Household Demand for LPG in Brazilian States

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Resumo

O consumo de combustíveis limpos é um fator chave para o desenvolvimento sustentável e o bem-estar das famílias. As famílias usam combustível como insumo para produzir serviços de energia, como cozinhar. Em geral, a acessibilidade, a acessibilidade e a conveniência do combustível influenciam a decisão de consumo das famílias. No entanto, em economias em desenvolvimento com alta penetração de combustíveis limpos, como o Brasil, o principal determinante é a acessibilidade. Assim, este estudo tem como objetivo analisar a demanda das famílias por gás liquefeito de petróleo (GLP), levando em consideração as recentes mudanças sociais e econômicas no Brasil. Aplicamos modelos estáticos e dinâmicos para dados em painel em nível estadual, para 2002-2018, período após a desregulamentação do preço do combustível no país. Nossos resultados sugerem que o preço do próprio combustível, o preço dos alimentos, a renda e a temperatura influenciam a demanda das famílias por GLP. Além disso, embora a demanda seja inelástica, descobrimos que o consumo de GLP das famílias é mais sensível a mudanças nos preços do que na renda, tanto no curto quanto no longo prazo.

Keywords: combustível limpo; modelos de painel dinâmico; demanda por energia; famílias.

Abstract

The consumption of clean fuel is a key factor for sustainable development and household welfare. Households use fuel as input to produce energy services, such as cooking. In general, affordability, accessibility, and the convenience of the fuel influence the consumption decision of households. However, in developing economies with high penetration of clean fuels, such as Brazil, it is understood that the main determinant is the affordability. Thus, this study aims to evaluate the household demand for liquefied petroleum gas (LPG), taking into account the recent Brazilian social and economic changes. We apply static and dynamic models for panel data at the states level from 2002 to 2018, the period after the fuel price deregulation in the country. Our results suggest that the own-price, food price, income, and temperature influence the household demand for LPG. Also, although demand is inelastic, we found that LPG consumption by households is more sensitive to changes in prices than income, both in the short and in the long run.

Keywords: clean fuel; dynamic panel model; energy demand; households.

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1 Introduction

The consumption of clean fuels is a key factor for sustainable development and household welfare. In 2015, the member states of United Nations (UN) included the goal of achieving universal access to clean fuels by 2030 in a set of measures to eradicate poverty, protect the planet and ensure prosperity for all as part of a new sustainability agenda, known as Sustainable Development Goals (SDG). The clean fuels adoption often involves the replacement of traditional biomass, such as firewood and charcoal, by modern and more efficient fuels, such as the liquefied petroleum gas (LPG), in a process known as household energy transition.

The efforts to promote the adoption of clean fuels can have significant effects on dimensions beyond sustainable development, as the use of traditional biomass by households may impact the health and well-being of individuals. According to the World Health Organization, indoor air pollution from the use of these fuels raises the risk of diseases in women, children and the elderly, who are family members who spend more time at home [32].

In general, affordability, accessibility, and the convenience of the fuel influence the consumption decision of households [3]. However, in developing countries with high penetration of clean fuels, such as Brazil, the main determinant is the affordability [6]. Among several developing countries in Africa, Asia, and Latin America, Brazil presents the highest consumption of LPG [5, 14]. Since the last century, Brazilian households have been replacing biomass by LPG, due to the growing urbanization, the rise of household income, and the government intervention based on price regulation and subsidies [6, 21]. According to the Continuous Brazilian Household Sample Survey (PNADC) from the Brazilian Institute of Geography and Statistics (IBGE), 98.2% of the households used LPG in 2018. However, due to recent changes of the price policy of LPG and the household income reduction related to the Brazilian economic crisis in 2015, the number of households that use firewood as an auxiliary fuel has been increasing in the country [25], since this fuel is obtained at no cost, mainly gathered from backyards.

This study aims to evaluate the sensitivity of LPG consumption of households regarding price and income, taking recent social and economic changes in Brazil into account. Accurate identification of the demand function parameters for residential LPG consumption is relevant for the provision of future demand. Most of the energy demand studies estimate the energy consumption from aggregate time series data at the country level. However, due to the regional heterogeneity of the Brazilian economy, the time series approach might bias the results, since this methodology does not allow controlling for unobserved characteristics related to household consumption. The use of a panel data allows us controlling for the unobserved heterogeneity regarding different patterns of consumption among regions. Therefore, this study employs static and dynamic models for panel data to estimate the LPG demand of the residential sector. We aggregate the data from multiple sources into an annual panel for 27 states from 2002 to 2016. We apply the Fixed Effects (FE) model and dynamic panel models, which include one-step and two-step Generalized Method of Moments (GMM).

Studies on energy demand have mostly centered on electricity. Lately, some of these studies estimate residential demand for electricity at the regional or local level through static models for panel data [7, 26, 20] and dynamic panel models [11, 13, 20, 26, 28, 30, 34]. Some studies also apply panel approach to estimate the household demand for fuel, such as natural gas [7, 12, 26, 34]. However, studies on LPG demand are focused on the determinant of household decision consumption of fuels [18, 22, 31] and a small number of papers estimates the residential demand for LPG [17, 36].

