Fuel Demand Elasticities in Brazil: A Panel Data Analysis with Instrumental Variables

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ABSTRACT

The aim of this paper is to provide demand elasticities for the three main fuels used in Brazil: gasoline, ethanol and diesel. We used a panel data approach at municipal level for the period between 2007 and 2016. The innovation in this study is in its introduction of a new instrumental variable for prices, combining three taxes and municipal distance from state capital. The main results are as follows: (i) the gasoline, ethanol and diesel demands are price elastic, meaning that all own-price elasticities are greater than one; (ii) ethanol consumption is more elastic when the CNG price is added as an explanatory variable, but this does not apply to gasoline; (iii) an increase in GDP positively affects the demand for gasoline and diesel (less than proportionally), but does not affect demand for ethanol; (iv) fleet size impacts the consumption of all fuels, except when the CNG price is excluded from the ethanol model; (v) the ethanol-to-gasoline price ratio is a relevant variable for the demand of both gasoline and ethanol.

Keywords: Fuel Demand, Causal Inference, Panel Data Analysis, Price Elasticity, Cross Price Elasticity
JEL Classifications: C13, C26, L11, Q41, Q2

1. INTRODUCTION

Following Storchmann (2005), in general terms, fuel demand is a derived demand because fuel consumption does not provide utility in itself, but rather the possibility of moving goods and people quickly, which is a requirement of modern economies. At the same time, reducing both pollution and dependence on fossil fuels are urgent needs. These two sentences could have been written 40 years ago, when the share of fossil fuels was 80% of total[1], as it is now, while the percentage of transport in relation to total energy consumption was very close to the 27% seen in current times[2].

In terms of pollution, transport is responsible for 23% of global energy-related CO_2 emissions, with nearly half generated by urban travel (Conti et al., 2016). This illustrates a crucial public choice in regards to urban mobility, including the relative favoring of certain fuels. In this regard, the Brazilian market has some interesting aspects, with gasoline[3], ethanol and compressed natural gas competing in the light-vehicle market, enabling a series of public policies addressing pollution, fossil fuel dependence and urban mobility concerns. However, the proper planning and implementation of such policies requires knowledge of the price elasticity of fuel demand and without this information, it is impossible to predict policy results.

An increase in the demand for goods leads to price increases, resulting in a spurious correlation between price and regression error (Coglianese et al., 2017). This primary source of endogeneity

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1   Data from World Bank, World Development Indicators Database.
2   Conti et al. (2016) indicate that the transport sector only increased 2 p.p. of its share of total primary energy consumption over the last forty years, taking over from industry as the sector with greatest demand.

3   Since March 2015, gasoline in Brazil has been a blend of 27% anhydrous ethanol and 73% gasoline (E27). Between 2001 and 2015, this ranged between E20 and E25. The composition is the same for the whole country. Henceforth, we will call this blend gasoline.

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does not allow for the use of traditional ordinary least-squares (OLS) to estimate elasticities. Instrumental variables (IV) have been widely used to overcome this. We highlight the use of regional dummies, proven oil reserves, a variable related to the international oil market, oil price shocks and taxes, as instruments for price elasticities in fuel markets.

Coyle et al. (2012) consider nominal tax variation over time to be an instrument which assumes that taxes rates and gasoline demand are not correlated. This instrument may not be exogenous if fuel buyers increase purchases prior to tax increases, and delay purchases following tax decreases (Coglianese et al., 2017), overestimating elasticities.

This study takes advantage of panel data for municipalities in Brazil, provided on a yearly basis, to construct an instrument based on both: (i) taxes; and (ii) distance from state capital. Previous critiques of overestimating elasticities due to anticipating consumption do not seem to apply here, since we utilize long-run panel data. Also, the lack of variability between municipalities (taxes only vary at state level) is overcome using distance from state capital. Distribution costs are directly related to prices and this cost is lower in capitals and their surroundings. Therefore, an instrument created using both a tax index and distance from state capital provides exogenous variation in time and municipality.

Thus, the aim of this work is to provide demand estimates for own- and cross-price elasticities for the three primary fuels used in Brazil − gasoline, ethanol and diesel. To the best of our knowledge, although several studies address this issue, none have applied this approach, combining taxes and distance in a municipality's long-run panel data. Furthermore, there is a lack of diesel estimates in Brazil, and studies that estimate the elasticities of the diesel market do not focus on the light fuel market, or vice-versa. Therefore, when we compare diesel elasticities with gasoline and ethanol ones, we are comparing elasticities from different methodologies. The possibility of comparison of elasticities from the same framework will be also a contribution of this study.

