Arbitrage between ethanol and gasoline: evidence from motor fuel consumption in Brazil

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Arbitrage between ethanol and gasoline: evidence from motor fuel consumption in Brazil*

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Abstract

Unlike regular cars, flex-fuel vehicles (FFVs) allow motorists to fuel on motor blends that contain between zero and one hundred percent of ethanol. This paper investigates how motorists arbitrage between hydrous ethanol and gasoline using aggregate fuel consumption data in Brazil. The ability of FFV motorists to arbitrage between fuel blends shapes of aggregate demands for hydrous ethanol and gasoline. I estimate using nonlinear seemingly unrelated regressions the demands for hydrous ethanol and gasoline in Brazil, and motorists preferences for hydrous ethanol. I find that on average, accounting for the relative energy contents of the two fuels, FFV motorists in Brazil slightly discount hydrous ethanol over gasoline. Most consumers switch between fuels when their relative prices are at near parity. I find that 20% of consumers still purchase hydrous ethanol when its price is about 10% above the price of gasoline. The distribution of preferences is not symmetric as 20% of consumers still purchase gasoline when there is a 15% discount on the price of hydrous ethanol.

Key words: Ethanol, Gasoline, Preferences, Flexible-fuel vehicles, Arbitrage

JEL classification: Enter JEL classification numbers here

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Energy policies in the United States and Brazil encourage the production of ethanol and its use in motor vehicles. Motivations for the adoption of these policies are numerous and include energy independence, farm income support and reducing carbon emission. Ethanol policies in the United States and Brazil have had significant impacts on their respective energy sectors.

One outcome of energy policies in both countries is the emergence of Flex-Fuel Vehicles (FFVs) that can run on fuel containing between zero and one hundred percent ethanol. This is unlike conventional cars that can run only on fuel blends that contain a low percentage of ethanol without causing damage to the fueling system and the engine. In the United States, most gasoline contains ten percent ethanol (E10) but other fuel blends with a higher ethanol content, such as E85, are also available. In Brazil, gasoline contains between 18 and 25 percent ethanol (E18-25) and fueling stations offer pure ethanol (E100) as well. In both countries, owners of FFVs can arbitrage between fuel blends depending on which fuel blend offers energy at the lowest cost.

When selecting a fuel for their vehicles, FFV owners may consider attributes other than the energy content of different fuel blends. For instance, FFV motorists may be willing to pay a premium for ethanol as they wish to support farmers or because ethanol is more environmentally friendly than gasoline. On the opposite, FFV owners may discount ethanol as it contains less energy per volume than gasoline, thus requiring more frequent fueling.

Knowledge of consumers' preferences for fuel blends is crucial in investigating energy policies in both the United States and Brazil. In particular, the United States is now hitting the so-called "blend wall". The blend wall refers to the limit imposed by the fact that most vehicles can run on fuel that contains no more than 10 percent of ethanol. As the US mandate on ethanol blending is scheduled to exceed 10 percent of the total consumption of fuel by cars in the United States, ethanol will have to be distributed through other gasoline blends such as E85.[1] The question is, what price will clear the market for fuels that contain higher blends of ethanol?

Brazil consumers' willingness to pay for ethanol is also important in investigating the impact of US ethanol policies. By its design and given current ethanol production capacities, US ethanol policies give rise to two-way trade between Brazil and the United States (Babcock, Moreira, and Peng 2013). US ethanol mandates differentiate between ethanol depending on the feedstock that it is produced from. Imports from Brazil help meet mandates for advanced biofuels, which are not produced from corn-starch. At the same time, the United States ship ethanol produced from corn-starch, responding to Brazil's demand for ethanol, which does not discriminate between the methods of production. Thus, an empirical description of Brazil's demand for ethanol, through understanding of Brazil FFV owners arbitrage between fuel types, is critical to an analysis of US ethanol policies.

This paper estimates Brazil's FFV owners preference for ethanol and gasoline. Consumers preferences for ethanol an gasoline have been investigated before. Salvo and Huse (2011) and Salvo and Huse (forthcoming) study willingness to pay for ethanol in Brazil and Anderson (2012) investigates willingness to pay for ethanol in Minnesota. This paper uses a panel of aggregate consumption and prices for ethanol and gasoline by Brazil' States. From a choice model of fuel, I derive expressions for the aggregate demand for ethanol and gasoline. The data allow me to test whether the distribution of willingness to pay has changed over time and whether consumers in States that produce ethanol are willing to pay a premium to support local ethanol production.

