MODELAGEM DA DEMANDA DE COMBUSTÍVEL NO BRASIL: A IMPORTÂNCIA DOS VEÍCULOS FLEX

Modeling fuel demand in Brazil: the importance of the flex-fuel vehicle

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Resumo: Este estudo avalia os efeitos da expansão dos veículos flex na frota brasileira de veículos leves sobre a demanda por etanol hidratado e gasolina no país. O estudo inclui uma análise crítica das estimativas anteriores de demanda de combustíveis no Brasil para explicar a importância de novas estimativas, que incluem dados após a introdução da tecnologia dos motores automotivos flex-fuel. Os resultados indicam que a demanda por etanol hidratado é elástica em relação aos preços, tanto do próprio combustível quanto preço cruzado da gasolina; que a demanda preço da gasolina é inelástica a ambos os preços; o preço da gasolina foi mais importante do que o preço do etanol para a decisão do consumidor entre os combustíveis alternativos; e, que a renda tem um efeito positivo e significativo sobre a demanda de gasolina, mas tem efeito negativo sobre a demanda de etanol hidratado. Estes resultados podem ser úteis para orientar a formulação de políticas que impulsionem o consumo de biocombustíveis no Brasil, considerando que, nos últimos anos, o mercado de etanol hidratado apresentou estagnação devido a distorções introduzidas pelas políticas do governo brasileiro.
Palavras-chave: Biocombustível; Demanda de combustível; Veículos flex.

Abstract: The study assesses the effects of an expansion of the share of flex-fuel vehicles in the Brazilian fleet on the demand for hydrated ethanol and gasoline fuel in the country. The study includes a critical analysis of previous estimates of Brazilian fuel demand in order to explain the importance of new estimates after the flex-fuel technological breakthrough. The results indicate that hydrated ethanol demand is elastic with respect to price (both own and cross gasoline prices); that gasoline demand is inelastic to both prices (own and cross ethanol prices); that the gasoline price was more important than ethanol price for consumer decision in choosing between alternative fuels; and that income has a positive and significant effect on gasoline demand, but a negative effect on hydrated ethanol demand. These results are useful to guide policymaking towards boosting biofuel consumption in Brazil, considering that in recent years the hydrated ethanol fuel market has stagnated due to distortions introduced by the Brazilian government policies.
Keywords: Ethanol biofuel; Fuel demand; Flex-fuel vehicle.

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1 INTRODUCTION

Contrary to what has been observed in various economies, where changes in the nature of the automotive fuel used have been driven mainly by subsidies and mandates, in Brazil, these changes were stirred by the introduction of an innovation in automotive engines. The flex-fuel car, introduced in 2003, allowed for 100 percent flexibility in the type of fuel used. This experience should be an outstanding example of induced changes in fuel consumption from more expensive and pollutant fuels - such as gasoline - to ethanol biofuel, resulting from consumer response to lower relative prices. Bioethanol production from sugarcane in Brazil, where soil and water is abundant and a strong and booming ethanol industry should supply ethanol at a relatively lower price than gasoline. However, after an intense expansion in bioethanol demand as the flex fuel share in the countries' fleet increased, this recipe of success was reversed by the Brazilian government policies that stimulated gasoline consumption at the expense of bioethanol.

In fact, after twenty years of continuous reduction, the Brazilian ethanol market entered a "new era" with the introduction of automobiles with flexible engines that can use a mixture of alternative fuels, such as hydrated ethanol and gasoline (E-27), in proportions to be defined by consumers. This enabled the alternative fuel demand to be determined by its relative price in the market, and ethanol consumption soared, even taking into account that the energy derived by burning ethanol is, on average, 70% of that obtained from the same volume of gasoline. Consumers regarded this as an important advantage provided by flex-fuel cars and their share in the Brazilian fleet increased very fast.

In view of this adjustment in the fuel market, it is interesting to estimate fuel demand elasticities in this market to understand and foresee possible changes as fuel consumption profile is determined by market forces. This should be useful for implementing government policy to encourage renewable fuel consumption opposed to mineral fuel, or even to reduce total fuel consumption, for both environmental and economic purposes. The environmental benefit is achieved by two major strategies to decrease the greenhouse gas emissions that cause global warming: reduction of fuel consumption by light vehicles, by promoting more efficient public transport; and increasing the use of alternative fuels containing less or no carbon originated from fossil fuels. The economic benefit results from the importance that fossil fuel demand has in the Brazilian economy, given that gasoline imports are responsible for a considerable deficit in Brazilian trade balance. In 2012, 2013, 2014 and 2015 the trade balance deficit for gasoline was approximately US$ 3 billion, US$ 2 billion, US$ 1.3 billion, and US$ 0.7 billion, respectively (Brazil, 2016). In order to determine policies and predict future fuel demand, it is relevant to know how the consumption of each fuel changes as their prices vary, and what is the response of total fuel consumption in face of price and income changes. This study sought to analyze these responses. Also, understanding the Brazilian market for this renewable fuel could be important in planning the introduction of flex-fuel vehicles into other countries.