The subsequent sections of this paper are presented as follows. Section 2 provides a brief description of the Brazilian fuel market and its main characteristics. The econometric method and identification strategy are discussed in Section 3. Section 4 explains how data set was constructed. The main results are reported in Section 5, and, finally 6 provides some concluding remarks.

2. SOME FACTS ABOUT BRAZILIAN FUEL MARKET

Brazil is highly dependent on roads and therefore on fossil fuels, and its cargo and public transport systems are diesel powered. Thanks to flex-fuel engines, the light-vehicle fleet is powered by gasoline, hydrous ethanol or any blend of the two. This creates a market separation between diesel (demanded by trucks and buses) and ethanol and gasoline (demanded by light vehicles). For the purposes of this study, this separation is interesting, since the demand probability of trucks and buses behaves differently from that for light vehicles in terms of price response. In Europe, for

example, where the diesel shares of the light-vehicle fleet rose from 28% to 42% between 2005 and 2015, this separation is not so clear cut (ACEA, 2018).

The Brazilian market has a long history of replacing gasoline with ethanol and since 1931 there has been a legal obligation to blend gasoline with anhydrous ethanol. Over the last few decades, the large-scale use of ethanol has prevented further increases in gasoline imports, in such a way that in 2008, for the 1st time since the late 1980s, ethanol consumption (anhydrous and hydrated) surpassed total gasoline consumption (ANP, 2009).

Before mid-2003, ethanol was considered an imperfect substitute for gasoline, because consumers at that time had to choose between buying a car powered by gasoline or by ethanol. From 2004 onwards there was a continuous increase in the number of flex-fuel vehicles, increasing the degree of substitutability between ethanol and gasoline, demonstrated in an increase in the own-price and cross-price elasticities of both demands (ethanol and gasoline) seen (Santos, 2013) and (Cardoso et al., 2019).

Consuming gasoline or ethanol is not an automatic choice based on lowest price criteria. Due to ethanol's lower energy content per liter, the ethanol price should be low enough to compensate for its higher per mile consumption. This correction is not the same for all cars[4], although a threshold of 70% is the government authorities' widely used and disseminated rule-of-thumb. Ethanol is a better choice when the ratio between prices (the ethanol price divided by the gasoline price) is <70%. This intricate substitutability must therefore be included in the model in order to estimate the price elasticity of demand for both fuels (Barros, 2015).

As well as ethanol and gasoline, there is a third fuel option for cars owners. Incurring some cost, consumers can adapt their engines to run on compressed natural gas (CNG) and thus choose the fuel with the best price-consumption arrangement between the three. Nevertheless, CNG is only available in large cities, meaning that a current impediment to its large-scale consumption is the lack of distribution infrastructure. Unfortunately, to the best of our knowledge, there is no data available on CNG consumption in the municipalities.

Another fact of interest is the composition of fuel prices in the retail market. Generally, prices are composed of the producers purchase price, distribution costs, taxes, and the retailers share. The second and third components suggest a means of overcoming the price endogeneity problem, providing causal estimates for fuel price elasticities.

Distribution costs are directly related to prices, because the greater the distance, the greater the cost of transportation and, consequently, the resale price. Likewise, lower prices are frequently observed in capitals and their surroundings. Because of the political and economic dominance of capitals, distance acts as a proxy for infrastructure, accessibility, or more competitive markets and, of

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4   Using data from Brazilian Labeling Program (PBE) of National Institute of Metrology, Standardization and Industrial Quality (Inmetro) we compared yield of flex fuel cars using gasoline and ethanol and found that this ratio varies between 0.65 and 0.75, with mean very close to 0.69.

course, it is not fuel consumption that determines the dominance of capitals or their location, but historical and social factors.

Fuel consumption is taxed through four different taxes charged by the States, Federal District, and Federal Government. The former levy the Contribution for Intervention in the Economic Domain (CIDE), the Social Integration Program (PIS), and the Contribution for the Financing of Social Security (COFINS), while the States and the Federal District levy the Tax on the Movement of Goods and Services (ICMS). However, no taxes are levied by the municipalities, a fact which may be explored.

The three fuels of interest to this study (gasoline, ethanol and diesel) are taxed at different degrees by the Brazilian government. Figure 1b shows the average taxes in Brazilian Reals per liter for the sum of CIDE, PIS, COFINS and ICMS over the whole period. The Figure 1a indicates the tax behavior for each fuel over time. The fact that there is variation over time indicates that taxes are not only a fixed effect for fuel. In Figures 1a and b it is easy to see that the Brazilian government is trying to prevent gasoline consumption, compared to ethanol and diesel. This choice is supported by pollution policies, since ethanol from sugarcane has lower greenhouse gas emissions compared to gasoline Goldemberg and Guardabassi (2010), and by inequality policies, since we believe that the gasoline tax is more progressive than the diesel tax[5].

