for residential electricity consumption and even fewer use some level of disaggregated data. Table 2 presents a summary of the empirical studies published in Brazil that estimate such elasticities.

Table 2 – Empirical Studies for Brazil and calculated elasticities

Author	Period	Level	Method	Short Run		Long Run	
				Price (-)	Income	Price (-)	Income
Uhr et al. (2017)	2004-2014	States	GMM	0.13-0.18	0.08-0.12	0.62-1.47	0.32-1.09
Villareal & Moreira (2016)	1985-2013	Country	OLS	-	-	0.230	0.188
Viana & Silva (2014)	1975-2006	Country	VAR/VEC	-	-	0.707	1.79
Irffi et al. (2009)	1970-2003	NE	DOLS	0.2078	0.013	0.687	0.684
Siqueira et al. (2006)	1970-2003	NE	VEC	0.298	0.181	0.412	1.40
Mattos & Lima (2005)	1979-2002	MG	VAR/VEC	-	-	0.258	0.532
Schmitd & Lima (2004)	1969-1999	Country	VAR/VEC	-	-	0.085	0.539
Andrade & Lobão (1997)	1963-1995	Country	VAR/VEC	0.06	0.212	0.051	0.2132
Modiano (1984)	1963-1981	Country	OLS	0.118	0.332	0.403	1.13

Notes: Uhr et al. (2017) use a state level panel comprising all Brazilian regions. Irffi et al. (2009) and Siqueira et al. (2006) work with the same aggregated dataset comprising the northeast region of Brazil. Mattos and Lima (2005) use data only for the state of Minas Gerais. The remaining studies work with aggregated data for Brazil.

Uhr et al. (2017) is the only study with some level of disaggregation. The authors estimate short-term and long-term price and income elasticities for the residential electricity consumption using data for the Brazilian states with a panel structure and a Difference GMM approach (Arellano and Bond, 1991). They estimate seven models incorporating different sets of control variables and find short-term price elasticities varying between 0.13% to -0.18% and the long-term price elasticity ranging between -0.617% to -1.472%. The short-term estimates for the income-elasticity range between 0.08% and 0.12%, and long-run coefficients between 0.324% to 1.095%.

All the remaining studies are based on time series analysis and aggregated data for Brazil or for specific regions mainly because of "data availability" issues (Villareal and Moreira, 2016; Viana and Silva, 2014; Irffi et al., 2009; Siqueira et al., 2006; Mattos and Lima, 2005; Schmidt and Lima, 2004; Andrade and Lobão, 1997; Modiano, 1984). Some estimate only long-run elasticities and only Villareal and Moreira (2016) work with recent data.

[5] See, for instance, Corton et al. (2016), Slough et al. (2015), Achão and Schaeffer (2009), Wachsmann et al. (2009), Ghisi et al. (2007), Cohen et al. (2005), and Januzzi and Schipper (1991) for subjects such as household energy requirements and electricity end-uses, structural changes in electricity consumption, consumption by income classes and in different regions, determinants of electricity use, rural electrification, production and distribution costs, energy crisis in 2001, and other related subjects.

4. Model Specification and Data

4.1. Model

Consider the Cobb-Douglas demand function with the following form:

$$C_{it} = A_{it}(P_{it})^{\alpha_1}(I_{it})^{\alpha_2}e^{X_{it}\delta} \quad (1)$$

In equation (1) the subscript *i* represents the individual and the subscript *t* represents different time periods. C_{it} is the demand for residential energy, P_{it} is the price of electricity (energy tariff), I_{it} is the real income, and X_{it} is a vector of control variables that affect the energy consumption. Taking the natural logarithm of equation (1), we have:

$$lnC_{it} = \ln A_{it} + \alpha_1 lnP_{it} + \alpha_2 lnI_{it} + X_{it}\delta \quad (2)$$

Replacing $\ln A_{it}$ by the terms $(\mu_i + \theta_t)$ and adding a stochastic error term u_{it} in equation (2), we come to the following econometric specification:

$$lnC_{it} = \mu_i + \theta_t + \alpha_1 lnP_{it} + \alpha_2 lnI_{it} + X_{it}\delta + u_{it} \quad (3)$$