The present study contributes to the literature on household energy demand estimating the elasticities of LPG demand using a panel data approach for Brazil. The Brazilian context is especially appropriate because it is a case applied to a developing country with high penetration of clean fuels, which could be a reference for other countries that are still going through the process of the household energy transition.

Our findings suggest that the own-price, food price, income, and temperature impact the residential demand for LPG. In the short-term, the own-price elasticity estimated is -0.13, the food price elasticity is -0.11, and the income elasticity is 0.09. In the long-term, the elasticities are -0.31, -0.25, 0.21 for own-price, food price and income, respectively. Thus, although inelastic both in the short and long term, we find that the households are more sensitive to price than income. Moreover, our results also indicate that the demand does not change significantly when the prices are kept fixed for LPG distributors, but the food price elasticity decrease by half, suggesting that households tend to be less sensitive to changes in food prices when disposable income increases. Regarding the effect of temperature, we find evidence that families use less energy to cook when the temperature is higher, which indicates that they consume foods that cook faster, such as vegetables, to meet their caloric needs in warmer periods.

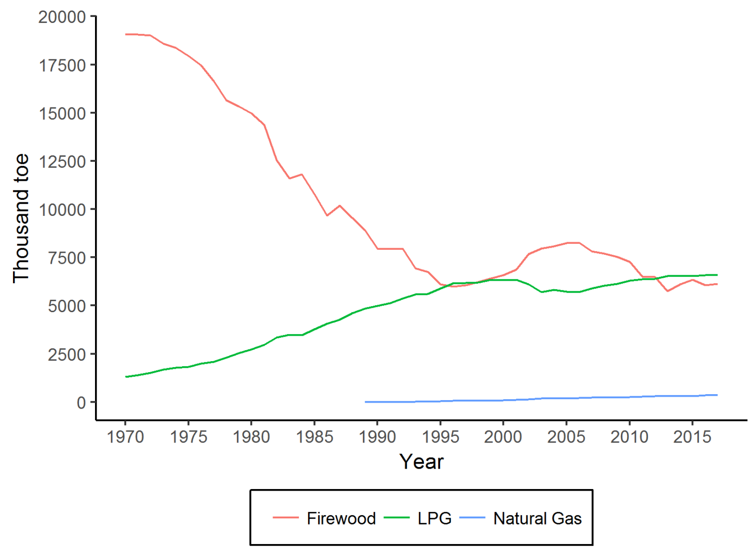
This paper is organized into five sections, including this introduction. Section 2 presents the LPG market in Brazil. Section 3 shows the theoretical framework, the empirical model, followed by a description of our dataset. Section 4 presents the main findings of the paper and analyzes the influence of the recent Brazilian price policy for LPG on the elasticities. Finally, the article ends with the final remarks and conclusions.

2 Background

Brazil presents the largest population in Latin America and the fifth largest in the world. According to IBGE, the country had more than 70 million households in 2018. The LPG is the primary fuel source in the residential sector in Brazil. It is estimated that more than 70% of LPG is destined to the residential sector and used predominantly for cooking [14]. Since the mid of the last century, households have been replacing firewood by LPG for this energy service in the country. The literature suggests the government intervention on the LPG market was successful in increasing the household adoption of clean and modern fuel in Brazil[1].

Until the 1950s, there was no direct intervention from the government on the LPG market. From the 1950s to the 1970s, the government starts regulating prices to foster the local production and to encourage the use of this fuel in remote regions [6]. In addition to this policy, the subsidies were introduced in the 1970s. Thus, in terms of final energy [2], the replacement of firewood by LPG increased sharply from 1970 to mid-1990, as shown in Figure 1.

Figure 1: Residential final fuel consumption in Brazil



Source: Energy Research Office (EPE).

Until 2000, the sale price was the same in all regions. In 2001, the Brazilian government deregulated the LPG prices. In the same year, it was created the *Auxílio-Gás* (Gas Aid) Program to deal with the effect of the higher LPG price on the poor household budget. The *Auxílio-Gás* Program consisted of a distribution of LPG vouchers to the households with monthly income up to half of the minimum wage. Although the program may have benefited some households, the consumption of LPG did not increase over the next three years. Furthermore, the increase of firewood consumption in the 2000s suggests that the households stacked fuel during this period[3]. In 2003, all the federal assistance programs, including the *Auxílio-Gás*, were unified into a broader conditional cash transfer program for families living in poverty or extreme poverty, the *Bolsa Família* Program (PBF).