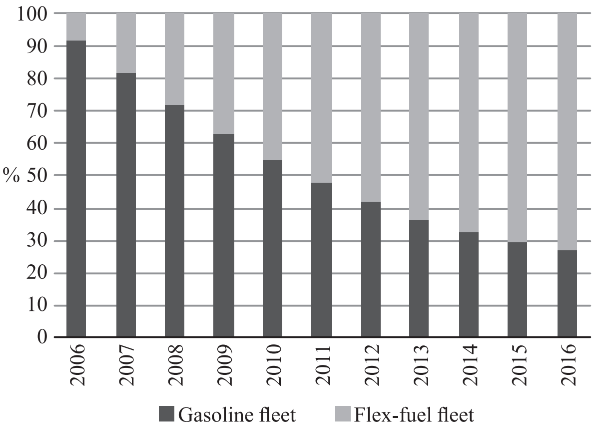
In addition to estimations of more recent elasticities, this study reviews other studies with similar objectives (section 2). The subsequent section explains the methods and data utilized. Section 4 describes and analyzes the results, comparing them with those reviewed in section 2. Conclusions are presented in section 5.

2 LITERATURE REVIEW

The use of ethanol as fuel in Brazil started in the 1930s, when anhydrous ethanol was first added to gasoline. In the 1970s, an independent fuel (hydrated ethanol) was introduced as a strategic response to the oil crises. When global oil prices escalated in 1973, Brazil was importing 78 percent of all oil (37.9 million tons) consumed by the country. The search for an alternative became a priority for the Brazilian government as it began to deal with inflation, combined with a growing need for foreign loans, and therefore a growing debt in foreign financial markets. In 1975, an ethanol program (entitled PROALCOOL) was launched by the Brazilian government, becoming a successful initiative as the country's fleet of vehicles that ran only on hydrated ethanol (E100) increased substantially. However, when oil prices were reduced and the sugar price rose in global markets, that proportion dropped. When global oil prices fell in the first years of the 1990s, Brazilians went back to buying gasoline cars. Later, during the 1997-2003 period, new policies and technological innovations provided a new perspective for ethanol consumption in Brazil (FREITAS; KANEKO, 2011). The major technological evolution was the launch of the first flex-fuel car in Brazil, in 2003.

Figure 1 presents the shares of the light vehicle fleet running on the main fuel types in Brazil after the flexible vehicle breakthrough. The fleets of vehicles consuming solely ethanol or gasoline are contracting, giving way to the new fleet of flex--fuel vehicles. With this change, new standards in fuel consumption have been emerging, and the econometric estimates created to represent the activity of Brazilian hydrated ethanol and gasoline demands should be reviewed.

Figure 1 - Brazilian automotive fleet, by fuel type; 2006 - 2016



Source: Unica (2017b).

Econometric estimates of hydrous ethanol and gasoline in Brazil are described in many studies. Most of them (summarized in Table 1A and 2A in the Annex, hydrated ethanol and gasoline, respectively) used time-series models. Souza (2010), Cardoso and Bittencourt (2012) and Santos (2013) used panel data, incorporating datasets from the 27 Brazilian state economies. Even within similar studies we observe some inconsistencies. In Von Randow et al. (2010), the authors found much greater price elasticities (-11.3 for hydrated ethanol and 12.8 for gasoline) than others who used the same or similar time-series and an analogous economic model, such as Serigati et al. (2010), Pontes (2009), Farina et al. (2010), Bacchi (2009) and Santos (2013). In those studies, the authors found own-price elasticity close to unity and a somewhat greater cross-price elasticity, between 1 and 1.5. However, the long-run price elasticities found by Santos (2013) are also higher. Melo and Sampaio (2014) analyzed the hydrous and anhydrous ethanol demand in Brazil. For hydrous ethanol demand, the price elasticity estimated was -0.95, and cross-price elasticity was 0.8 for gasoline price. Cesca and Bottrel (2016) estimated the demand elasticities for gasoline and hydrous ethanol demand in Brazil using the more recent periods of 2004 and 2014. The authors found elastic price and income elasticities for both fuels. In the hydrous ethanol demand they found 0.69, -1.03, and 2.19 for income, own price and cross-price elasticities, respectively. Apart from these differences in results, none of these studies considered the flex-fuel fleet as an explanatory variable, even though the hydrous ethanol demand in Brazil increased very fast in the 2000s.

Thus, to address this shortcoming, Souza (2010), Freitas and Kaneko (2011), Caroprezo (2011), Cardoso and Bittencourt (2012) and He (2013) included this fleet in the ethanol demand model. This change made price elasticities higher. The own-price elasticity found in these studies was between -1.2 and -3.3, and the cross-price elasticity, between 0.5 and 2.8. This shows how elasticities in a well-specified model can be quite different from the elasticities in a model where important variables are omitted. Another problem detected by Costa and Guilhoto (2011) was the absence of the assumption that, as the flex-fuel fleet grows, the own-price elasticity of demand for hydrated ethanol is expected to increase. Thus, the price elasticity for demand found by Azevedo (2007), Oliveira et al. (2008) and Iooty et al. (2009) does not reflect the behavior of consumers with flex-fuel vehicles nowadays, because the period analyzed included more years without these new vehicles. Other studies reviewed (described in Table 1A in Annex) used a time-series, combining periods with and without the flex-fuel vehicle, which could mask the current elasticity values observed with the new fleet.