The next section provides background information regarding Brazil's ethanol policies, technical information about the types motor fuel available in Brazil and

[1] There are other approaches to go over the blend wall, including the use of accumulated RINs and the blending of advanced biofuels to substitute for ethanol produced under conventional methods.

illustrations of the spatial heterogeneity in Brazil's consumption and production of ethanol. The section that follows reviews the literature. I then derive a model of fuel choice and show expressions for the aggregate demand for ethanol and gasoline by Brazilian consumers. The two sections that come next describe the empirical model and the data. I follow by presenting and discussing estimation results and finally, I conclude.

Background

Brazil federal government has intervened in the motor fuel market for several decades, shaping the demand and the supply for gasoline and ethanol. This section provides a brief overview of Brazil's ethanol policy, describes the types of motor fuel and discuss geographical heterogeneity in Brazil's motor fuel market.

Overview of Brazil's ethanol policy

Investments in ethanol production in Brazil dates back to the 1930s. Still, ethanol remained a marginal share of automotive fuel consumption until the 1970s when the increase in oil price spurn investment and further government intervention. In the early 1970s, oil prices increased rapidly, threatening the ability of the military regime to rule due to the fuel shortages, inflation, deficits, and diminishing currency reserves (Martines-Filho, Burnquist, and Vian 2006). In addition to the rising oil prices, the price of sugar, the main feedstock in Brazil ethanol production, began falling in 1975.

In response to the increase in the price of oil and decrease in the price of sugar, the Brazilian government created in 1975 ProÁlcool. The stated objective of ProÁlcool was to stimulate domestic fuel supplies to reduce the reliance on imported oil. In 1979, in response to the second oil shock, ProÁlcool began focusing on expanding the demand for ethanol. The same year, cars running on ethanol only (E100 cars) were introduced along with subsidies for the purchase of those cars. The incentives included, reduced registration fees, tax credits for ethanol cars, and regulated ethanol prices that were capped at 65% of gas prices (Hira and de Oliveira 2009). Ethanol car sales represented only 1% of total car sales in January of 1980 but 73% of all car sales by December of 1980.

The growth of the ethanol market was stunted by the decline in oil prices in the 1980s. In addition to falling oil prices, an increase in sugar prices increased ethanol production costs (Hira and de Oliveira 2009). After the collapse of the ethanol market, the Brazilian government ended its programs supporting the ethanol sector in the early 1990s. The government then passed a law in 1993 requiring a gasoline blend that contains a minimum quantity of ethanol per volume. In 2013, this gasoline blend contains between 18-25% of ethanol.

In early 2000s, oil prices began to rise, bringing focus back to the ethanol market. This led to the introduction of FFVs in 2003. Helped by tax credits for the purchase of FFVs (Barros 2010), sales of FFVs surpassed the sales of gasoline vehicles in Brazil soon after their introduction (Hira and de Oliveira 2009). Now about 90% of new cars are FFVs and the number of FFVs even surpassed in 2012 the number of cars that run on gasoline only (Unica 2013). Salvo and Huse (2011) note that the share of FFVs has likely been growing faster in North/North-East States as car stocks have been growing more rapidly in those States during the last decade. In contrast, the share of E100 cars decreased from 15% in 2002 to 4% by the end of 2010 (Du and Carriquiry 2013).

The government involvement in Brazil energy market extends as well into the price of gasoline. The price of oil was officially deregulated in 2002. However, Petrobras, a company owned in part by the federal government, still sets the price of oil products periodically (Bank Central of Brazil 2008). The objective of this policy if to limit the rate of inflation in Brazil.

Types of motor fuel

Fuel policies in Brazil have created markets for various types of motor fuels. In addition to ethanol and gasoline, some cars in Brazil can run on compressed natural gas (CNG) or switch between gasoline and CNG or run on diesel. However, these cars represent a small share of Brazil's car fleet and will therefore be ignored in the remainder of this paper.

The two main motor fuels in Brazil are hydrous ethanol and gasoline C. Hydrous ethanol, hereafter alcohol, is ethanol produced from distillation and contains about 4 percent of water. Gasoline C is a mix of pure gasoline (gasoline A) and anhydrous ethanol. The production of anhydrous ethanol requires the dehydration of hydrous ethanol, which is costly but allows blending of ethanol into gasoline.