Equation (3) requires a panel data approach to control the fixed effects relative to the characteristics of the consumer that are constant over time (μ_i). It should be noted, however, that the residential consumer might have his electricity consumption level associated with household structural characteristics (*h*) and/or family characteristics (*f*). In addition, the weather might have seasonal/monthly effects (*m*) on the energy bill, as might specific years (*y*), e.g., during summer or a year with abnormally high temperatures. Therefore, our empirical strategy follows the following equation:

$$lnC_{hfmy} = \mu_h + \pi_f + \omega_m + \theta_y + \alpha_1 lnP_{hfmy} + \alpha_2 lnI_{hfmy} + X_{hfmy}\delta + u_{hfmy} \quad (4)$$

Terms μ_h, π_f, ω_m, θ_t are the mentioned fixed effects. The subscripts *h*, *f*, *m*, and *t*, represent, respectively, the same household, the same family observed in the two different time periods of the sample (1998-99 and 2008-13), the month of observation, and year of observation. The dependent variable, lnC_{hfmt}, is the residential energy consumption, defined as the natural logarithm of the consumed kWh (kilowatts per hour). The coefficients of interest are α_1 and α_2, which represent, respectively, the price and income elasticities of household electricity demand, which are associated with variables lnP_{hfmt} and lnI_{hfmt}. The first is the amount paid per kWh and the last the household income. The interpretation of the coefficients is straightforward:

$$\frac{\partial lnC_{hfmy}}{\partial lnP_{hfmy}} = \alpha_1 \text{ and } \frac{\partial lnC_{hfmy}}{\partial lnI_{hfmy}} = \alpha_2 \quad (5)$$

The vector containing the control variables is represented by X_{hfmt}. The parameter vector δ identifies the effects of the controls on energy consumption. Finally, u_{hfmt} represents the random disturbance.

Controls are separated into 5 groups: Group 1 representing household architectonic characteristics (number of rooms, bathrooms and restrooms in the residence), Group 2 for electrical equipment ownership (number of sound systems, air conditionings, vacuum cleaners, electric showers, microwaves, refrigerators, irons, washing machines, and computers in the residence), Group 3 representing property status (if own residence, residence in acquisition, leased, rented, and others) and kind of residence (if house, apartment or flat, and others,) Group 4 containing household occupant's characteristics (average age of the residents, number of occupants under 18 years, and the instruction degree of the head of the family), and Group 5 for social benefits variables (if one of the occupants receives *Bolsa Familia*[6] or enrolls in another social benefit program or if this person receives at least half of the national minimum wage).

For the correct identification of the price and income elasticities, we must make sure that all possible sources of bias in the parameters are controlled for. Basically, we might have three major sources of endogeneity: measurement error, simultaneity, and omitted variable bias. The first is unlikely because data collection was done randomly by a known research center with experienced personnel. It should be noted that there is no selection bias in the sample because data collection did not depend on the choice of the consumers. The second source of endogeneity, the simultaneity problem, is not sustainable because electric energy prices are regulated by the central government and the residential energy tariff is rigid in the short-run (it does not react to changes in demand). If doubts, check section 2.

The third source of endogeneity must be carefully considered. The omitted variable bias occurs when we disregard relevant variables that are potentially correlated with the other explanatory variables (prices and income). On that case, the error term becomes correlated with the explanatory variables and the estimates become biased and inconsistent. The panel data approach allows us to eliminate that bias when the omitted variables are constant over time, such as those within a given household, or a given family.

4.2. Data

We use data from the *Pesquisa de Orçamento Familiar* (POF, or Household Budget Survey) which is conducted by the *Fundação Instituto de Pesquisa Econômica* (FIPE, or Economic Research Institute Foundation). The data collected by the POF survey is not entirely open to the public because it contains private information regarding the interviewed families. We had access to the complete sample and could obtain information about the household's energy consumption, family income, property details, among other variables. The sample covers residences in the metropolitan area of São Paulo and was available at two different periods, 1998-99 (POF98) and 2008-13 (POF08). For the first sample, information was collected from 1,207 residences between 1998 and 1999, with households being selected randomly. The second period of the collection took place during the years 2008 to 2013 and information was collected from 3,126 residences. The second survey followed the households of the first sampling, and randomly enlarged the sample, that is, domiciles interviewed in the first sample were also interviewed for the second sample. This allowed us to control for residential and family fixed effects as mentioned before.