Only Souza (2010) and He (2013) estimated a complete model that distinguished the periods before and after flex-fuel vehicles were introduced. In Souza (2010), there are ranges of price elasticity values in that study that appear because the author separated the price data into three different series, depending on the relation between hydrated ethanol and gasoline prices. In general, the author found that in Brazilian states where the hydrated ethanol price was less than 65% of the price of gasoline, the price was more inelastic than in those states where it was higher than 65%. The elasticity values (-1.41, 0.92, -2.35 and 1.91, respectively, to hydrous ethanol price and gasoline price for the period 2001-2006, and hydrous ethanol price and gasoline price for the period 2006-2009) correspond to those in Brazilian states where the hydrated ethanol price was 65-75% of the gasoline price, which was true for the majority of states. However, as we can see in Figure 1, the fleet of flex-fuel vehicles in the period analyzed (2006 to 2009) was still very small, a deficiency which this study attempts to eliminate. In He (2013), the author also estimated a complete model, as Souza (2010), but using a 3-stage least squares simultaneous equations system with three equations: on the demand side of hydrous ethanol; on the demand side of anhydrous ethanol and on the supply ethanol. This author verify that the price elasticities (own and cross) of demand for hydrated ethanol became elastic after the introduction of flex-fuel vehicles, as expected. However, the gasoline demand was not considered by this author, as well the differences in the Brazilian states, as was done in this study.

Regarding the studies that analyzed gasoline demand in Brazil, we can use the same considerations from the hydrated ethanol demand estimates, namely those after the introduction of flex-fuel vehicles, where the own-price and cross-price demand elasticities changed. Thus, taking into account the elasticities estimated in more recent periods by Pinto Junior et al. (2006), Silva et al. (2009), Bacchi (2009), Gomez (2010), Vilela and Pinto Junior (2010), Farina et al. (2010), Souza (2010) and Santos (2013), the own-price elasticity ranged between -0.1 and -1, and the cross-price elasticity for hydrated ethanol, with exception to the negative values observed in two cases, ranged between 0.1 and 0.2. However, Iootty et al. (2009) found much greater elasticities. Income elasticity was mostly stable within the studies, except in Gomez (2010), where it was negative, and in Iootty et al. (2009), where it was more than 1.0. Income elasticity ranged between 0.1 and 0.7 regardless of the period analyzed. From the results reported by Silva et al. (2009) and Souza (2010), we can conclude that, during the post-flex vehicle period, the gasoline demand changed, becoming more elastic.

However, unlike the ethanol demand, within the gasoline demand analysis the fleet was not generally used as an explanatory variable. Only Souza (2010) included this variable. Other features of the studies reviewed are: (i) Santos (2013) used a different explanatory variable, *per capita* consumption, for both ethanol and gasoline; (ii) some studies included additional explanatory variables other than fuel prices, income and fleet; and (iii) other studies analyzed the demand behavior separately for each Brazilian state. The use of *per capita* consumption by Santos (2013) would be justified if the fuel for light vehicles (ethanol or gasoline) was consumed by all individuals. However, while population growth reached 1% per year in recent years, the light vehicle fleet growth was 7% per annum[1]. Therefore, the use of *per capita* consumption in that analysis cannot be the best approach. The extra variables included in some studies, as mentioned in item (ii), were diesel, in Azevedo (2007); natural gas and diesel, in Iootty et al. (2009); and natural gas, in Pinto Junior et al. (2006), Freitas and Kaneko (2011), and Santos (2013). However, except for Freitas and Kaneko (2011), the results for these other fuels were not satisfactory.

Concerning item (iii), the only reason to consider demand separately by region is that the average income is very different among the Brazilian regions. However, when the income variable is incorporated into the model, such separation is no longer required. Differently from the supply model – where ethanol production shows varied behavior among the regions in Brazil, as described by Costa et al. (2006) –, there is no motive for consumers to modify their consumption behavior among different Brazilian regions.

Rodrigues and Bacchi (2014) estimated the total demand for these fuels (gasoline, hydrous ethanol and vehicular natural gas) in Brazil, from April 2003 to March 2013. The authors focus on the importance of the fleet on fuel demand, and do not discriminate fuel type, as was performed in this study. Hence, considering fuel prices as a whole, the authors found that the demand for these fuels presented lower impact due to changes in their prices, with elasticities -0.09 in the short run and -0.163 in the long run. In regard to income, the elasticities found were 0.4 and 0.659 in the short and long run, respectively.

In summary, among the studies that have analyzed the fuel demand in Brazil, as described in this section, many did not use the following: panel data, important explanatory variables such as in-

1 Percentages deduced by the authors based on data supplied by Unica (2017b) and IBGE (2017c).

come and fleet, or the more recent period when flex-fuel vehicles appeared in increasing numbers in the light vehicles fleet. Furthermore, out of more than 20 studies analyzed, only five considered both hydrated ethanol and gasoline (Iootty et al.; 2009, Bacchi; 2009, Farina et al.; 2010, Souza; 2010 and Santos; 2013). Among these, only Souza (2010) used the flex-fuel fleet as an endogenous variable. Finally, only Rodrigues and Bacchi (2014) described the fuel consumption of the whole light vehicle fleet with dedicated ethanol, dedicated gasoline, and flex-fuel vehicles. Nonetheless, since they did not discriminate gasoline and ethanol prices, we can analyze the different impacts from these two different fuel prices. This is important given they are not perfect substitutes, and total fuel consumption demand is key because the ethanol or gasoline demand only demonstrates the changes between the fuels chosen by consumers, but it does not show fuel demand behavior as a whole. With regard to the estimates published by Souza (2010), while the model was a better estimate of the fleet's current situation, the author used monthly data, whereas annual data is more suitable to identify the long-term consumption profile, as described by Iootty et al. (2009). Also, income and fleet data is available in annual information. Costa and Burnquist (2016) also used a hydrous ethanol demand model considering the hydrous ethanol and gasoline prices, income and the fleet of the flex-fuel vehicles, but these authors did not estimate the demand equation. This model was used to derive the impact of gasoline price on hydrous ethanol price. These authors also used panel data with Brazilian states and a period from 2006 to 2015.