In 2013, the blending requirements for gasoline C, hereafter simply referred to as gasoline, were bounded by regulation such that gasoline contains a minimum of 18% ethanol and a maximum of 25% ethanol. The regulation allows for some flexibility in adjusting the gasoline blend to respond to shocks on the ethanol market. For instance, in 2010, ethanol content in gasoline were adjusted down after poor cane sugar harvests, which cause higher prices for ethanol. Table 1 shows ethanol content in Brazil since 2003.

Ethanol and gasoline do not contain the same energy content per volume. A rule of thumb in Brazil is that ethanol contains about 70% of the energy of gasoline (Barros 2010). The last column of table 1 shows how the relative energy content of hydrous ethanol and gasoline varies given how much ethanol enters in gasoline. Despite changes in the share of ethanol that enters into gasoline, the relative energy content of the two fuels remained close to the 70% mark.

Table 1. Anhydrous ethanol in gasoline and relative energy content

From	to	Share of ethanol	Relative energy
January 1, 2003	April 30, 2003	20	0.691
May 1, 2003	February 28, 2006	25	0.704
March 1, 2006	November 20, 2006	20	0.691
November 21, 2006	May 30, 2007	23	0.700
June 1, 2007	January 31, 2010	25	0.704
February 1, 2010	April 30, 2010	20	0.691
May 1, 2010	September 30, 2011	25	0.704
October 1, 2011	-	20	0.691

Notes: The share of ethanol into gasoline is from section 2.2.2 in Barros (2010) and from data on fuel consumption in Brazil compiled by Unica (2013). The relative energy content is calculated by the author based on data from Empresa de Pesquisa Energética (2012). The ratio represents the relative energy of hydrous ethanol with respect to gasoline C.

Spatial distribution of production and consumption of ethanol

Brazil is a large country that comprises 27 states which greatly differ in area, population and wealth. Geography is an important factor in the development of Brazil and impacts fuel production and consumption of motor fuel as distance affect the costs of moving fuel from production centers to consumption areas.

The four panels in figure 1 show the geographical distribution of a) total ethanol production per capita, b) alcohol consumption per capita, c) the ratio of alcohol to gasoline prices and d) the consumption share of hydrous ethanol in motor fuel.[2] All prices are in 2002 Real ($R) per liter. The data are described in the data section of the text.

Panel a) of figure 1 shows that the total production of ethanol (the sum of hydrous and anhydrous ethanol) per capita. The production of ethanol is located in areas with large sugarcane plantations. The coastal state of Sao Paulo is the largest producer of ethanol and also the State with the largest population. States neighboring

[2]The consumption of alcohol here, of course, refers only to consumption of alcohol as a motor fuel and not alcohol for human consumption.