3. IDENTIFICATION STRATEGY AND MODEL

Following Dahl (1979), fuel consumption (fc_{it}) can be modeled as a function of prices (fp_{it}), substitute prices (sp_{it}), income (inc_{it}), and the fleet vehicles (fl_{it}). Thus, the model of interest takes the form:

$$fc_{it} = f(fp_{it}, sp_{it}, inc_{it}, fl_{it}) \qquad (1)$$

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5   Fuel taxes are usually regressive, they place a greater burden on the poor than the rich. We believe that the diesel tax is more regressive than the gasoline and ethanol taxes, because diesel tax works as a consumption tax (all goods include some diesel for delivery), while the gasoline tax has a greater effect on the richer portion of the population, which owns more cars. Brazil is a middle-income country, where roughly 60% of households have a car or motorcycle (IBGE, 2018), and this group is surely richer than the remaining 40%.

Note that equation (1) refers to a panel data which allow us to control for unobservable heterogeneity, where subscripts $i = 1,..., n$, and $t = 1,..., T$ indicate municipality and time respectively such that the number of observations is $n \times T = nT$.

To capture the elasticities, we take equation (1) in the $\log - \log$, including the year and city fixed effects. So, this becomes:

$$\log(fc_{it}) = \beta_0 + \beta_1 \log(fp_{it}) + \beta_2 \log(sp_{it}) + \beta_3 \log(inc_{it}) +$$
$$\beta_4 \log(fl_{it}) + \alpha_i + \gamma_t + u_{it} \qquad (2)$$

β_0 is the constant and the other β's are the associated elasticities; α_i and γ_t are full sets of dummies used to capture unobserved heterogeneity across individuals and time; and u_{it} is the error component independent and identically distributed.

Due to bi-directional causation between consumption and prices, estimating the demand elasticity for fuel is challenging. The results from regression analysis may confound the relationship between variables, and the direction of causation is not clear, biasing estimators. instrumental variables (IV) are widely used to overcome endogeneity issues.

An instrument needs to be exogenous and relevant at the same time. We require a variable that affects prices but not quantity, except via prices, i.e., a good instrument must be correlated with price but not with unobserved shocks in fuel demand. Even so, the validity of the instrument depends on the non-correlation between the fuel demand shocks.

A variety of instruments can be found in the literature, of these we note the use of regional dummies, proven oil reserves, a variable related to the international oil market, oil price shocks, and the gasoline taxes nominal variation. In municipal level panel data, we require an instrument that varies at city and time level. In Figures 1a and 1b we have shown that taxes vary across time. Figure 2 indicates that there is also variation between Brazilian states, although these maintain the tax burden sequence of fuels (*gasoline >diesel >ethanol*). This ensures the feasibility of using taxes as an instrument for the states.

Nevertheless, the joint use of these two taxes only provides variability across states and periods and there remains a need for a source of variability across municipalities. One characteristic

Figure 1: Brazilian taxes for gasoline, ethanol and diesel (reals per liter) (a) Taxes over time (mean for Brazil) (b) Mean for the whole period
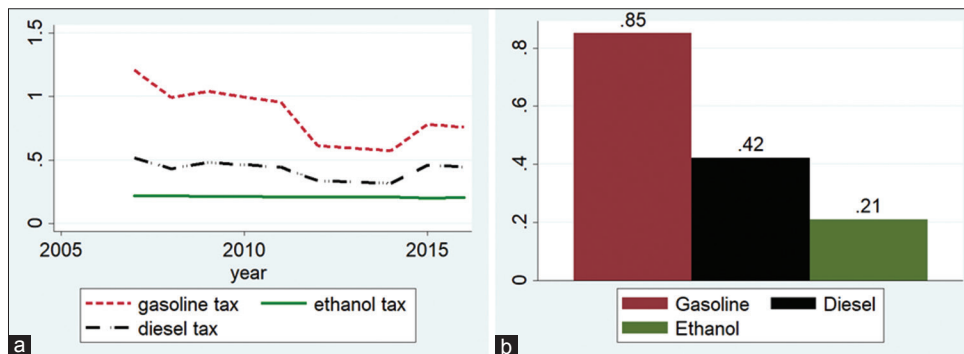
Source: Authors' calculation. (a) taxes are the sum of the Contribution for Intervention in the Economic Domain, Social Integration Program, Contribution for the Financing of Social Security and ICMS; (b) these are not averages weighted by consumption for each state, meaning that each state is a representative agent