Taking the fragilities mentioned above into account, this study elaborated and estimated a new economic model for fuel demand (hydrated ethanol and gasoline) in Brazil in recent years, and simulated some changes in the fuel market by employing recent data to test the model. In order to validate the results obtained in this study, the values reported by the other authors described in this section are considered and discussed. The next section presents our model, data and method.

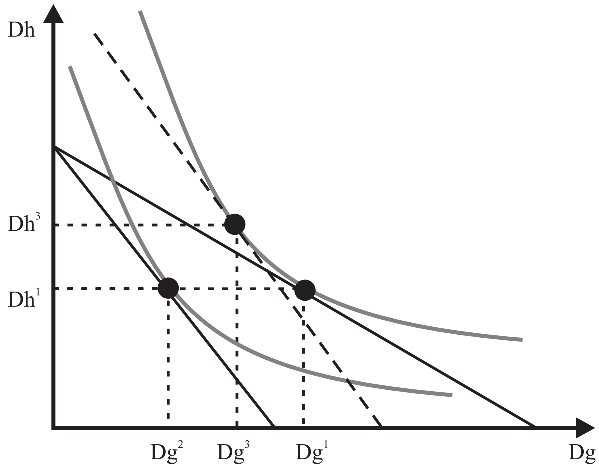
3 MATERIAL AND METHODS

This section presents an economic model to describe the Brazilian fuel market in recent years. Subsequently, the econometric techniques employed to obtain coefficient estimators are presented and discussed. The procedure takes the data's panel specification into account, aggregating the Brazilian states over a period.

3.1 Theoretical and empirical specification

This study analyzes consumer behavior by considering two substitute goods: hydrated ethanol and gasoline. The consumer demand theory derives the demand for each of these goods not only as dependent on their price and consumer income, as has been usually done, but also as dependent of the other product's price. This is the substitution effect (Ferguson, 1988) described in Figure 2, which presents consumer utility as the indifference curve, and defines the demand of both fuels by the interception of the income restriction in this curve. Initially, the gasoline demand is Dg^1 and hydrous ethanol demand is Dh^1. The final effect of the increase in gasoline price (in Dg^2 and Dh^1) contains not only the effect of the increase in this price, but also the impact on consumer income, since the income restriction retreated and changed its inclination. If we disregard the change in the income inclination, we can only see the substitution effect in hydrous ethanol demand due to gasoline price increase, i.e. the increase in demand from Dh^1 to Dh^3. In gasoline demand, the impact due to price alone is from Dg^1 to Dg^3.

Figure 2 – Price and Substitution effect and income effect on the demand of the two substitute fuels, hydrous ethanol (*Dh*) and gasoline (*Dg*), in order to obtain an increase in gasoline price



Source: Ferguson (1988).

Additionally, consumers require an instrument to consume fuels, i.e. vehicles. Hence, the number of vehicles is also a dependent variable to explain fuel demand, as described in several studies mentioned in the previous section.

Considering such theory, this study described three models of fuel demand in Brazil: hydrated ethanol demand, gasoline demand and gasoline plus hydrated ethanol demand. For this last model, referred to as total fuel demand, since these two fuels are by far the most commonly consumed by light vehicles in Brazil, the volume consumed was expressed in terms of equivalent gasoline volume consumption. To obtain this value, the hydrated ethanol volume was multiplied by a technical coefficient to convert it into gasoline consumption. This coefficient is 0.7 (Unica, 2017a). This study includes three models that are based on the same theoretical demand specification (demand for gasoline, demand for hydrated ethanol and automotive demand for fuel) which considers consumption as function of the own and cross product price- where prices are hydrated ethanol price (*Ph*), the gasoline price (*Pg*)-, of the income (*Y*) and of the fleet of vehicles (*Fleet*)[2] that consume the fuel specified by the model. Equation (1) describes the theoretical model used:

$$D = f(Ph, Pg, Y, Fleet) \quad (1)$$

However, in order to estimate the influence of each variable on consumer demand in the form of elasticities, equation (1) is described in the logarithm form, as show in equation (2).

$$D = \alpha_0 + \alpha_1 Ph + \alpha_2 Pg + \alpha_3 Y + \alpha_4 Fleet \quad (2)$$

For gasoline demand (*Dg*), we expect a positive coefficient for α_1 because, as described in economic theory, an increase in hydrated ethanol price spurs the demand for this product. For coefficients α_2, α_3 and α_4, we expect positive signs because, if either gasoline price, income, or the fleet grows, the theory indicates that *Dg* rises. Conversely, for hydrated ethanol demand (*Dh*), α_1 is expected to be negative and $\propto_2$ positive. For total fuel demand (*Dt*), $\propto_1$ and $\propto_2$ would both be negative. The model described in equations (1) and (2) was the same employed for only four of the more than twenty studies described in the review above, but not with the same econometric treatment, i.e. considering the differences between Brazilian states. In addition, the time series used was the most recent within the studies reviewed, which is important for a new market analysis.