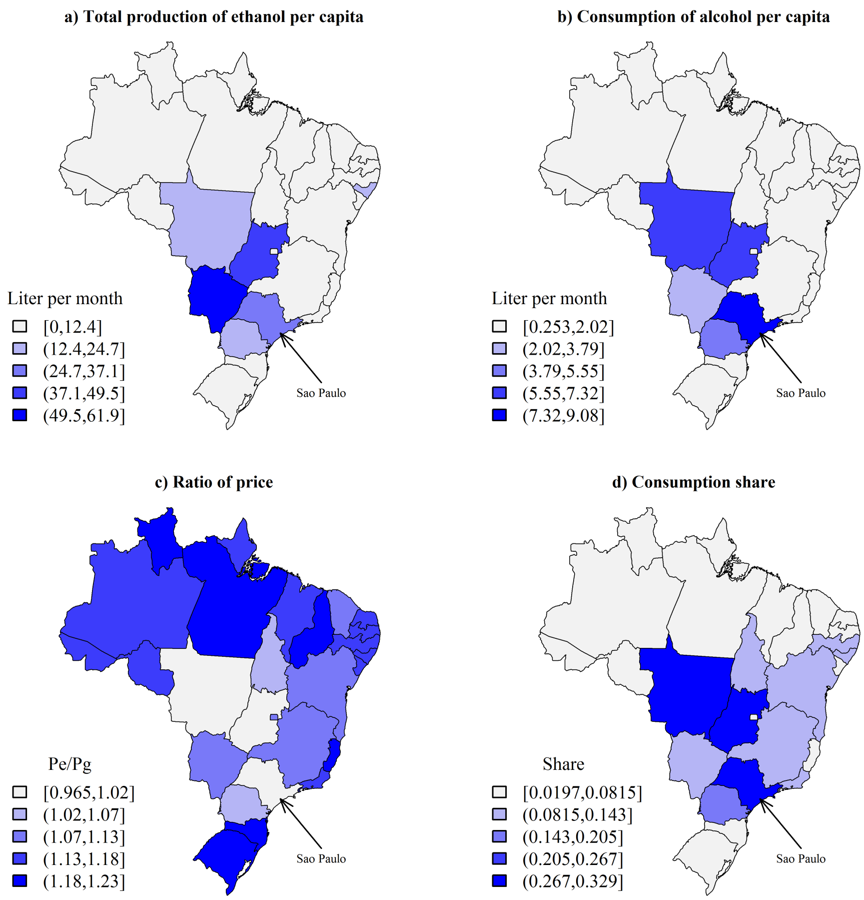


Figure 1. Ethanol market by States in 2011

Sao Paulo also have significant ethanol productions but smaller populations. Panel b) of figure 1 shows that the consumption of alcohol per capita is concentrated in the states producing ethanol.

Panel c) reports the ratio of the price of alcohol, corrected for its energy content relative to gasoline, and the price of gasoline. As such, prices are at parity when the price ratio equals one. In States where the price ratio is below one, alcohol is discounted relative to gasoline. On the opposite, if the price ratio is above one, motorists pay a premium for alcohol. Alcohol is relatively less expensive in ethanol producing States, reflecting the difference in cost of distributing ethanol in States away from production areas. Ethanol producing States also tend to tax alcohol less than non-producing States. The price ratio is above one in states away from ethanol production. Alcohol is mostly transported by rail and roads with the largest transportation costs for deliveries in Center-West region, away from the production center in the Southeast (Valdes 2011). Panel d) of figure 1 shows that consumers that the relative consumption of hydrous ethanol is largest in states producing ethanol, where ethanol is relatively less expensive.

Figures 1 highlights geographical heterogeneity in Brazil's ethanol market. Although differences in consumers willingness to pay for ethanol might explain some of that heterogeneity, the spatial distribution of prices suggest that distance from production areas are an important factor. The empirical approach will use this heterogeneity to identify consumer willingness to pay for ethanol in Brazil.

Literature

The demand for fuel in Brazil has received much attention. Recent studies include Iootty, Pinto, and Ebeling (2009) who use static and dynamic systems of equations to estimate the demand gasoline, ethanol, diesel and compressed natural gas (CNG) and de Freitas and Kaneko (2011) who emphasize on regional disparities in motor fuel demand. These two studies, and many others, that estimate demands for motor fuel are related to this paper but however not directly relevant. The focus here is on how consumers arbitrage between different types of fuel and that literature is rather sparse.

A necessary conditions for consumers to be able to arbitrage between fuel types in the short-run is that their vehicles can run on multiple types of fuel. Ferreira, de Almeida Prado, and da Silveira (2009) highlight that condition in their model of choice of motor fuel in the short-run and choice vehicle in the long-run. The authors show that expectations regarding future price of alcohol and gasoline determine the consumers' choice of vehicle type in the long-run. The model predicts that in the long-run that the prices of ethanol and gasoline should coincide, once accounting for the energy difference of the two motor fuels. Ferreira, de Almeida Prado, and da Silveira (2009) find strong evidence of cointegration between the prices of ethanol and gasoline in Brazil. Du and Carriquiry (2013) reach a similar conclusion that there is a long-run equilibrium between the prices of alcohol and gasoline in Brazil. In response to a shock, the prices of alcohol and gasoline converge to their long-run equilibrium in about three months.

Salvo and Huse (2011) describe a model where FFV motorists can arbitrage between alcohol and gasoline. If consumers arbitrage between the two motor fuels on the basis of the relative energy contents, the price of alcohol should be about 70% of the price of gasoline. However, as Salvo and Huse (2011) show, under certain market conditions, such as high sugar prices prompting exports of sugar, equilibrium prices may diverge from parity. Salvo and Huse (2011) show from estimates of the volatility of relative motor fuel prices and from cointegration analysis that alcohol and gasoline prices have been increasingly moving in step. These results reflect the increased arbitrage ability of motorist from the growth in the penetration of FFVs.

Preference for alcohol over gasoline may reflect factors other than the relative energy content of the two types of fuel. Salvo and Huse (forthcoming) observe that time costs, vehicle range, technological concerns, habits, environmental concerns and home bias may affect preferences. As such, there is a distribution of consumers with a range of valuation for alcohol and gasoline. To investigate those preferences, Salvo and Huse (forthcoming) conduct a survey of Brazilian motorists. The authors find that about 20% of motorists still purchase gasoline when the price of gasoline is 20% above the parity price of alcohol. Symmetrically, there is roughly 20% of motorists that still purchase alcohol when the price of alcohol is 20% above parity.