Figure 2: Average taxes in Brazilian states for gasoline, ethanol and diesel (reals per liter)
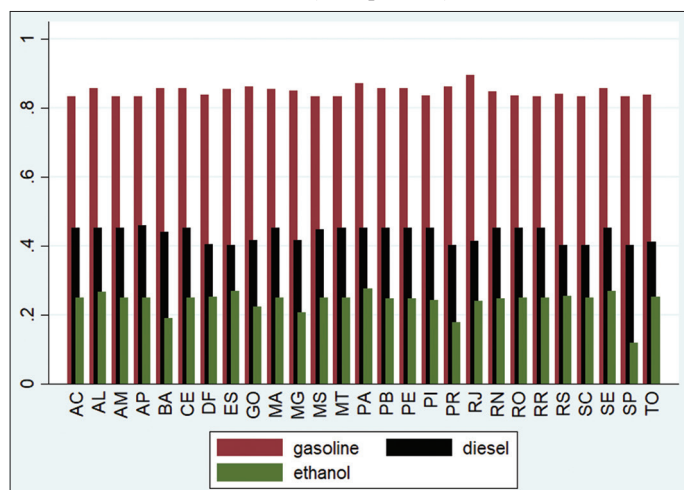
Source: Authors' calculation. Taxes are the sum of Contribution for Intervention in the Economic Domain, Social Integration Program, Contribution for the Financing of Social Security and ICMS

that distinguishes municipalities is their distance from the state capital. In this sense, we could use the distance to the producer as an instrument. However, one could argue that diesel consumption is the most important freight component or even that producer location is somewhat determined by consumption. For example, proximity to large consumer centers is decisive in determining distributor and producer locations.

One way to overcome these issues is to use distance between municipality and state capital. As discussed in Section 2, unlike producers, there is no possibility that fuel consumption could affect distance from state capital.

Based on the above, our proposal is to use ICMS, CIDE, PIS, COFINS, and distance from state capital to construct an index. Separately, no index component has sufficient variability to correct endogeneity, however, considered as a single variable we may obtain an instrument that varies in both dimensions and can be used to solve the endogeneity problem.

4. DATASET

We used data collected from different sources, which are: the Brazilian National Agency of Petroleum, Natural Gas, and Biofuels (ANP); the Brazilian Institute of Geography and Statistics (IBGE); the Brazilian National Traffic Department (DENATRAN); and the National Federation of Fuels and Lubricants Trade (Fecombustveis). The full sample was composed of 555 Brazilian municipalities between 2007 and 2016, totaling 5550 observations. However, due to missing values we were only able to create unbalanced panels. Data regarding gross domestic product (GDP), number of inhabitants, and distance between municipality and state capital are all available on the IBGE website. With respect to number of inhabitants, it is important to note that the last population count occurred in 2010. For non-decennial years we used intercensal

estimates for municipality residents. Since there is no yearly income data at municipal level, GDP data has been used as a proxy for income. Despite its limitations, this is perhaps the only way to obtain an annual income measure by municipality. With this in mind, we deflated the GDP using the National Consumer Price Index (IPCA), also measured by the IBGE, and divided it by the number of inhabitants to derive per capita real consumption level.

Data regarding gasoline (gc), ethanol (ec), and diesel (dc) consumption in liters, as well as nominal prices in Brazilian Reals for gasoline (gp), ethanol (ep), diesel (gp), and CNG (np) are collected and maintained by the ANP and available on its website. Fuel consumption, as above, was taken in per capita real terms and prices were deflated using the IPCA.

Fleet (fl) data, that is the monthly number of vehicles by municipality, is available on the DENATRAN website. In order to obtain a yearly number, we calculated the average number of automobiles per year and divided the result by number of inhabitants.

The instrument is constructed around four variables, namely: distance from state capital, ICMS, CIDE, and the PIS and COFINS taxes. Distance from each municipality to the state capital was computed according to orthodromic distance, i.e., the shortest distance from the latitude and longitude coordinates to the center of each location, also obtained from the IBGE website.

The Fecombustveis Annual Report provides information about the ICMS tax rate by state and year. However, obtaining the CIDE, PIS and COFINS values required a little more work. We started by searching through Federal Regulations and Laws (available on the Brazilian Government website) to determine whether or not these taxes had been levied. We then considered whether the CIDE, PIS and COFINS levied in any given year were enforced for more than 6 months. The final amount was the mean of these values in real terms (deflated by the IPCA).

Since there are three different index component measures, we needed to convert these into one. To this end, we rescaled the components by dividing their values by the maximum. Finally, the index was calculated as the average of these 4 values. Since each fuel is taxed differently, we obtained three instruments, one for gasoline prices (ig), the second for ethanol (ie), and the third for diesel prices (id).