Thus, in this study, we used equation (2) to estimate hydrated ethanol demand and gasoline demand. Some impacts due to changes in Brazilian taxes on these fuels were estimated considering the results found in this study. These impacts could be interpreted as previsions in fuel demand behavior due to changes in fuel policies.

3.2 Econometric technique

According to Hsiao (1986), a model for panel data has several advantages over cross-sectional or time-series models. This is particularly so when there is heterogeneity among the units included in the study, such as the states in this case, which can be controlled by this type of modeling procedure.

It is believed that there are several state features that affect the variable (fuel demand) explained in this study, but which cannot be observed and, therefore, are not included in the model as explanatory variables. The quality of public transports, cultural aspects, and the size of cities are good examples to illustrate the issue. While they are not easy to measure and represent, omitting these variables from the model can lead to biased results. The panel data model is recommended for this type of estimation, since the model considers the differences between individual units (such as the states, in this case). Hsiao (1986) also pointed out another advantage of panel data: additional observations that can be used within the panel model procedure enable the number of degrees of freedom to be increased, in such a way that collinearity between the explanatory variables is reduced and the quality of parameter estimates are improved.

Panel data estimation relies on the hypothesis that in the estimation procedure, the heterogeneity among cross-sectional units is taken into account. The one-way random effects (RE) and fixed effects (FE) models are those most frequently used with panel data.

2 This analysis focuses on light vehicles in Brazil, since they are the ones equipped with flexible motors. According to Anfavea (2017), only about 5% of the new light vehicles registered in Brazil per year run on diesel.

The fixed effects model assumes that the intercept (α_0) varies from one state to another, but is constant through time. The parameters of the explanatory variables are constant for all individuals and at all times (Griffiths et al., 1993). Since these response parameters do not vary among states or through time, all the behavioral differences among them will be captured by the constant term. Therefore, the estimated constant term in the fixed effects model can be interpreted as the effect of the variables omitted in the model. A basic characteristic of these models is that they rely on the assumption that differences among cross-sectional units can be captured by means of an intercept term, specific to each cross-sectional unit. The random effects (RE) models assume, with regard to the fixed effects, that the intercept varies between states but not through time, while the explanatory variable coefficient is constant for all individuals and at all times. The difference between the models is how the intercept is interpreted. In the FE model, the intercept is considered a constant (fixed value) correlated with the explanatory variables in any period of time, while in the RE model the constant coefficient ($\propto_0$) is treated as a random variable. This means the RE model assumes that the set of individuals for which there is information is a random sample from the population within a larger number of individuals. The FE model is thus appropriate when the observations are available for the whole population.

The Hausman test can be used to identify whether the model should be treated as FE or RE when it is unclear which one is preferable. In the case under analysis, the FE is more appropriate since there is no reason to believe that constant characteristics of the states are randomly related to fuel prices in any period of time. However, this test should confirm this. Another form of estimation that can be used with panel data is the dynamic model. This is employed when it is important to consider some lagged variables in the model, especially the dependent variable (RABE-HESKETH; SKRONDAL, 2012). This type of model should be used for the fuel demand, as was performed by Santos (2013). However, unlike the present study, Santos (2013) neither considered the fleet as an independent variable, nor used a database created after the introduction of flex-fuel vehicles, nor used annual data.

For the dynamic econometric model, Arellano and Bond (1991) proposed an efficient estimation procedure, employing an extension of instrumental-variables estimation called generalized method of moments (GMM), which was also used in this study to estimate demand models.

In both econometric models we test the absence of autocorrelation in residues. For such, the Woodridge test and Arellano-Bond test were used to verify the autocorrelation, respectively, for FE or RE models and for the dynamic econometric model.

This study estimates fuel demand elasticities separately for hydrated ethanol and gasoline. In addition, we carried out estimation by two methods for panel data, as previously described: either the fixed or random effects model (depending on the Hausman test result) and the dynamic model. For all these estimates, the data used, with sources and units, are listed in Table 1. The monetary variables, income (*Y*), and gasoline and ethanol prices were deflated by the National Consumer Price Index - INPC (IBGE, 2017b). All data used included all 27 Brazilian states and annual data for the period from 2006 to 2016.

Table 1 – Data used and sources

Code	Description	Unit	Source
Dg	Gasoline consumption	m^3 of gasoline volume	ANP (2017)
Dh	Hydrated ethanol consumption	m^3 of hydrated ethanol volume	ANP (2017)
Y	From GDP deflated	million Brazilian reals (R$)	IBGE (2017a)
Fleet	Gasoline and flex-fuel vehicles fleet	thousand units	UNICA (2017b)
FleetFlex	Flex-fuel vehicle fleet	thousand units	UNICA (2017b)
Pg	Consumer gasoline price deflated	R$ per liter	ANP (2017)
Ph	Consumer hydrated ethanol price deflated	R$ per liter	ANP (2017)

Note: *for this data, the volume of gasoline consumed was added to 70% of the hydrated ethanol volume consumed (Unica, 2017a).