Preference of ethanol in the United States has also received some attention from the literature. Anderson (2012) estimates preference for E85 in Minnesota. Estimates show that the consumption of ethanol is sensitive to price as a $0.10 per gallon increase in the price of E85 yields 12-16% decline in the consumption of E85.

Model

This section derives expression for aggregate demand for alcohol and gasoline. Salvo and Huse (2011) and Du and Carriquiry (2013) both describe the demand for alcohol in a similar framework but do not consider heterogenous preferences. The choice model in Salvo and Huse (forthcoming) considers that consumers may have heterogenous preferences for fuels. However, the framework in Salvo and Huse (forthcoming) is adapted to individual fuel consumption unlike this model that derives expressions for aggregate demands.

The model builds on the assumption that consumers maximize utility for their consumption of motor fuel and other goods. The outcome of the utility maximization problem is that a consumer i demands a quantity

(1) $$q_i = q(p_j, \mathbf{z_i} | car_i)$$

of motor fuel of type $j = a, g$, where the subscript a stands for alcohol and the subscript g stands for gasoline.[3] The price and quantity of alcohol are measured in their gasoline energy equivalent. The vector $\mathbf{z_i}$ is other variables that affect the consumption of motor fuel (e.g. income, location) and $car_i = \{E100, FFV, gas\}$ is the type of car owned by consumer i.

Note that the model focuses on the short-run demands for motor fuels. More precisely, the model does not include car purchase decisions, which effectively determine the ability of consumers in the long-run to arbitrage between fuels. The model considers the car fleet as exogenous and that arbitrage between fuel types, if feasible, is a short-run decision determined by relative fuel prices.

Alcohol demand by E100 cars

Cars that run exclusively on alcohol have been around since the beginning of the 1980s. Although the size of the fleet of E100 has long been declining, there is still a non-negligible number of cars in Brazil that can run on alcohol only.

Denote by N_a the number of consumers that own a E100 car. As these consumers are constrained to purchase alcohol, the total consumption of alcohol by E100 cars is

(2) $$Q_a^{E100}(N_a, p_a, \mathbf{z}) = N_a q(p_a, \mathbf{z}|E100).$$

That is, the demand for alcohol by E100 cars is an increasing function of the number of E100 cars, a decreasing function of the price of alcohol and a function of other variables that affect the demand for motor fuel. The price of gasoline does not appear in (2) as owners of E100 cars are constrained into purchasing alcohol.

[3]To simplify the notation, I do not indicate time or location although they matter in the demand for motor fuel.

Alcohol and gasoline demands by FFVs

FFVs offer their owners the flexibility to purchase any fuel blend. Thus, owners of FFVs can select a fuel based on relative prices and a quantity based on the price of the selected fuel.

Owners of FFVs arbitrage between alcohol and gasoline depending on prices and their preferences for the two types of fuel. Let me write that a FFV owner i derives θ_{ia}/p_a in utility per unit of alcohol and derives θ_{ig}/p_g in utility per unit of gasoline. That is, a FFV owner derives utility θ_{ij} for fuel j but discounts that utility by dividing by the price p_{ij}. Given the ability to arbitrage between fuel, the demand by one FFV motorist is

$$(3) \quad q_i(p_a, p_g, \mathbf{z_i}|FFV, \theta_i) = \begin{cases} q_{ia} > 0, q_{ig} = 0 & \text{if } \theta_i \geq p; \\ q_{ia} = 0, q_{ig} > 0 & \text{if } \theta_i < p, \end{cases}$$

where $\theta_i \equiv \theta_{ia}/\theta_{ig}$ and $p \equiv p_{ia}/p_{ig}$. Expression (3) says that a FFV owner purchases alcohol if the utility of alcohol relative to the utility of gasoline is greater than the relative prices of the motor fuels.