Summary statistics of the data set are presented in Table 1. One may observe that per capita diesel consumption is almost double the consumption of gasoline, whereas average ethanol consumption is less than half that of gasoline. Note also that the number of CNG price observations is much smaller than for the other fuel prices, since this is only available in a small number of cities that have the requisite infrastructure.

The gasoline instrument is on average the highest, followed by diesel, and then ethanol. This is due to Brazils fuel tax policy, which imposes higher taxes on gasoline.

There is another variable (de) which has not yet been described. This is a dummy that is equal to 1 when the ethanol to gasoline ratio is above 70%, and zero when it is not. As discussed in Section 2, its purpose is to capture the state of the ethanol-gasoline price ratio and its influence on the consumption of these two fuels.

5. MAIN RESULTS

As a starting point, we estimated demand equations by OLS. The resulting elasticities are reported in Table 2. The estimated price elasticity for all three fuels obtained the expected signal. The parameters of interest are −1.4 for gasoline (gp), −2.8 and −3.5 for ethanol (ep), and −1.2 for diesel (dp). Overall, the results are in line with theory, although columns (2) and (4) report negative estimates for the CNG price (np). This is a not expected result because, as an, albeit imperfect, substitute good, we would expect a positive cross elasticity of demand. However, the empirical evidence is that CNG is a complementary good for gasoline. GDP (gdp) and fleet vehicles (fl), which capture the effect of income and the number of consumers, are both positively correlated to consumption. Note also that the diesel model does not include a price for a substitute good as an explanatory variable, since, in fact, there is none. As mentioned above, we constructed an unbalanced panel, meaning that two-way transformation is not applicable. Hence, we fitted one-way fixed effects models with time dummies, which raises the question of whether or not we need to control for time effects. The Wald test (F test [γ_t]) is used for comparison between a model with or without time dummies. In line with the results found in row dt, time dummies were included (but not reported) in the model.

As indicated in Section 3, a valid instrument only affects the dependent variable through its effect on explanatory variable. Unfortunately, we cannot test the exogeneity of the instrument because this is a population assumption, but it is clear that fuel consumption in municipalities cannot affect either taxes or distance from capital. Moreover, the two relevant assumptions that must be met are the correlation between the endogenous variable and the instrument, and the orthogonality of the instrument and the error term. In the first case, the assumption relies on economic theory

Table 1: Descriptive statistics

Variable	N	Mea	Standard deviation	Min	p (25)	p (75)	Max
gc_{it}	5,550	195.068	105.135	6.745	129.997	243.522	2,290.358
ec_{it}	5,514	72.156	84.285	0.010	13.869	99.506	644.474
dc_{it}	5,550	345.370	349.610	15.582	130.780	428.445	4,457.364
gp_{it}	5,496	3.917	0.371	3.211	3.643	4.129	5.769
ep_{it}	5,417	2.817	0.389	1.904	2.539	3.069	5.052
dp_{it}	5,441	3.055	0.249	2.481	2.870	3.239	4.464
de_{it}	5,417	0.584	0.493	0.000	0.000	1.000	1.000
np_{it}	1,970	2.516	0.359	1.728	2.241	2.748	4.234
gdp_{it}	5,550	29.314	23.342	4.270	15.526	36.198	314.638
f_{it}	5,550	0.387	0.181	0.011	0.245	0.522	0.879
ig_{it}	5,550	0.913	0.210	0.556	0.727	1.066	1.556
ie_{it}	5,550	0.307	0.089	0.133	0.264	0.359	0.667
id_{it}	5,550	0.740	0.135	0.456	0.649	0.832	1.208

Table 2: OLS regressions. Dependent variable in column labels

Coefficient	(1)	(2)	(3)	(4)	(5)
	log (gc)	log (gc)	log (ec)	log (ec)	log (dc)
log (gp_{it})	−1.423***	−1.448***	2.849***	3.542***	
	(0.162)	(0.276)	(0.490)	(0.859)	
log (ep_{it})	0.202***	0.318***	−1.983***	−1.711***	
	(0.072)	(0.123)	(0.216)	(0.354)	
log (dp_{it})					−1.196***
					(0.362)
log (np_{it})		−0.177***		0.014	
		(0.047)		(0.178)	
log (gdp)	0.134***	0.102***	0.098	0.0004	0.199***
	(0.027)	(0.036)	(0.061)	(0.106)	(0.046)
log (fl_{it})	0.653***	0.864***	0.428***	1.161***	0.256***
	(0.056)	(0.108)	(0.152)	(0.258)	(0.099)
de_{it}	0.058***	0.061***	−0.128***	−0.149***	
	(0.008)	(0.011)	(0.022)	(0.039)	
γ_t	Yes	Yes	Yes	Yes	Yes
nT	5,417	1,966	5,407	1,966	5,441
SSR	0.110	0.083	0.331	0.291	0.203
F−test (γ_t)	34.19***	20.50***	26.71***	3.90*	5.71*