4 EMPIRICAL RESULTS AND DISCUSSION

The elasticities estimated for the hydrated ethanol demand (*Dh*) and gasoline demand (*Dg*) estimated for Brazil through the 2006 to 2016 period are shown in Table 2. The independent variables are shown in the first column, where D_{t-1} is the lag-dependent variable used only in the dynamic econometric model. The hydrated ethanol price (*Ph*), gasoline price (*Pg*), and income (*Y*) are used in all three demand models. However, while for the hydrated ethanol demand only the flex-fuel vehicle fleet (*FleetFlex*) was used, for the gasoline fuel and total fuel demand, all the light vehicles running on ethanol or gasoline (*Fleet*) were considered.

The results showed that the value of elasticities estimated by fixed or random effects models were higher than those estimated by the dynamic econometric model. For both hydrated ethanol and gasoline demand, the tests indicated that the fixed effects model was more appropriate than the random effect model. The econometric model's assumptions were satisfied since the Wooldridge test (for the FE model) and Arellano-Bond test (for the dynamic model) did not identify the presence of autocorrelation in both models at 1% of statistical level of significance.

For hydrous ethanol demand, the FE model presented adjustment coefficients equal to 0.3, 0.93 and 0.83, respectively, within, between and overall groups. For both FE and dynamic models, with exception to the income (*Y*) variable, the signs of all coefficients were as expected, and their significance was at a 5% or 10% statistical level.

For gasoline demand, the FE model presented adjustment coefficients equal to 0.92, 0.98 and 0.98, respectively, within, between and overall groups. For both the FE and dynamic models, the signs of all coefficients were as expected, and their significance levels were at 5% or 10%.

Both the fixed effect and dynamic models provided similar and robust results. Taking these results into account, we verified that:

i) The estimated hydrous ethanol demand shows that consumers respond to fuel prices relatively more intensive way than in the estimated gasoline demand.
ii) The gasoline demand is responsive to income changes, while the hydrous ethanol demand is not.
iii) The cross-price elasticity for hydrous ethanol demand was higher than the relative response to its own price elasticity; the contrary occurred for gasoline price elasticities.
iv) Hydrated ethanol and gasoline demand react the fleet changes in a similar manner.

The results presented in (i) to (iii) seem to suggest that consumers will switch from gasoline, a fossil fuel, to ethanol biofuel in a more expressive manner when gasoline prices increase than when hydrous ethanol price are reduced which is an important aspect to be explored while defining policy to stimulate the consumption of less pollutant fuels in a country.

To explain the income elasticity in the hydrous ethanol and gasoline demand equations, we consider the two types of consumers: (a) those with gasoline dedicated vehicles; and (b) those with flex-fuel vehicle, which account for the majority of consumers.

Even being minority, the consumers classified in (a) are able to influence the elasticities of the gasoline demand and are expected to present a higher response to income changes, since they do not have an option to switch between fuels when there is a change in the relative prices of fuels. Hence, changes in income are important for them and could change their gasoline demand in a same trend. For the consumers characterized as (b) the behavior seems to be different; these represent the majority in the market and are the only consumers of hydrous ethanol. Therefore, they could not only choose consume more or less fuel due to changes in income, but, in the case of income reduction, they also could consume the cheaper fuel. Besides this, the negative income elasticity indicate that these consumers (once since they have vehicles, they are not the poorest), apparently, regardless of the fuel price relationships, prefer consume a higher-yielding fuel, which leads them to less refueling (gasoline), than to consider environmental issues and seek to consume a product that causes with less environmental impacts (hydrous ethanol). Thus, the results suggest a preference of the Brazilian consumers. Politically, this is an interesting result, showing that, in order to promote the biofuel use, a greater price incentives should be offered to consumers to promote biofuel use.

Table 2 - Elasticities estimated for gasoline and hydrated ethanol demands in Brazil, Period: 2006 to 2016

		Dh		Dg	
		Fixed effects model	**Dynamic model**	**Fixed effects model**	**Dynamic model**
Constant	α_0	1.59†		0.59*	
D_{t-1}		-	0.44*	-	0.29*
Pg	α_1	5.28*	2.39*	-0.66*	-0.42*
Confidence interval (95% probability)		3.45 to 7.12	0.13 to 4.64	-1.04 to 0.29	-0.82 to -0.025
Ph	α_2	-2.51*	-1.98*	0.37*	0.27*
Confidence interval (95% probability)		-3.18 to -1.84	-2.86 to -1.10	0.21 to 0.52	0.16 to 0.39
Y	α_3	-0.17†	-0.81*	0.40*	0.43*
Confidence interval (95% probability)		-0.97 to 0.62	-1.58 to -0.03	0.23 to 0.57	0.25 to 0.61
FlexFleet	α_4	0.60*	0.29**	-	-
Confidence interval (95% probability)		0.41 to 0.79	-0.02 to 0.62		
Fleet		-	-	0.66*	0.38*
Confidence interval (95% probability)				0.54 to 0.78	0.21 to 0.56
Test F or χ^2 of model		27*	363*	734*	1080*

* Denotes statistical significance at 5% level.
** Denotes statistical significance at 10% level.
† Statistically non-significant.
Source: Author's calculations

Tables 1A and 2A in the Annex show the value of the elasticities obtained in the studies discussed in the section 2. While comparing the results found in this study with those from the other studies, the behavior of the hydrous ethanol demand described in Table 2 is only similar to those described by Caroprezo (2010), where gasoline price elasticity is higher than hydrous ethanol price elasticity and income did not influence the demand, only the fleet. About the absence of income influence, several other studies obtained the same result, as in He (2013), Freitas and Kaneko (2011), for Center-South region, and other studies that not included the fleet in their models (AZEVEDO, 2007; OLIVEIRA et al., 2008).