Between 2002 and 2016, the government established price differentiation based on the cylin-

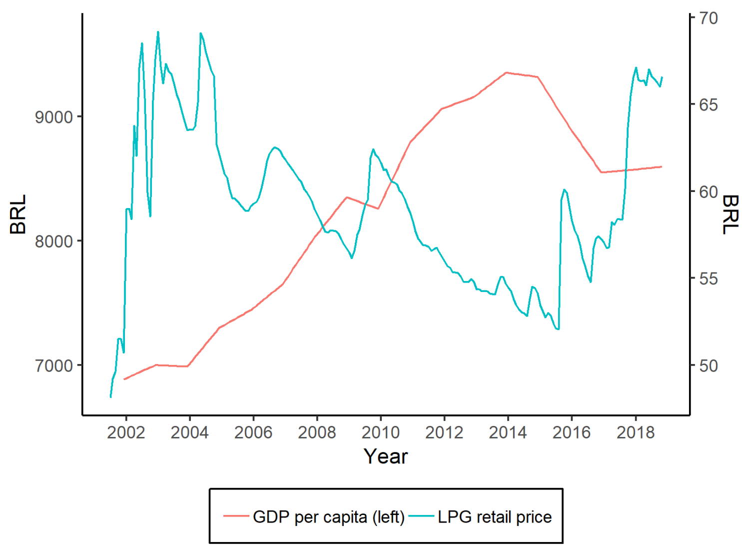
[1]For a broader review of papers on LPG subsidy policies in Brazil and Latin America, see [29].

[2] Final energy is the energy which the households buys or gather, a different definition of useful energy which is the input in an end-use application.

[3]Households may consume a portfolio of multiple fuels with different physical characteristics, a theory called fuel stacking [15]. The reasons for using multiple fuels may include source availability, costs, and risks associated with supply disruption.

der type, where the most popular in the residential sector is the 13 kilograms cylinder (P13). Although the Brazilian law guarantees a final competitive price, the price of the P13 was kept fixed for the distributor from December 2002 to September 2015, as a strategy of the federal government to maintain low inflation rates. Thus, as shown by Figure 2, from 2002 to 2015, we observe a decreasing trend of the LPG real price for residential consumers. After 2015, the price surges again due to price liberalization. Finally, in 2017, a new pricing policy determined that the final price to the distributors should be formed by the average monthly prices of butane and propane in the European market.

Figure 2: GDP per capita and average price of LPG (13 kg cylinder)



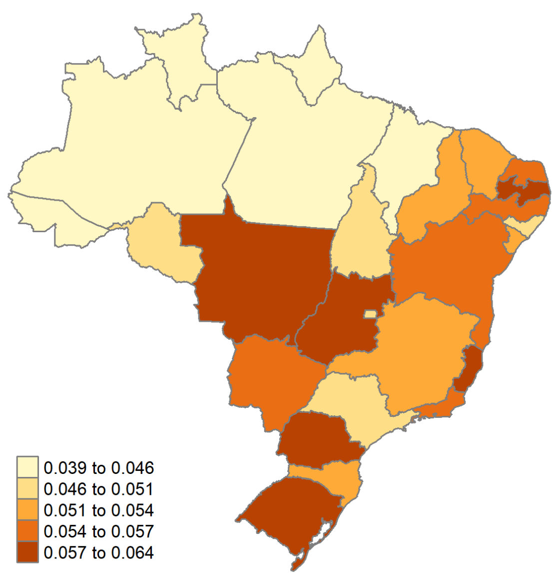
Source: EPE and IBGE.
Notes: Deflated by the Brazilian Consumer Price Index (IPCA).

Besides the price policies, the income effect might have had an impact on the LPG consumption in Brazil. In the last two decades, the number of households under the poverty and extreme poverty lines decreased in the country. An extensive literature that aims to study the determinants of the higher welfare level in Brazil suggests that the improvement in family socioeconomic conditions would be associated with increases of the household labor and non-labor income (see [16, 24, 8]. The higher labor income would be associated with the real growth of the minimum wage, better labor market conditions, and economic growth. On the other hand, the increases of the non-labor income would be associated with public cash transfer policies, such as the PBF, and the Continuous Payment Benefit (BPC), a conditional cash transfer for poor disabled people and elderly.

However, it is important to highlight that since 2014, the socioeconomic conditions and welfare of households in Brazil are affected by the lower economic growth and unemployment. Neri [23] shows that between the end of 2014 and the end of 2017, the poverty in Brazil increased from 8.38% to 11.18%, which means a contingent of 23.3 million people, more than the Chilean population in the period. Figure 2 shows that the GDP per capita, proxy for household income, has been decreasing since 2014, the period in which an increase of the LPG price has been observed. These factors may have determined the household's choice of fuel or combination of fuels in Brazil during this period, especially among the poorest. [25]. In this context, data from the Continuous Brazilian Household Sample Survey (PNADC/IBGE) points the number of households using biomass (firewood or charcoal) and LPG for cooking, as a fuel stacking process, reached more than 13 million, a 27.2% increase between 2016 and 2018.

Brazil is a federation composed of 27 states and divided into five regions with different biomes, cultures, traditions, and development level. LPG distribution reaches all Brazilian municipalities and 98.2% of the households in 2018, according to PNADC. As a federation, the states have the autonomy to establish taxes on fuel. These differences between states are expressed through the heterogeneity of LPG consumption in the country, as shown by Figure 3.

Figure 3: Residential LPG consumption in Brazil in 2017 (m^3 per capita)



Fonte: EPE and IBGE.

The North region, where the socioeconomic development is related to the exploitation of natural resource from Amazonia, presents the lower per capita consumption compared with the other regions. However, the Southeast region, which has the most industrialized and the biggest urban areas, also presents states with the low per capita consumption. Thus, deal with the heterogeneity of GLP consumption among the territory is one of the goals of this study.