One-way fixed-effects estimates from a log−log specification. Estimated standard errors in parentheses are cluster robust at the municipal level. Models (1), (3), and (5) was estimated for the full sample. Models (2) and (4) were estimated for the restricted sample to municipalities with non-zero CNG prices. *, **, and *** are significant at 90%, 95%, and 99% levels, respectively. F−test (γ_t) is the joint test whether time dummies are significantly different from zero. γ_t (Yes or No) indicates whether time dummies were included (but not reported) in model

and intuitive reasoning. The latter may be tested at first-stage regressions.

Table 3 provides the results obtained from the first stage regressions in which the coefficient of interest is the log of prices. In all the regressions there is strong evidence of a positive correlation between fuel prices and instrument. Here, *dt* indicates the need to only include time dummies in models (3) and (4). Note, however, that the decision is made on the basis of F test (γ_t) results in second stage regressions.

The instrument is positively correlated with fuel prices, as well as with their components. The results lend confidence to the validity of our instrument. In fact, the *F*-statistics of the excluded instruments, labeled *F-test (excl. instr.)*, are far from 10 which, according to Staiger and Stock (1997), is a good indicator that there are no weak instrument problems. In addition, with only one variable in each model, the F-test is equal to t-test squared.

A word of caution is required regarding the use of our instrument for ethanol. Since federal taxes do not apply to ethanol prices, there is some lack of variability at municipal level, but this may be overcome if the instruments variability is sufficient to eliminate endogeneity bias. Moreover, in line with the results presented in Table 3 we believe that the problem has been solved. We now performed regressions with the results presented thus far, controlling for endogeneity. Table 4 present second stage regressions of our specifications.

The estimated elasticity of gasoline consumption with respect to its price is −1.74 in model (1) and −1.57 in the model (2) which are close to those reported in Vilela (2015).What is surprising

is that the elasticity of gasoline decreases when including CNG price as an explanatory variable in the model. At a glance, this seems to be contradictory, because one would expect an increase in elasticity due to the existence of another substitute good. However, CNG is only sold in large cities and this might reflect the fact that vehicles are more necessary in such places, resulting in a decrease in elasticity. Ethanol elasticity is −5.00 in model (3) and −5.25 in (4), meaning that its elasticity is smaller in large cities. Compared to previous study findings, our estimates are smaller than those reported by Santos (2013) (−8.46) and larger than those estimated in Freitas and Kaneko (2011) (−1.66). The CNG price does not affect ethanol consumption, which leads us to conclude that there is no substitutability between ethanol and CNG.

For diesel, the estimated elasticity is −1.36 while the estimate provided by Cardoso and Jesus (2018) is around −0.80. Over the period analyzed, diesel consumption was only affected by income and not by fleet size, meaning that an increase of 100% in per capita GDP leads to an increase of 14.6% in diesel consumption. These findings suggest that Brazil has high own-price elasticity for diesel and low-income elasticity.

Cross-price elasticity is quite different for gasoline and ethanol. For gasoline these values are 0.57 and 0.60 in models (1) and (2), while for ethanol they are 4.93 and 5.84 in models (3) and (4), respectively. The difference shows a lower cross-price elasticity of demand for gasoline in relation to ethanol, than for ethanol in relation to gasoline prices. As expected, in both cases an increase in the substitute good price leads to a decrease in fuel consumption. GDP positively impacts gasoline and diesel consumption. The estimated income elasticity for gasoline is 0.147 and 0.162 in

Table 3: First stage regressions. Dependent variable in column labels

Coefficient	(1)	(2)	(3)	(4)	(5)
	log (*gp*)	log (*gp*)	log (*ep*)	log (*ep*)	log (*dp*)
log (ig_{it})	0.146***	0.144***			
	(0.003)	(0.005)			
log (ie_{it})			0.310***	0.265***	
			(0.010)	(0.015)	
log (id_{it})					0.128***
					(0.004)
log (gp_{it})			0.868***	0.776***	
			(0.038)	(0.052)	
log (ep_{it})	0.219***	0.212***			
	(0.012)	(0.017)			
log (np_{it})		0.042***		-0.054***	
		(0.014)		(0.016)	
log (gdp_{it})	−0.010*	−0.009	−0.004	−0.010	−0.063***
	(0.005)	(0.009)	(0.006)	(0.008)	(0.008)
log (fl_{it})	−0.153***	−0.159***	−0.105***	−0.072***	−0.107***
	(0.005)	(0.012)	(0.014)	(0.021)	(0.005)
log (de_{it})	−0.024***	−0.023***	0.020***	0.008**	
	(0.002)	(0.004)	(0.003)	(0.003)	
γ_t	No	No	Yes	Yes	No
nT	5,417	1,966	5,407	1,966	5,441
SSR	0.030	0.030	0.034	0.028	0.047
F−test (*excl.instr.*)	1844.7***	789.9***	924.9***	319.9***	1263.8***