In regard to the gasoline demand model, in comparison with the other studies (Table 2A in Annex), the elasticities found in this study are more similar to those found by Souza (2010).

The third and last model, similarly to the model estimated by Rodrigues and Bacchi (2014), attempted to adjust a model for total fuel demand (gasoline plus ethanol). Unlike that study, this paper did not include natural gas in the empirical model. We only considered hydrous ethanol and gasoline prices. Another important difference from that study was that we used gasoline and ethanol prices distinctly, while those authors used only one fuel price. Considering the results previously described, this is an important difference, for we verified that consumers presented different behaviors in face of price variations in both of these fuels.

For that model, we verified that the FE model proved to be better and it did not present autocorrelation in the 1% significance level. However, the dynamic model was not well adjusted, presenting symptoms of the autocorrelation problem. The FE model shows an adjustment coefficient equal to 0.94, 0.98, and 0.98, respectively, within, between and overall groups. With exception to the hydrous ethanol price (*Ph*) variable, the signs of the all coefficients were as expected and significant at the 1% statistical level. Equation (3) shows the elasticities estimated, and the confidence intervals with 95% probability are presented below each significant elasticity.

$$\ln(Dt) = 2.22 - \underset{(-0.88 \text{ to } -0.26)}{0.57}\ln(Pg) + 0.019^{ns}\ln(Ph) + \underset{(0.14 \text{ to } 0.42)}{0.28}\ln(Y) + \underset{(0.57 \text{ to } 0.76)}{0.67}\ln(Fleet) \quad (3)$$

These elasticities corroborate the results described for the model estimated separately for hydrous ethanol and gasoline, i.e. gasoline price and fleet were more important for consumer behavior than income. Hydrous ethanol price has a low impact on fuel demand.

Table 3 shows a simulation of the volume consumed for both fuels in 2016 and the changes in those volumes when their prices rise in 1%. This calculation was based on elasticity values given by the dynamic econometric model. These elasticities are also show in Table 3.

Table 3 – Hydrated ethanol and gasoline consumption observed in 2016 and change in volume determined by a 1% increase in fuel prices, using the elasticities estimated in this study (unit of volume: 1000 m3)

	Elasticity	Observed Volume 2016	Change in volume for:		
			1% increase in *Pg*	1% increase in *Ph*	1% increase in both prices
Hydrated ethanol consumed (*Dh*)	-1.98 (*Ph*) 2.39 (*Pg*)	15,008	359	-297	62
Gasoline consumed (*Dg*)	-0.42 (*Pg*) 0.27 (*Ph*)	43,019	-181	116	-65

Source: Author's calculations.

The results estimated in this study show that, if the gasoline price increases by 1% (due to an increase in the CIDE tax, for example), we could expect a growth of more than 2% in hydrous ethanol demand. In the volume consumed in 2016, that means around 360 thousand m^3 in ethanol consumption. This shock in gasoline price could also promote a 0.42% reduction in gasoline demand, i.e. approximately 181 thousand m^3 in gasoline consumption during a year considering the 2016 volume as the base.

Considering the increase in PIS/Cofins determined in July 2017 by the federal government, we can predict that, for each 1% increase in the gasoline and hydrous ethanol prices for consumers in this year, ethanol consumption should grow approximately 60 thousand m^3, and gasoline consumption should drop approximately 65 thousand m^3. This means a total fuel reduction of 21.5 thousand m^3 in gasoline equivalent. By using the total fuel demand equation described in equation (3), this estimated reduction is 294 thousand m^3 in gasoline equivalent. The difference between these values (-21 and -294) disappears when we consider the range of elasticities described in the confidence interval. Once this rise in PIS/Cofins was higher for gasoline than for hydrous ethanol, the impact described would be even more positive to hydrous ethanol demand and more negative to gasoline demand. These results depend on the impact upon their prices, which is not known by the time this paper is finalized. However, the elasticities described can be used for this simulation. The impact will be lower depending on how much the consumers respond these changes in prices by replacing gasoline for hydrous ethanol. Therefore, in the years to come, after observing the impact of this policy, more accurate elasticities should be reconsidered.

5 CONCLUSIONS

The evaluation of consumption behavior including the period of expansion of flex-fuel vehicles shows that there the gasoline cross-price elasticity with respect to hydrated ethanol is higher than the own price elasticity value in hydrous ethanol demand, and also that hydrous ethanol demand does not respond to income as expected. This information and more up-to-date data to estimate the elasticities are improvements provided by this study.

The results suggest that consumers would rather consume higher-yielding fuel, requiring less refuels (gasoline), than consider environmental issues and consume the renewable fuel. Based on this, we conclude that Brazilian consumers are more oriented to convenience than to environmental appeal.

The higher value of the cross-price elasticity for gasoline compared to that for own price elasticity in hydrous ethanol demand is an important conclusion for policymakers, given that tax increases for gasoline could be more efficient than tax cuts in hydrous ethanol to spur hydrous ethanol demand. In addition, for the purpose of discouraging gasoline demand, besides tax raise, the government should also discourage vehicle imports, since these consume exclusively gasoline.