3 Model and data

3.1 Theorethical framework

Households use energy to produce energy services, such as lighting, cooling and cooked food. Thus, LPG can be considered an intermediate good for households. According to the household production theory, households acquire intermediate goods that they use as input to produce final goods that are useful for them[4]. In our case, households combine LPG with raw food to produce a composite energy good, the cooked food.

Adapting the model from Filippini [10] and Labandeira et al. [19], the production function of the composite energy good (x) can be defined as a function of quantities consumed of LPG (g) and raw food (d):

$$x = x(g, d) \tag{1}$$

The household has a utility function that depends on the quantity of the composite energy good, the quantity of a composite numerary good (y), and the characteristics that influence their preferences (z):

$$u = u(x, y; z) \tag{2}$$

Following Deaton and Muellbauer [9], the household decision process is a problem of optimization in two stages. In the first stage, the household minimize the production cost of the energy good. In the second stage, the household maximize their utility. The problem in the first stage is:

$$\begin{aligned} \min \quad & p^e e + p^d d \\ \text{s.t.} \quad & x = x(g, d) \end{aligned} \tag{3}$$

where p^e is the price of LPG, p^d the price of raw food. As a result, the cost function is obtained,

$$c = c(p^e, p^d, x) \tag{4}$$

Applying Shepard's lemma, we obtain the demand derived from LPG,

$$e = \frac{\partial c(p^e, p^d, x)}{\partial p^e} = e(p^e, p^d, x) \tag{5}$$

In the second stage, the household maximizes its utility, subject to its budget constraint,

$$\begin{aligned} \max \quad & u = u(x, y, z) \\ \text{s.t.} \quad & r = c(p^e, p^d, x) + y \end{aligned} \tag{6}$$

[4]For more detail of the household production theory see [4, 9]

where r is the household income. Solving the maximization problem 6, we obtain the demand functions for the goods x and y. In the case of LPG,

$$x^* = x^*(p^e, p^d, r; z) \tag{7}$$

Substituting the demand function 7 in 5, we find the residential demand for LPG:

$$e = e(p^e, p^d, x^*(p^e, p^d, r; z)) = e(p^e, p^d, r; z) \tag{8}$$

Thus, the residential demand for LPG is a function of the prices of LPG, the prices of raw food, income, and preferences. Indeed, in response to price changes, households may change their consumption of raw food, which may alter the demand for LPG[5].

3.2 Empirical model

Most of the energy demand studies estimate the energy consumption from aggregate time series data at the country level. However, due to the regional heterogeneity of the Brazilian economy, the time series approach might bias the results, since this methodology does not allow controlling for unobserved characteristics related to the residential LPG consumption. The use of panel data allows controlling for the unobserved heterogeneity regarding different patterns of LPG consumption among regions.

This study employs a static model – the Fixed Effects (FE) model – and dynamic models – one-step and two-step Generalized Method of Moments (GMM) – for panel data to estimate LPG demand in the residential sector. For the Fixed Effects estimation[6], we use the following empirical model:

$$\begin{aligned} lnLPG_{i,t} = \beta_0 + \beta_2 lnINC_{i,t} + \beta_3 lnPE_{i,t} + \beta_4 lnPF_{i,t} + \\ \beta_5 lnER_{i,t} + \beta_6 lnHDD_{i,t} + \beta_7 lnCDD_{i,t} + u_{i,t} \end{aligned} \tag{9}$$

where the dependent variable $LPG_{i,t}$ is the per capita consumption of LPG; $INC_{i,t}$ is the household's income; $PE_{i,t}$ is the LPG price; $PF_{i,t}$ is the price of raw food; $ER_{i,t}$ is the employment rate; $HDD_{i,t}$ and $CDD_{i,t}$ are the heating degree days (HDD) and cooling degree days (CDD) in the state i in year t; and $u_{i,t}$ is the error term.

Besides the income and the prices, we include in equation 10 other variables that could influence the total consumption of LPG, such as the unemployment rate and the temperatures measure HDD and CDD. Reducing the unemployment rate may lead to an increase in the number of people who consume cooked food outside the home and, consequently, may reduce residential consumption of LPG per capita. The HDD and CDD measure the non-linear relationship between

[5]Stove is another input to produce cooked food. However, we assume the ownership of stoves remains constant in the period.

[6]For details of the fixed effect panel model see [35].

energy consumption and temperature. Each day with a mean temperature below a threshold is counted as one HDD. HDD is calculated over a year by adding up the differences between each day's mean daily temperature and the reference temperature. The CDD day is the cooling counterpart of the HDD.

Due to unobserved idiosyncratic characteristics of the Brazilian States that may influence the residential LPG consumption, we would expect that u_{it} contains a fixed effect parameter for each state. These characteristics may be related to geography, demographic, cultural or other unobservable time-invariant factors. In such case, the error term can be expressed by $u_{it} = c_i + \varepsilon_{it}$, in which c_i is the fixed effect at the state level and ε_{it} is an error-term not correlated to the residential LPG consumption.