To estimate price and income elasticities for the residential electricity consumption we consider those families that had information about the electricity bill, with the consumption of electric energy (kWh) and paid values. Thus, the valid sample for the POF98 was 627 residences and for the POF08, 947 households. There are 270 domiciles with information for the light bill that are observed in both samples. Missing data on electric power consumption is

[6] The *Bolsa Família* Program (PBF) is an income transfer program of the Brazilian Federal Government instituted by Provisional Measure 132, dated October 20, 2003, converted into a law on January 9, 2004, by Federal Law n. 10,836. Enrollment in the program is a necessary condition for reducing the light bill.

likely caused by the resident not having the energy bill for that month available for presentation to the researcher at the time of the interview[7].

The variable for the household energy consumption is given by the kilowatts appearing in the light bill that were consumed in the same month of the interview. The interviewers did not consider previous electricity bills. Therefore, consumed energy and paid values were collected only upon the exhibition of the current light bill. Since energy tariff information was not gathered by the research, we calculate the electricity price by dividing the total paid value by the amount consumed in that residence[8]. For the empirical analysis, both variables are transformed to the natural logarithm. The per capita family income was calculated by the summing up all individual incomes and then dividing it by the number of economically active agents in that residence. For the empirical analysis, this variable was also transformed to the natural logarithm. The use of these variables in the natural logarithm form allows us to directly identify the price and income elasticities that are represented by the associated angular coefficients in the linear regressions.

Control variables are divided into five groups. Group 1 representing household architectonic characteristics (number of rooms, bathrooms and restrooms in the residence), Group 2 for electrical equipment ownership (number of sound systems, air conditionings, vacuum cleaners, electric showers, microwaves, refrigerators, irons, washing machines, and computers in the residence), Group 3 representing property status (if own residence, residence in acquisition, leased, rented, and others) and kind of residence (if house, apartment or flat, and others,) Group 4 containing household occupant's characteristics (average age of the residents, number of occupants under 18 years, and the instruction degree of the head of the family), and Group 5 for social benefits variables (if the person who pays the bill receives *Bolsa Familia*[9]or enrolls in another social benefit program – SocialTariff1 – or if this person receives as paycheck not more than half of the national minimum wage – SocialTariff2)[10]. For the variables in group 4, the average age of the residents is constructed by dividing the sum of the ages of all residents, by the number of people living in the domicile. The instruction degree of the head of the family is given by seven education dummies[11].

Additionally, we have dummy variables identifying if the same residence is observed in both periods (POF 98 and POF08) if the same family continued living in the interviewed households[12], the month of data collection and the year of data collection. In that way, we could control for household fixed-effects, family fixed-effects, seasonal/monthly fixed-effects, and macroeconomic/policy shocks captured by year fixed-effects.

Table 3 presents the descriptive statistics separated by the two sampling periods, POF98 and POF08.

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[7] We can consider that the domiciles left the panel randomly because we have information for all the other variables besides the energy bill. According to Cameron and Triverdi (2005) and Baltagi (2008), if missing data are random, then converting it into a panel structure results in a nonbiased sample. Therefore, analysis considering unbalanced or incomplete panels entails, at most, only a loss of efficiency.

[8] We are dealing with the actual cost of electricity to the families, considering the costs of generation, transmission, and distribution, that are incorporated into the energy tariff, plus taxes and charges at federal, state, and municipal levels. Paid values were deflated using the Consumer Price Index (General prices) calculated by FIPE (IPC/FIPE) and January 1998 as the reference period.

[9] The *Bolsa Família* Program (PBF) is an income transfer program of the Brazilian Federal Government instituted by Provisional Measure 132, dated October 20, 2003, converted into a law on January 9, 2004, by Federal Law n. 10,836. Enrollment in the program is a necessary condition for reducing the light bill.

[10] People in those conditions are entitled to an energy discount and/or are eligible for the Social Energy Tariff program.