A limitation for these estimations, since actual fuel prices in Brazil decreased in most of the period analyzed and the flex-fuel fleet is still on the rise, further estimations in future periods are recommended to complement the market behavior analysis as analysis of price asymmetry. Also, the range of elasticities values for gasoline price is still very large, mainly in cross-price elasticity for hydrous ethanol demand.

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ANNEX

Table 1A - Hydrated ethanol demand elasticities in Brazil, taken from the literature

Source	Period analyzed	Elasticities for each explanatory variable			
		Deflated hydrated ethanol price	Deflated gasoline price	Deflated income	Fleet
Azevedo (2007)	January 2002 to June 2006	SR: -0.459† LR: -1.04†	SR: -0.364† LR: 1.3†	0.13†	-
Oliveira et al. (2008)	1995 to 2006	-0.058*	-0.598**	1.6†	-
Iootty et al. (2009)	1970 to 2005	-3.58	8.09	0.077	-
Bacchi (2009)	July 2001 to August 2006	-0.934	1.25	-	-
Pontes (2009)	July 2001 to October 2008	-0.934	1.374	1.255	-
Farina et al. (2010)	January 2002 to August 2009	-1.23	1.45	-	-
Souza (2010)	July 2001 to August 2006	-1.41*	0.92*	0.4*	1.56*
	September 2006 to December 2009	-2.35*	1.91*	0.22**	3.7*
Serigati et al. (2010)	July 2001 to April 2009	-0.78*	1.03*	0.69*	-
Von Randow et al. (2010)	July 2001 to October 2009	-11.26	12.79	0.458	-
Freitas and Kaneko (2011)[a]	January 2003 to April 2010	-1.658*	2.32*	0.913†	1.94*
		-1.40*	0.589*	0.80*	3.75*
Caroprezo (2011)	July 2001 to December 2010	-2.48	4.21	-2.05	1.92
Cardoso and Bittencourt (2012)	July 2001 to July 2011	-3.30	2.82	0.91	25.51
Santos (2013)[b]	July 2001 to December 2010	SR: -1.252* LR: -8.46*	SR: 1.182* LR: 7.99*	SR: 0.55* LR: 3.72*	-
He (2013)	July 2001 to December 2002	-0.92*	0.87*	Non significant	1.93*
	January 2003 to December 2011	-1.67	1.47		3.50*
Melo and Sampaio (2014)	July 2001 to March 2011	-0.95	0.8		
Cesca and Bottrel (2016)	January 2004 to December 2014	-1.03	0.69	2.19	

Notes: SR – short-run elasticity; LR – long-run elasticity.
* Denotes statistical significance at 5% level.
** Denotes statistical significance at 10% level.
† Implies statistically insignificant.
[a] These authors estimated demand elasticities only for regions. The upper row has the demand estimates for the Center-South region of Brazil and the lower row has the demand estimates for the North-Northeast region.
[b] The dependent variable for this study was per capita consumption and not total consumption as in the others.

Table 2A - Estimated gasoline demand elasticities for Brazil

Source	Period analyzed	Elasticities for each explanatory variable			
		Hydrated ethanol price	Gasoline price	Income	Fleet
t	1973 to 1998	-	-0.319	0.6	
Samohyl and Dantas (1998)	1955 to 1995	-	SR: -0.19* LR: -0.28	SR: 0.33* LR: 0.46	-
Alves and Bueno (2003)	1974 to 1999	SR: 0.229† LR: 0.48***	SR: -0.09† LR: -0.464***	SR: 0.12** LR: 0.12*	-
Roppa (2005)	1973 to 1995	SR: -0.19† LR: 0.4	SR: -0.07† LR: -0.63	SR: 0.47* LR: 0.16	-
Pinto Junior et al. (2006)	July 2001 to August 2006	SR: 0.16* LR: 0.18*	SR: -0.12** LR: -0.14**	SR: 0.26* LR: 0.30**	-
Nappo (2007)		-	-0.196*	0.69*	-
Schumemam (2007)	July 2001 to February 2007	-	SR: -0.38 LR: -0.3176	SR: 0.21 LR: 0.53	-
Silva et al. (2009)	2001 to 2006	0.049	-0.945*	0.154**	-
	2003 to 2006	0.611*	-1.5*	0.37*	-
Iootty et al. (2009)	1970 to 2005	1.503	-3.848	1.188	-
Bacchi (2009)	July 2001 to August 2006	-0.103	-0.101	0.412	-
Gomez (2010)	January 2000 to December 2008	0.20	-0.46	-0.21	-
Vilela and Pinto Júnior (2010)	July 2001 to December 2008	Nd	SR: -0.514** LR: -0.47	nd	
Farina et al. (2010)	January 2002 to August 2009	0.28	-0.63	-	-
Souza (2010)	July 2001 to August 2006	-0.20***	-0.29*	0.077**	1.14†
	September 2006 to December 2009	0.16*	-0.37†	0.327†	0.292†
Santos (2013)[a]	July 2001 to December 2010	SR: 0.1* LR: 0.293*	SR: -0.399* LR: -1.186*	SR: 0.176* LR: 0.523*	-

Notes: SR – Short Run elasticity; LR – Long Run elasticity.
* Denotes statistical significance at 5% level.
** Denotes statistical significance at 10% level.
*** Denotes statistical significance at 20% level.
† Implies statistically insignificant.