The use of a static model for panel data, such as the Fixed Effects, do not consider the household behaviors over time. Thus, we estimate a dynamic panel model. Moreover, dynamic panel models may be more accurate to estimate short-run and long-run price and income elasticities.

Balestra and Nerlove [2] was the pioneering study on energy demand using dynamic panel model. The authors estimated the demand equation for natural gas in the residential and commercial sectors of the United States. In the context of the Brazilian energy market, the articles that applied dynamic panel models are Santos [27] that estimated the car fuel demand, and Uhr, Chagas, and Uhr [30] that estimated the residential electricity demand.

Following the literature on dynamic panel models in the context of energy demand, we estimate the demand equation based on the partial adjustment model. This model allows obtaining consumer adjustment coefficients, elasticities on the short-run and long-run. Thus, we use the following empirical model:

$$\begin{aligned} lnLPG_{i,t} = \beta_0 + \alpha lnLPG_{i,t-1} + \beta_2 lnINC_{i,t} + \beta_3 lnPE_{i,t} + \beta_4 lnPF_{i,t} + \\ \beta_5 lnER_{i,t} + \beta_6 lnHDD_{i,t} + \beta_7 lnCDD_{i,t} + u_{i,t} \end{aligned} \tag{10}$$

where $LPG_{i,t-1}$ is the lagged LPG consumption in the state i in year t.

We expect a consistent inertial behavior in household LPG consumption – given by the statistical significance of the lagged variable coefficient (α), meaning that the current LPG demand has a positive effect on future demand.. The inclusion of the lagged dependent variable is a representation of the inertial behavior of the demand, arising from the hypothesis of adaptive expectations, in which, due to psychological, technological or institutional reasons, consumers do not change their habits immediately after changes in prices or income, since this would result in some level of welfare loss.

We obtain the short-run elasticities directly from the estimated coefficients. The long-run income elasticities, for instance, will be expressed as $\beta_2/(1 - \alpha)$.

Due to the presumable correlation between the lagged dependent variable and the error term, the estimation by Ordinary Least Squares (OLS) is inconsistent. Thus, following the methodology proposed by Arellano and Bond [1], we estimate the dynamic panel model by the

Generalized Method of Moments (GMM). This method is useful in addressing the endogeneity of the lagged dependent variable. However, under the heteroskedastic error term, the standard errors are biased. Therefore, we additionally apply the Windmeijer [33] robust standard errors.

3.3 Data

This study uses Brazilian data for the 27 states from 2002 to 2018. Until 2002, the LPG price was the same in all states. Thus, we use the period after the deregulation of the LPG in the country. We aggregate the data from multiple sources into an annual panel.

The Energy Research Office (EPE) provides the residential demand for LPG at the state level. Per capita consumption is calculated using the population data from the Brazilian Institute of Geography and Statictics (IBGE). LPG prices are from the National Agency for Petroleum, Natural Gas and Biofuels (ANP) and correspond to prices of the 13-kilogram canister, the most popular among the Brazilian households. The DIEESE (Inter-Union Department of Statistics and Socio-Economic Studies) provides the price of basic food basket for each state capital, which we use as a proxy for the price of raw food of states.

The employment rate and household income are from IBGE households' surveys. We use the Brazilian Household Sample Survey (PNAD) microdata to calculate the employment rate and the income from 2002 to 2015, and the Continuous Brazilian Household Sample Survey (PNADC) to calculate these variables from 2016 to 2018[7]. Thus, we ensure the consistency of time series for the employment rate for each state. We use the Brazilian official inflation index – The Extended National Consumer Price Index (IPCA) – from IBGE to deflate the prices and income variables.

Concerning the temperature variables, we have the HDD and the CDD. Both variables are calculated based on the daily average temperature provided by the Brazilian National Institute of Meteorology (INMET), collected from 264 weather station distributed across the country. Weather stations are not distributed over all states. Thus, we calculated the average daily temperature for the municipalities with more than 100 thousand inhabitants employing the spatial interpolation (inverse of the distance) of the data from the stations. [8]. Then, we aggregate the municipalities' temperature weighted by the population to find the state-level temperature measures. Twenty-three degree Celsius is taken as the cut-off temperature[9].

Table 1 shows the summary statistics of the variables used in estimations.

[7]The PNAD is an annual survey from IBGE, which aimed to determine the Brazilian household's characteristics. The Continuous PNAD (PNADC) replaced the PNAD in 2016.

[8]Appendix A.1 shows the spatial distribution of INMET weather stations

[9]We also use different references from 18°C to 26°C.

Table 1: Summary statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
LPG Consumption	459	-9.93	0.20	-10.59	-9.41
LPG Price	459	3.33	0.11	3.05	3.76
Food Price	319	5.08	0.14	4.73	5.39
Income	459	5.97	0.39	5.10	7.03
Employment Rate	459	62.58	5.57	40.53	72.10
HDD	459	5.46	1.74	1.42	7.92
CDD	459	4.45	1.89	0.00	6.95

Note: All variables are log transformed, except the *employment rate*.