[11] The seven indicative variables are Illiterate; Elementary school incomplete, elementary complete, Secondary incomplete, secondary complete, University incomplete, University complete or more.

[12] Approximately 37% of the sample in the second period is composed of households with the same family.

Table 3 – Descriptive statistics

Variables	POF98		POF08	
	Mean	**S.D.**	**Mean**	**S.D.**
Consumption (kWh)	338.8419	247.8868	226.2494	114.9706
Price	.4039461	2.448862	.2135505	.1286827
Income	1822.132	2118.64	1788.973	1741.554
Group 1				
# Bedrooms	2.00319	.8534778	2.016701	.7823369
# Bathrooms	1.258373	.6010421	1.34238	.621539
# Restrooms	.1786284	.4267299	.0939457	.2989793
Group 2				
# Air Conditioners	.0095694	.0974317	.0125261	.1202996
# Dishwashers	.1212121	.3266342	.0365344	.1932002
# Washing machines	.7192982	.4839212	.8507307	.3874393
# Irons	1.15311	.4717269	1.049061	.3751616
# Stereo systems	1.028708	.6512255	.8048017	.5858822
# Vacuum Cleaners	.3572568	.4927177	.3789144	.4939065
# TVs	1.722488	.9639781	1.84238	.9563074
# Fans	.8484848	.8019605	.9665971	.9528767
# Computers	.1961722	.4208443	.5793319	.6042956
# Microwaves	.5119617	.5221305	.7599165	.4297952
# Freezers	1.020734	.3635344	1.028184	.2291209
# Electric showers	1.192982	.6635767	1.269311	.5876807
Group 3				
Dummy Own Residence	.6507177	.4771239	.6210856	.4853702
Dummy Resid. in Acquis.	.076555	.2660964	.0605428	.2386143
Dummy Leased	.1786284	.3833467	.1920668	.3941311
Dummy Loaned	.0797448	.271114	.1169102	.3214811
Dummy Invasion	.0143541	.1190404	.006263	.0789324
Dummy Others	-	-	.0031315	.0559015
Dummy House	.8755981	.330303	.888309	.3151505
Dummy Apartment/Flat	.1132376	.3171361	.1085595	.3112482
Dummy Shack	.0111643	.1051535	-	-
Dummy Room	-	-	.0031315	.0559015
Group 4				
Age	32.38864	13.84341	41.69451	17.31672
Children	1.588517	1.214816	1.186848	1.127019
Group 5				
SocialTariff1	.0255183	.1578191	.0448852	.2071601
SocialTarrif2	-	-	.0146138	.1200636

Note: We have 627 valid observations for POF98 and 958 valid observations for POF08. The pooled sample has 1585 observations. The seven dummies for the instruction degree of the head of the family, dummies for months, and year dummies were omitted to avoid excessive rows.

We can see from Table 3 that both periods have similar means for most variables. However, it's important to note that both electricity consumption and energy prices are lower for the second period of sample[13]. Regarding the controls, the majority remains very close

[13] The energy/rationing crises of 2001 changed the Brazilian habits regarding energy consumption. Even with lower prices, the residential energy consumption returned to 2000 levels only in 2005 (WEO,2013). During the

between periods, except for the number of dishwashers, number of computers, and the average age of the residents.

5. Empirical results

Estimation results for equation (4) are reported in Table 4. We present nine models differing basically in the use of control variables. Specification 1 is a Pooled OLS with no controls and/or fixed-effects. Subsequent models add separately both the fixed effects as well as the control variables and are estimated using panel data techniques. In the last specification (Model 9) all controls and fixed-effects are considered. Price and income elasticities of household electricity demand, for each specification, are represented by the ε_P and ε_I coefficients, respectively.

The results reported in Table 4 show that the price elasticity (ε_P) has the expected sign, being negative for all proposed specifications and it's mostly inelastic. This means that an increase in the residential cost of energy reduces the amount of kWh consumed by the individual households, but with smaller impact reflecting the "essential-good" characteristic of electric energy. In more specific terms, the calculated price elasticities vary between -0.4445 (model 3) and -0.5644 (model 1). For the complete specification (Model 9), a 1% increase in the residential electricity cost reduces the residential energy consumption by 0.50%.