One-way fixed-effects estimates from a log−log specification. Estimated standard errors in parentheses are cluster robust at the municipal level. Models (1), (3), and (5) were estimated for the full sample. Models (2) and (4) were estimated for the restricted sample of municipalities with non-zero CNG prices. *, **, and *** are significant at 90%, 95%, and 99% levels, respectively. γ_t (Yes or No) indicates whether time dummies were included (but not reported) in model. F−test (excl. instr.) is the joint test whether excluded instrument is significantly different from zero

Table 4: Second stage regressions. Dependent variable in column labels

Coefficient	(1)	(2)	(3)	(4)	(5)
	log (gp)	**log (gp)**	**log (ep)**	**log (ep)**	**log (dp)**
log (gp_{it})	−1.737***	−1.556***			
	(0.099)	(0.166)			
log (ep_{it})			−5.000***	−5.248***	
			(0.372)	(0.864)	
log (dp_{it})					−1.358***
					(0.192)
log (gp_{it})			4.928***	5.835***	
			(0.516)	−1.051	
log (ep_{it})	0.567***	0.598***			
	(0.050)	(0.073)			
log (np_{it})		−0.347***		−0.170	
		(0.046)		(0.202)	
log (gdp_{it})	0.147***	0.162***	0.100	−0.033	0.146***
	(0.025)	(0.039)	(0.066)	(0.113)	(0.048)
log (fl_{it})	0.373***	0.301***	0.095	0.805	0.010
	(0.037)	(0.086)	(0.160)	(0.292)	(0.044)
de_{it}	0.034***	0.034***	−0.054**	−0.112**	
	(0.007)	(0.010)	(0.027)	(0.045)	
γ_t	No	No	Yes	Yes	No
nT	5,417	1,966	5,407	1,966	5,441
SSR	0.122	0.101	0.351	0.311	0.208
F–test (γ_t)	0.68	0.17	87.93***	16.76***	0.01

One-way fixed-effects estimates from a log−log specification. Estimated standard errors in parentheses are cluster robust at the municipal level. Models (1), (3), and (5) were estimated for the full sample. Models (2) and (4) were estimated for the restricted sample to municipalities with non-zero CNG prices. *, and **, *** are significant at 90%, 95%, and 99% levels, respectively. F-test (γ_t) is the joint test whether time dummies are significantly different from zero and γ_t (Yes or No), indicates whether time dummies were included (but not reported) in the model

models (1) and (3), and, as mentioned above, 0.146 for diesel in model (5). Income elasticity for ethanol is not significant, meaning that it does not influence consumption level. In particular, despite the fact that this is not statistically significant, model (4) suggests that ethanol is an inferior good.

Fleet size has different impacts on estimates and is statistically significant only in models (1), (2), and (4). If the number of vehicles double, gasoline consumption increases by about 37% in model (1) and 30% in (2). The difference between these results is partly explained by the estimates for the price elasticity of ethanol in which only model (4) is statistically different from zero. We interpret this result as meaning that in large cities there is a greater demand for ethanol, especially in Sao Paulo state, the largest producer in the country.

Variable de captures the intricate relationship between ethanol and gasoline prices. The usual interpretation is of a change in intercept, i.e., a percentage deviation from the base line fuel consumption. We therefore note that gasoline consumption is about 3.4% higher in both models if $De = 1$. Alternatively, if the price ratio is smaller than 70%, ethanol consumption increases about 5.4% in model (3) and 11.2% in model (4). The fact that the threshold effect is more pronounced in model (4) reinforces our interpretation that the substitutability degree between gasoline and ethanol is more pronounced in large cities.

More generally, comparing our results to those of previous studies, our main contribution is to provide estimates of demand elasticities for the three main fuels consumed in Brazil – gasoline, diesel and ethanol-based on a city-level database which allows us to construct instruments combining taxes and distances from state capital.