4 Results

This study aims to estimate the sensitivity of LPG demand concerning the fuel price, food price, and income. First, we apply a static model for panel data at the state level from 2002 to 2018. Then, secondly, we use dynamic models to estimate the short and long-term elasticities. Due to the lack of data for all the 27 Brazilian states over the period considered, our panel is unbalanced.

Table 2 shows the results for the estimations under the Fixed Effects method. The table presents four set of estimations differing in terms of the inclusion of control variables in the demand equation. The estimation (1) is the benchmark model, which is conditional only on LPG and food price, besides the income. In estimation (2), we include the *employment rate*, and in (3) we consider the temperature measures *HDD* and *CDD*. Finally, in estimation (4), we show the complete specification. In such estimation under Fixed Effects model, we are able to control for observable and unobservable state level heterogeneity that is constant over time, such as tax and price policies at the state level, and characteristics of households living in the region, for instance cultural tradition, tastes and cooking preferences.

According to Table 2, the *LPG price* and *food price* parameters are statistically significant when we include controls in the model. As we expect, the negative signs of *LPG price* and *food price* are consistent with the theory of demand for normal goods. The own-price elasticity ranges from -0.142 to -0.284, and the food price elasticity ranges from -0.156 to -0.158. These results suggest the households are more sensitive to changes in LPG price than in food price. On the other hand, we cannot reject the null hypothesis that the *income* parameter is not equal to zero for all specifications under this estimation. Thus, the household demand for LPG may be perfect inelastic in income.

Regarding the control variables, Table 2 also shows that the *employment rate* and *CDD* are statistically significant. The negative parameter of *employment rate* indicates that a higher proportion of employed individuals means a lesser use of energy at home. This lower level of energy consumption may be explained by workers cooking less food at home and eating outside

Table 2: Static model - fixed effects estimations

Variable	(1)	(2)	(3)	(4)
LPG Price	-0.135	-0.276***	-0.142*	-0.284***
	(0.0802)	(0.0602)	(0.0781)	(0.0601)
Food Price	0.0412	-0.158**	0.0316	-0.156**
	(0.0782)	(0.0666)	(0.0818)	(0.0664)
Income	-0.00536	-0.00940	-0.00124	-0.00529
	(0.0643)	(0.0469)	(0.0639)	(0.0470)
Employment Rate		-0.0137***		-0.0136***
		(0.00266)		(0.00264)
HDD			-0.0261***	-0.0127
			(0.00917)	(0.00861)
CDD			-0.0138**	-0.0141**
			(0.00549)	(0.00516)
Constant	Yes	Yes	Yes	Yes
Observations	319	319	319	319
R-squared	0.038	0.234	0.062	0.250
Number of UF	27	27	27	27

Note: *** p<0.01, ** p<0.05, * p<0.1. Robust standard deviation in parentheses. All variables are log transformed, except the *employment rate*.

their home during workdays. Indeed, it is worth noting that the inclusion of the *employment rate* in the model increases significantly the explained variance of the LPG consumption, given by the R^2 statistic, which indicates the relevance of this variable in the demand function of LPG. The *CDD* parameter is negative, as expected. This finding suggests that households cook less – or they prefer to cook food that takes less time of preparation, such as vegetables – in periods with a higher temperature. On the other hand, we do not find evidence that the households use more LPG during periods with low temperature since *HDD* is not statistically significant under the complete specification.

Although consistent, the use of a static model for panel data such as the Fixed Effects model is not appropriate to infer about the household economic decisions and the elasticities over time. Thus, Table 3 shows the short-term results of estimations using dynamic models and the Generalized Method of Moments (GMM). We apply the one-step GMM in the specifications (1) to (4) and two-steps GMM in the specification (5) to (8), where in the later we apply the Windmeijer's (2005) correction procedure. Similarly to the fixed effect estimations, we present four models for each GMM differing in the inclusion of control variables in the energy demand equation. For all models, the Sargan test, for the validity of the dependent variable as instrumental variables, led to the rejection of the hypothesis of over-identification restriction. Additionally, the Arellano-Bond test (AB) led to a non-rejection of the hypothesis of no serial autocorrelation in residuals.

Table 3: Dynamic model - GMM estimations

Variable	One-Step GMM				Two-Steps GMM			
Varible	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Lag(Consumption)	0.604***	0.584***	0.596***	0.571***	0.614***	0.603***	0.600***	0.566***
	(0.0527)	(0.0589)	(0.0535)	(0.0598)	(0.0557)	(0.0656)	(0.0712)	(0.0684)
LPG Price	-0.0777***	-0.103***	-0.0896***	-0.121***	-0.0795***	-0.104***	-0.0922***	-0.133***
	(0.0201)	(0.0188)	(0.0218)	(0.0196)	(0.0258)	(0.0197)	(0.0261)	(0.0271)
Food Price	-0.0807***	-0.107***	-0.0712***	-0.102***	-0.0800***	-0.120***	-0.0763**	-0.111***
	(0.0189)	(0.0273)	(0.0177)	(0.0239)	(0.0256)	(0.0337)	(0.0307)	(0.0331)
Income	0.0912***	0.0898***	0.0931***	0.0914***	0.0874***	0.0912***	0.0850***	0.0905***
	(0.0273)	(0.0254)	(0.0267)	(0.0246)	(0.0276)	(0.0263)	(0.0310)	(0.0263)
Employment Rate		-0.00205		-0.00251**		-0.00237		-0.00286**
		(0.00127)		(0.00123)		(0.00144)		(0.00143)
HDD			0.000375	0.00165			0.00124	0.00335
			(0.00338)	(0.00350)			(0.00561)	(0.00442)
CDD			-0.0104**	-0.0109**			-0.00925*	-0.0102**
			(0.00436)	(0.00432)			(0.00527)	(0.00436)
AB(1)	0.0050	0.0039	0.0054	0.0042	0.0097	0.0079	0.0122	0.0093
AB(2)	0.3632	0.4183	0.6658	0.8032	0.3836	0.4424	0.6717	0.8178
Observations	276	276	276	276	276	276	276	276
Number of States	27	27	27	27	27	27	27	27