The results for income elasticity (ε_I) also show the expected signs, with positive coefficients across specifications. The coefficients magnitudes vary between 0.1977 (model 8) and 0.3222 (model 1), reflecting that increases in real income produce positive impacts on energy consumption. However, as for the price elasticities, these impacts are small. Considering the Model (9), a 1% increase in the average household income implies an increase of approximately 0.21% in residential electric energy consumption. That is, the residential consumption of electric energy is income-inelastic.

In general terms, the results in Table 4 are different from those at previous works for Brazil. The comparison of our results with the existing literature is hard because the periods of analysis are different, as well as the applied methodologies and the data's degree of aggregation. As highlighted in the literature review, no other work for Brazil has identified price and income elasticities with this level of data disaggregation, nor with the applied methodology. It should be noted, however, that Siqueira et al. (2006) fond relatively close coefficients. Their calculated price and income elasticities are, respectively, 0.30, and 0.18. They use aggregated data for Northeast Brazil and the 1970-2003 period.

With respect to the international literature, the works of Schulte and Heindl (2017), Wang and Mogi (2017), Zhou and Teng (2013), Arthur et al. (2012), Filippini and Pachauri (2004), and Nesbakken et al. (1999) found a price elasticity of electric energy demand close to -0.50, for different countries and different data structures. Zhou and Teng (2013), using urban-household level data for China, also found an income elasticity close to 0.21.

The next section presents robustness checks for our results.

1998-2008 period, we also observe the expansion of electricity access to low-income families through energy programs (*Luz para Todos, Tarifa Social de Energia*), social programs (*Bolsa Familia* and others) and economic growth.

Table 4– Estimated Price and Income Elasticities

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
ε_P	-.5644***	-.4897***	-.4445**	-.4506**	-.4488**	-.4639**	-.4811***	-.5011***	-.5038***
	(.0526)	(.1480)	(.1941)	(.1905)	(.1905)	(.1864)	(.1734)	(.1759)	(.1768)
ε_I	.3222***	.2616***	.2450**	.2440**	.2347**	.2018*	.2158**	.1977*	.2054*
	(.0193)	(.0930)	(.0966)	(.0981)	(.1036)	(.1094)	(.1076)	(.1072)	(.1125)
Group1	-	-	-	-	Yes	Yes	Yes	Yes	Yes
Group2	-	-	-	-	-	Yes	Yes	Yes	Yes
Group3	-	-	-	-	-	-	Yes	Yes	Yes
Group4	-	-	-	-	-	-	-	Yes	Yes
Group5	-	-	-	-	-	-	-	-	Yes
House. FE	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Family FE	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	-	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	-	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2 Adjust.	0.3316	0.4565	0.4873	0.4862	0.4822	0.4754	0.5052	0.5056	0.5046
Obs	1585	1585	1585	1585	1585	1585	1585	1585	1585

Notes: Significance level, * < 0.10; **<0.05; ***<0.01, showed only for ε_P and ε_I. Specification (1) refers to a Pooled OLS model. Specifications (2) to (9) are estimated using panel data techniques and only differ in the used controls and/or fixed-effects. Robust t statistics in parentheses. Group 1: Household architectonic characteristics. Group 2: Electrical equipment ownership. Group 3: Property status and kind of residence. Group 4: Household occupant's characteristics. Group 5: Social Benefits. Household FE: if the same residence observed in both periods (POF98 and POF08). Family FE: if the same family living in the household in both periods (POF98 and POF08). Month FE: month of data collection. Year FE: year of data collection. The number of observations refers to 627 valid observations for POF98, and 958 valid observations for POF08.

5.1. Robustness Checks

Here we consider different samples and methodologies than from the previous section. We first identify the price and income elasticities by disaggregating the valid data for each sample separately (POF98 and POF08). In model (1) we calculate the coefficients considering the POF98 using a standard OLS approach. In specification (2) we consider observations from POF08 and estimate de elasticities also using an OLS methodology.

In the model (3) data are aggregated and price and income elasticities are estimated using a random effects approach (RE-FGLS). For the model (4) we restrict the sample only to the households that appear in both samples and run the regression assuming the random effects hypothesis (RE-FGLS). In specification (5) we also restrict the sample to repeating residences but calculate the coefficients with a First-Difference methodology. Finally, we present the fixed effects model only for the households that repeat in both samples (balanced panel with fixed-effects, model 6).