In aggregate, the demand for alcohol and gasoline by FFV owners will depend on the prices of the two fuels, their relative prices, and the preferences of FFV owners for the two fuels. Let the relative utility of motor fuel be distributed according to a cumulative density function $H(\theta)$, a probability density function $h(\theta)$, on the interval $[0,\infty)$. If $\theta = 0$, this means that a motorist strictly prefers gasoline over alcohol. On the opposite, if $\theta \to \infty$, then a motorist strictly prefers alcohol over gasoline. Assuming that owners of FFVs each have one car and that there N_f owners of FFVs, the total demand for alcohol by FFVs is

$$(4) \quad Q_a^{FFV}(N_f, p_a, p_g, \mathbf{z}) = N_f \int_p^\infty q(p_a, \mathbf{z}|FFV)h(\theta)d\theta = (1 - H(p))N_f q(p_a, \mathbf{z}|FFV).$$

Analogously, the total demand for gasoline by FFV owners

$$(5) \quad Q_g^{FFV}(N_f, p_a, p_g, \mathbf{z}) = N_f \int_0^p q(p_g, \mathbf{z}|FFV)h(\theta)d\theta = H(p)N_f q(p_g, \mathbf{z}|FFV).$$

That is, the total consumption of alcohol and gasoline by FFVs depend on the number of FFVs, the price of alcohol, the price of gasoline, the relative prices of alcohol and gasoline, variables that affect the demand for motor fuel, and the distribution of consumers preference for alcohol and gasoline. I write that the total demand for fuel by FFV owners is $Q^{FFV} = Q_a^{FFV}(N_f, p_a, p_g, \mathbf{z}) + Q_g^{FFV}(N_f, p_a, p_g, \mathbf{z})$.

As explained by Salvo and Huse (forthcoming), many factors explain motorists willingness to pay for motor fuel. If those factors are not constant across States and time, this means that the distribution of preference is a function of State specific variables and time series variables. One example of such variable is the number of FFVs. Flex cars have been available in Brazil car market since 2003. The early buyers of FFVs might have been those that value the consumption of ethanol the most. If true, the implication is that the distribution of the parameter θ is a function of the number of FFVs N_f and that the distribution function $h(\theta)$ shifts to the left as the number of FFVs increases. Another possibility is that ethanol supporters already owned a E100 car when FFVs first became available. In such a case, the early adopters of FFVs were not ethanol lovers which means that the distribution of preference for ethanol shifts to the right as ethanol lovers replace their E100 cars for FFVs. The empirical model will verify the distribution of preference shifts over time by adding a time trend to the estimation of the distribution of consumers preferences. The empirical model will also verify if consumers in ethanol producing States pay a premium for ethanol by adding ethanol production as an explanatory variable to the distribution of preferences for alcohol versus gasoline.

Gasoline demand by gasoline cars

Like cars that run exclusively on alcohol, gasoline cars do not offer their owners the flexibility to select among fuel types. The size of the gasoline car fleet has been diminishing both relative to the total size of the car fleet and in nominal value (Unica 2013).

The total consumption by gasoline cars is the product of the number of gasoline cars N_g and the consumption of gasoline by individual cars:

(6) $Q_g^{gas}(N_g, p_g, \mathbf{z}) = N_g q(p_g, \mathbf{z}|gas)$.

The demand by gasoline cars increases with the number of cars and decreases with respect to the price of gasoline.

Total demand for alcohol and gasoline

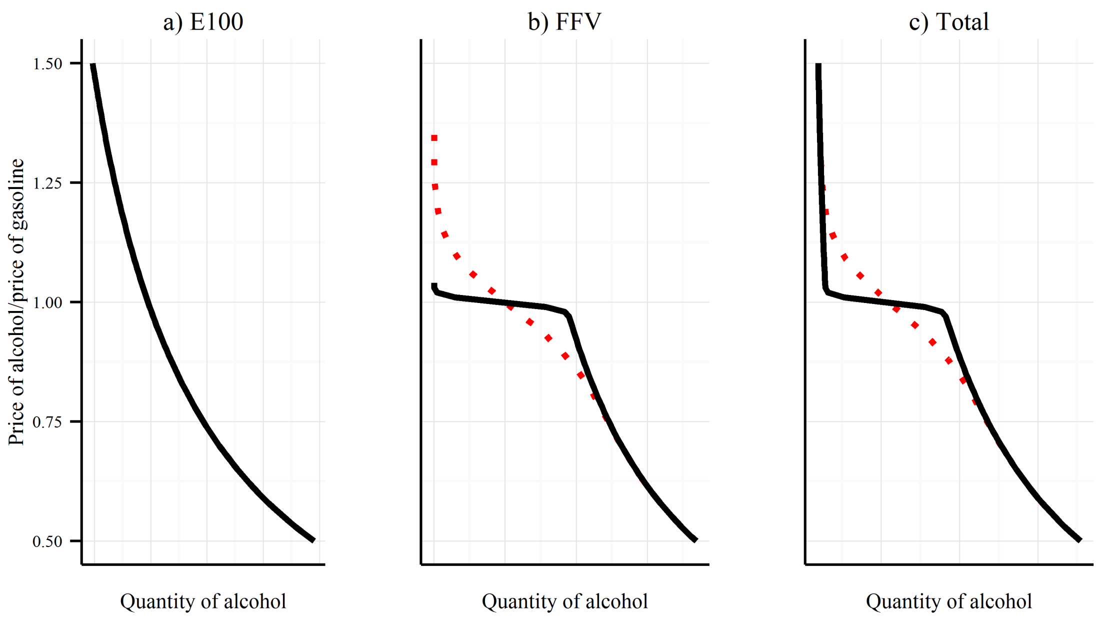
The total demand for alcohol is the sum of the demand by E100 cars and FFVs