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Robust standard deviation in parentheses. All variables are log transformed, except *employment rate*. AB(1) and AB(2) are the Arellano and Bond (1991) tests for autocorrelation in differences (p-value shown).

According to Table 3, the lagged variable coefficient is positive and statistically significant for all estimated models. The result is consistent with the inertial behavior of the household consumption, that is, a positive effect of the current LPG demand on the future demand.

Likewise the previous static model, the *LPG price* and *food price* parameters are statistically significant for all models. The own-price elasticity ranges from -0.078 to -0.133, and the food price elasticity ranges from -0.080 to -0.120. Under the dynamic model, the *LPG price* parameter is lower than those found with the static model, which suggests a correlation between inertial behavior of households and the fuel price. The *food price* parameters estimated by the dynamic models are not significantly different from the results of the static model. On the other hand, in this new set of estimations, the parameter of the *income* is statistically significant and the sign is positive, as expected by the theory. The income elasticity range from 0.087 to 0.093. Finally, results for the control variables in the second set of estimations remain the same.

Next, Table 4 presents the short and long-run elasticities, estimated based on the complete models (4) and (8) from Table 3. As shown in 3, the long-run income elasticities may be calculated as $\beta_3/(1 - \alpha)$, for instance. The results suggest the LPG consumption remain inelastic in price and income changes in the long-term. The long-run own-price elasticity ranges between -0.282 and -0.307, whereas the food price elasticity ranges between -0.238 and -0.2549. The income-elasticity ranges between 0.208 and 0.213. In general, although still inelastic, this table shows that the sensitivity regarding LPG consumption of households is higher in long than in the short-run, households are able to adapt to new conditions and replace more easily with other inputs or technologies.

Table 4: Short and long-term elasticities

Variable	One-Step GMM		Two-Steps GMM	
	Short-term	Long-term	Short-term	Long-term
LPG Price	-0.0896***	-0.2824***	-0.133***	-0.3066***
	(0.0218)	(0.0123)	(0.0271)	(0.0221)
Food Price	-0.0712***	-0.2376***	-0.111***	-0.2549***
	(0.0177)	(0.0117)	(0.0331)	(0.0281)
Income	0.0931***	0.2131***	0.0905***	0.2086***
	(0.0267)	(0.0155)	(0.0263)	(0.0226)

Note: *** p<0.01, ** p<0.05, * p<0.1. Robust standard deviation in parentheses and were generated using the delta method.

The estimations above evidence that the household LPG consumption is inelastic in the short and long run in prices and income changes. However, it should be noted that our result suggests that LPG is less elastic in price and income in the long run compared with the electricity, the main energy source used households in Brazil. Using panel data for the Brazilian states for the period between 2004 2014 to estimate the elasticities for the residential sector, Uhr, Chagas, and Uhr

[30] find that long-term price elasticity ranges -0.617 to -1.472 and long-term income elasticity varies from 0.324 to 1.095. Thus, LPG represents a more essential good for the household than electricity in Brazil.

4.1 Policy effects

In this section, we estimate the effect of policies of price control on household demand for LPG. As discussed in the Section 2, the price of P13 was kept fixed to the distributor over 12 years as a federal government strategy to maintain low inflation rates. Thus, we introduced the additive and multiplicative time dummy variable *policy* for the period between 2003 and 2014, when the government adopted such policy. Table 5 shows the short-term results for the one-step GMM, where the estimation (1) is the benchmark and in the others – (2) to (5) – we introduce the time dummy variable, besides interactions of this variable with LPG and food price, and income.