6. CONCLUDING REMARKS

All things considered, our findings are consistent with research which demonstrated that the gasoline demand is price elastic and that the same conclusion can be drawn for ethanol and diesel. Ethanol consumption is more elastic when adding the CNG price as an explanatory variable, while gasoline is not. Unfortunately, data availability is a potential limitation and this issue should be addressed in future studies. An increase in GDP also positively affects demand for gasoline and diesel, but not for ethanol. Fleet size also impacts all fuel consumption, except if we exclude the CNG price from the ethanol model.

The ethanol-to-gasoline price ratio provides evidence that consumers are aware of the best price-consumption relationship. In this sense, if the dummy is higher than 70% there is a small increase in gasoline consumption. However, when the price ratio favors ethanol consumption the impact is higher. Our findings also conclude that the cross-price-elasticity of ethanol is higher than gasoline. Thus, changes in gasoline prices tend to affect ethanol consumption more than changes in the ethanol price affect the demand for gasoline. This is true even when the substitutability level is dependent on price ratio.

The difference between our estimates and those estimated previously suggests that this theme might be addressed in future research, particularly applying techniques for casual inference from non-experimental data.

Specifically, there is a need to further investigate the reasons underlying the ethanol-to-gasoline price ratio in a flex-fuel country. Further studies should also investigate diesel demand, a topic rarely studied in Brazil.

REFERENCES

ACEA. (2018), ACEA, The Automobile Industry Pocket Guide 2016/2017, Tech. Rep., European Automobile Manufacturers' Association, Brussels. Available from: https://www.acea.be/uploads/publications/acea_pocket_guide_2016_2017.pdf. [Last accessed on 2018 Feb 20].

ANP. (2009), Anuário Estatístico Brasileiro do Petróleo, Gás Natural e Biocombustíveis. Technical Report, Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Available from: http://www.anp.gov.br. [Last accessed on 2018 Mar 10].

Barros, S. (2015), Biofuels-ethanol and Biodiesel. Techreport BR15006. Washington, DC: USDA Foreign Agricultural Service. Available from: http://www.gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_8-4-2015.pdf. [Last accessed on 2018 Mar 10].

Cardoso, L.B., Jesus, C.S. (2018), Elasticidades da Demanda Por Diesel no Brasil. 46º Encontro Nacional de Economia da ANPEC. Rio de Janeiro, RJ. Available from: https://www.anpec.org.br/encontro/2018/submissao/files_I/i11-e00af90dec405c5d0626840b35c32359.pdf. [Last accessed on 2018 Dec 25].

Cardoso, L.C., Bittencourt, M.V., Litt, W.H., Irwin, E.G. (2019), Biofuels policies and fuel demand elasticities in Brazil. Energy Policy, 128, 296-305.

Coglianese, J., Davis, L.W., Kilian, L., Stock, J.H. (2017), Anticipation, tax avoidance, and the price elasticity of gasoline demand. Journal of Applied Econometrics, 32(1), 1-15.

Conti, J., Holtberg, P., Diefenderfer, J., LaRose, A., Turnure, J.T., Westfall, L. (2016), International Energy Outlook 2016 with Projections to 2040. Washington DC, United States: Technical Report, USDOE Energy Information Administration (EIA).

Coyle, D., DeBacker, J., Prisinzano, R. (2012), Estimating the supply and demand of gasoline using tax data. Energy Economics, 34, 195-200.

Dahl, C.A. (2012), Measuring global gasoline and diesel price and income elasticities. Energy Policy, 41(C), 2-13.

Freitas, L.C., Kaneko, S. (2011), Ethanol demand in brazil: Regional approach. Energy Policy, 39(5), 2289-2298.

Goldemberg, J., Guardabassi, P. (2010), The potential for first-generation ethanol production from sugarcane. Biofuels, Bioproducts and Biorefining, 4(1), 17-24.

IBGE. (2018), Pesquisa Nacional por Amostra de Domicílios, PNAD. Tech. Rep., Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro, URL Rio de Janeiro. Available from: https://www.ibge.gov.br/estatisticas/sociais/trabalho.html. [Last accessed on 2018 Jun 02].

Santos, G.F. (2013), Fuel demand in Brazil in a dynamic panel data approach. Energy Economics, 36, 229-240.

Staiger, D., Stock, J.H. (1997), Instrumental variables regression with weak instruments. Econometrica, 65(3), 557-586.

Storchmann, K. (2005), Long-run gasoline demand for passenger cars: The role of income distribution. Energy Economics, 27, 25-28.

Vilela, T.M.M. (2015), Three Essays on Gasoline and Automobile Markets in Brazil. PhD Thesis, Pontifícia Universidade Católica do Rio de Janeiro. Departamento de Economia, Rio de Janeiro (RJ). Available from: http://www.dbd.puc-rio.br/pergamum/tesesabertas/1111780_2015_completo.pdf. [Last accessed on 2018 Apr 22].