(7) $Q_a(N_a, N_f, p_a, p_g, \mathbf{z}) = N_a q(p_a, \mathbf{z}|E100) + (1 - H(p))N_f q(p_a, \mathbf{z}|FFV)$.

That is, the demand for alcohol depends on the price of alcohol and its relative price with respect to gasoline, the number of vehicles that can fuel on alcohol and on FFV owners preference for ethanol. The demand for alcohol increases with respect to N_a, N_f and p_g by decreases with respect to p_a.

Figure 2 illustrates the shapes of the demands for a) alcohol by E100 given in expression (2), b) alcohol by FFVs given in expression (4), and c) alcohol by all cars given in expression (7).

Panel b) of figure 2 shows the demand for alcohol by FFV owners for two distributions of preferences for alcohol. In the first case, the thick black line, consumers differ little in their preference for alcohol. As such, as the price of alcohol is slightly above the price of gasoline, a few consumers begin switching to gasoline. Then, with a small decrease in the price of alcohol, a large number of FFV owners switch to gasoline. As the price ratio is slightly below one, then all FFV owners fill their car using ethanol. This large change in consumption for a small change in price is illustrated in panel b) and c) of figure 2 by the segment of the demand for alcohol that relatively flat when the ratio of prices is near one.



Note: The figure shows two cases for the preference for ethanol by FFV owners. The continuous line shows a case where the range of valuation for alcohol is narrow. The squared dots show a case where FFV owners have a wide range of valuation for alcohol.

Figure 2. Shape of demand for alcohol

In the second case, the red squares, consumers widely differ in their valuation of ethanol. The squares in panel b) of figure 2 shows that at about a 35% premium for alcohol, some FFV owners begin switching from gasoline to alcohol. The consumption of alcohol then increases as the relative price of alcohol declines. It is not until there is a 25% discount on alcohol that all FFV motorists purchase alcohol. Thus, the squares in figure 2 show that the more consumers differ in their preference for ethanol, the more the switch between motor fuels occurs slowly and appears smooth in a graph of the total demand for alcohol.

The two cases illustrated in figure 2 assume that the mean willingness to pay for ethanol equals one. If the mean willingness to pay is above, this implies that the demand in panel b) of figure 2 would shift up and consumers would on average switch fuel at a price ratio above one. On the opposite, if the mean willingness to pay is below one, then consumers would on average switch fuel at a price ratio of less than one.

The total demand for gasoline is the sum of the demand for gasoline by FFVs and the demand by gasoline cars

$$(8) \quad Q_g(N_a, N_f, p_a, p_g, \mathbf{z}) = N_g q(p_g, \mathbf{z}|gas) + H(p) N_f q(p_g, \mathbf{z}|FFV).$$

The demand for gasoline declines with respect to N_f, p_g but increases with respect to N_g and p_a. Note that the demand for gasoline with respect to the price ratio p follows a pattern opposite of the one for alcohol illustrated in panel c) of figure 2. As the price of alcohol increases relative to gasoline, FFVs owners shift to gasoline such that the demand for gasoline increases.

Econometric model

Recall that the objective of this paper is to identify how FFV owners in Brazil arbitrage between alcohol and gasoline. Expressions (7) and (8) show that the ability of FFV owners arbitrage between motor fuels affects both the aggregate demand for alcohol and the aggregate demand for gasoline. As such, (7) and (8) form a system of equations that can be used to estimate the distribution of consumers valuation of alcohol.