Table 5: Dynamic model for the effect of the LPG price policy

Varible	(1)	(2)	(3)	(4)	(5)
Constant	-3.682***	-3.991***	-4.042***	-3.945***	-4.617***
	(0.591)	(0.577)	(0.611)	(0.637)	(0.631)
Lag(Consumption)	0.571***	0.550***	0.545***	0.495***	0.469***
	(0.0598)	(0.0597)	(0.0622)	(0.0625)	(0.0563)
LPG Price	-0.121***	-0.108***	-0.151***	-0.121***	-0.0997***
	(0.0196)	(0.0227)	(0.0367)	(0.0226)	(0.0250)
Food Price	-0.102***	-0.0876***	-0.0894***	-0.170***	-0.0656**
	(0.0239)	(0.0239)	(0.0230)	(0.0453)	(0.0282)
Income	0.0914***	0.0959***	0.123***	0.0828***	0.0370
	(0.0246)	(0.0232)	(0.0276)	(0.0271)	(0.0308)
Policy		0.00882	-0.347	-0.585**	-0.386***
		(0.00836)	(0.219)	(0.269)	(0.0856)
Policy x LPG Price			0.109		
			(0.0687)		
Policy x Food Price				0.115**	
				(0.0522)	
Policy x Income					0.0631***
					(0.0135)
Controls	Yes	Yes	Yes	Yes	Yes
AR(1)	0.0042	0.0030	0.0029	0.0027	0.0038
AR(2)	0.8032	0.6648	0.7023	0.6930	0.5190
Observations	276	276	276	276	276
Number of States	27	27	27	27	27

Note: *** p<0.01, ** p<0.05, * p<0.1. Robust standard deviation in parentheses. All variables are log transformed, except *employment rate*.

The estimation (2) indicates that *policy* parameter is not statistically significant. Therefore, the introduction of the additive dummy did not change the intercept of the demand curve. From the estimation (3), the multiplicative results show that the policy did not induce changes in the own-price between 2003 and 2014. On the other hand, we can observe in (4) that the food price elasticity decreased from -0.102 to -0.055 (-0,170 + 0.115). Finally, although the interaction between *policy* and *income* is statistically significant in (5), there was a small change in income elasticity that decreased from 0.0914 to 0.0631 (0.000 + 0.0631).

Therefore, these findings suggest that the policy of price control of residential LPG and its decrease in real terms, as shown by Figure 2 of Section 2, did not increase the demand for this energy source, since the parameter *policy* parameter is not statistically significant. However, during 2003 and 2014, the food price elasticity decreased by half. This could evidence that reducing fuel prices raises the share of household income allocated to food, which makes the decisions of households regarding food consumption less sensitive to food price changes.

5 Conclusions

In developing countries with high penetration of clean fuel, the principal determinant is the affordability. Thus, this study proposes an estimation of the sensitivity of residential LPG demand concerning energy prices, food prices, and income in Brazil. Understanding of the sensitivity of LPG household demand is a relevant issue since it could allow the policy design addressing the universal access to clean fuels, guaranteeing its adoption in the long-term and meeting the Sustainable Development Goals (SDG). To our knowledge, the present study is the first to estimate the LPG demand for the residential sector using static and dynamic panel data for Brazil. Besides its relevance in terms of understanding the magnitude of the elasticities in the short and long run, in the national context, the paper collaborates to the international empirical literature on energy demand.

Our results suggest that the own-price, food price and income influence the residential demand for LPG. The static model estimations indicate that the own-price and food price elasticities are negative and statistically significant. However, when we include the lagged consumption, consistent with the inertial behavior of the household, in a dynamic model approach, the income elasticity becomes statistically significant with a positive sign. Also, although inelastic in the short and long term, we find the households are more sensitive to price than income. Moreover, our results also indicate when the prices are kept fixed for LPG distributors, the demand does not change significantly, but the food price elasticity decrease by half, suggesting that households tend to be less sensitive to changes in food prices when disposable income increases. Regarding the effect of temperature, we find evidence that families use less energy to cook when the temperature is higher, which indicates that they consume foods that cook faster, such as vegetables, to meet their caloric needs in warmer periods.

Although this study estimates the average elasticities for Brazilian households, it is essential to highlight that low-income families tend to face higher prices and income elasticities. Also, extreme weather events can lead to higher food prices and reduce the energy consumption of poorer households through two channels: reduction of food consumption, and ii) consumption of lower-quality foods, such as highly processed meats, that are cheaper and require less cooking time. In this sense, financial incentives for the acquisition of clean fuel to the low-income population should be considered, since nutrition and other health problems occur when they cannot afford LPG regularly. One short-term alternative could be a focused voucher program, as Brazil has already had in the past, where the subsidies for low-income families are used to buy only LPG. In the long-term, it should be invested in the LPG supply chain and develop a more competitive domestic market to make LPG cheaper. However, more in-depth studies on the subject must be carried out to propose evidence-based policies.

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A Appendix

A.1 Spatial distribution of weather stations

Fonte: INMET.

A.2 Fixed effects estimation - complete sample

Varible	(1)	(2)	(3)	(4)
LPG Price	-0.239***	-0.358***	-0.245***	-0.371***
	(0.0816)	(0.0804)	(0.0804)	(0.0807)
Income	0.114*	0.0292	0.0982	0.0279
	(0.0617)	(0.0589)	(0.0618)	(0.0573)
Employment Rate		-0.0123***		-0.0122***
		(0.00226)		(0.00219)
HDD			-0.0483***	-0.0239**
			(0.0135)	(0.00944)
CDD			-0.0167**	-0.0216***
			(0.00655)	(0.00655)
Constant	Yes	Yes	Yes	Yes
Observations	459	459	459	459
R-squared	0.156	0.316	0.189	0.334
Number of UF	27	27	27	27

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Robust standard deviation in parentheses. All variables are log transformed, except *employment rate*.