Table 5 presents the results for all six models, considering robust standard errors for heteroscedasticity in all specifications.

Table 5- Calculated Elasticities for different samples and methods

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
ε_P	-.6438***	-.2562**	-.5837***	-.5052***	-.4980***	-.5038***
	(.0601)	(.1230)	(.0585)	(.1139)	(.1021)	(.1032)
ε_I	.1043**	.1764***	.1527***	.1700***	.2780***	.2054***
	(.0438)	(.0305)	(.0260)	(.0470)	(0631)	(.0657)
R2	0.5378	0.3657	0.4583	0.4605	0.4331	0.4667
Obs	627	958	1,585	540	270	540

Notes: Significance level, * < 0.10; **<0.05; ***<0.01; Robust t-statistics in parentheses. We consider all the controls from Model 9 in Table 4, except for specifications 1 and 2 because they are cross-sections estimated with OLS approach (the fixed effects of residence and family are not considered). Is Model 3, the hypothesis of random effects is considered for households, but family, month and year fixed effects are also included. Models 4 to 6 are balanced panels. Model 4 is estimated under random effects. Models 5 and 6 control for household fixed-effects using first-difference and fixed-effects techniques, respectively.

In Table 5, all estimations show the expected signs and are statistically significant for the price elasticity (ε_P) and the income elasticity (ε_I). Models 1 and 2 show a large variation between the estimated coefficients for the two different periods using OLS methodology. Models 4 to 6 show more similar results to table 4, even though they have significantly smaller samples. Price elasticity ranges between -0.505 and -0.498. Income elasticities are between 0.278 and 0.17. We apply a Hausman specification test to compare models 4 and 6 and results suggest that the fixed effects approach is recommended (Chi² of 84.35 with a p-value of 0.0017).

Model 6, restricting the sample to only those households that appear in both samples (balanced panel with fixed-effects), produced the same coefficients as Model 9 in Table 4 (unbalanced panel with all controls and fixed-effects). Therefore, in both models, the price elasticity of residential energy demand is -0.5038 (ε_P), and the income price elasticity for residential energy demand is 0.2054 (ε_I).

6. Conclusions and Policy Implications

This paper fills a gap in the literature on residential energy consumption in Brazil. We are the first to empirically estimate price and income elasticities for household electricity consumption using microdata and a panel approach. Household level data is more informative than aggregated data because we can control for household and family characteristics that might affect energy consumption, seasonality, and other unobservable characteristics, such as macroeconomic/policy shocks, by using fixed effects. We also include a variety of observable variables as controls for household architectonic characteristics, electrical equipment ownership, property status, kind of residence, household occupant's characteristics, and social benefits. No previous work for Brazil employs this level of disaggregation and such comprehensive list of individual characteristics to estimate the parameters. Therefore, our main contribution to empirical research is an accurate identification of price and income elasticities for the residential electrical consumption for the São Paulo metropolitan area.

The estimated price elasticity ranges from -0.26 to -0.64, and the estimated income elasticity between 0.11 and 0.32. Considering the most appropriate model, the price and income elasticities of the demand for residential electric power are, approximately, -0.50, and 0.21, respectively. Results are robust even for different methodologies and selected smaller samples. The unbalanced panel with all controls and fixed-effects included (Model 9 in Table 4) produced the same coefficients as the balanced panel with the smaller sample and fixed effects (Model 6 in Table 5). Considering those models, the price-elasticity of residential energy demand and the income-elasticity of residential energy demand are, respectively, -0.50 and 0.21, revealing that the consumption of electricity is inelastic and responds very little to increases in the cost of energy or family income.

The policy implications of the presented results are diverse. We have identified that the consumer's sensitivity to price and income variations is small so that increases in real family income will have little impact on the demand for energy, as increases in the energy cost. The calculated elasticities can be used by policymakers, energy production and distribution companies to target investment and/or forecasting strategies. In addition, indirectly, the results can serve as instruments for environmental policies and studies associated with the generation of greenhouse gases.

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