The system of equations includes three demand expressions: the demand for alcohol by E100, the demands for alcohol or gasoline by FFVs and the demand for gasoline by gasoline cars. Even though there are more demand expressions to estimate than there are equations, it is possible to identify parameters of each equations through the non-linearity introduced by the distribution function $H(p)$.

Let me begin by describing the cumulative density function for the preference of consumers for motor fuel. Recall that the preference parameter θ is defined over the positive interval. Consistently, the empirical model assumes that the preference parameter for motor fuel is distributed according to a log-logistic distribution which support is on the positive interval. The expression for the cumulative log-logistic distribution is:

$$(9) \quad H(p) = H(p; \alpha_{kt}, \beta) = \frac{p^{\beta}}{\alpha_{kt}^{\beta} + p^{\beta}},$$

where $\alpha_{kt} > 0$ and $\beta > 0$. The parameter α_{kt} is the median of the distribution function and therefore scales the distribution function. Note the subscripts k and t that respectively denote State and time as the distribution of preference may shift through space and time. The parameter β shapes the distribution function and is assumed constant across States and time. For $\beta > 1$, the mode of the log-logistic distribution function is greater than zero.

I model a shift in the distribution function through the parameter α_{kt}. In the first model, I assume that the median, and hence the mean, is constant such that $\alpha_{kt} = \alpha$. The second model allows for the population of FFV owners to shift over time by adding a time trend to the mean such that $\alpha_{kt} = \alpha + \tau * Trend_t$. This model captures a shift in the distribution of preference for alcohol in the population of FFV motorists because early purchasers of FFVs might have been those that value ethanol the most or the least. The time trend captures other effects such as, for example, learning by consumers of the relative energy content of the two types of fuel. The third model accounts for ethnocentric preferences related to local ethanol production. The median of the distribution thus shifts with respect to the total ethanol production (the sum of hydrous and anhydrous ethanol production) per capita such that $\alpha_{kt} = \alpha + \tau * Trend_t + \pi * production\_ethanol_{kt}$. The motivation for this model is that consumers may value the purchase of ethanol to support local sugar cane production and thus are willing to pay a premium for the purchase of alcohol. Adding the production of ethanol should not cause a simultaneity bias because the production of ethanol is located closed to sugar cane production areas, which is located in areas with geo-climatic conditions favorable to sugar cane production. Thus, willingness to pay for ethanol in a region should not cause ethanol production in the same region, thus removing potential endogeneity issues with adding ethanol production in the equations for the demands for alcohol and gasoline.

Heterogeneity in quantities and prices for gasoline and alcohol across States and time allow for the estimation of the model. Heterogeneity across States is particularly important. Figure 1 shows that the production of ethanol is centered around the State of Sao Paulo. The production of gasoline is located nearby as oil is exploited of the Southeastern coast of Brazil. Thus, as the production of fuel is located in a specific region of Brazil, the costs of distributing motor fuel differ across States because of transportation costs. As a result of these conditions on the supply of motor fuels, there is heterogeneity in the prices of alcohol and gasoline, as well as their ratio. It is the difference in relative prices across States from conditions on the supply that allows for the estimation of consumers' preferences for fuel. In each State, the market clears where the marginal consumer is indifferent between ethanol and gasoline. As relative prices differ across States, the data allow the estimation of the distribution of preferences from the marginal consumer that clears the market at a given time and location. I discuss later in the text the potential endogeneity problem and how prices are instrumented.

Consistent with the assumption that there is one FFV motorist that is just indifferent between alcohol and gasoline, given prevailing prices, the demand equations are expressed on a per capita basis. That is, all quantity variables that enter the empirical model (consumption, car fleet and GDP) are measured on a per capita basis. An advantage of this approach is that it implicitly accounts for changes in population.

In the empirical model, the expressions for fuel demands all take the same linear form. The demand for alcohol by E100 car in State k at time t is

$$(10) \quad Q_{akt}^{E100} = \alpha_a + \beta_a p_{akt} + \gamma_a fleet_{kt} + \lambda_a fleet_{kt} trend_{kt} + \tau_a trend_{kt} + \xi_a GDP_{kt} + \delta_{\mathbf{a}}' \mathbf{X_{kt}},$$

where $\mathbf{X_{kt}}$ is a vector of control variables that include States fixed effects and monthly dummies. Data on the number of E100 cars are not available. Instead, as proxies, I use the total size of the car fleet, the product of the size of the car fleet and a trend variable, and a trend. Together, variables for the car fleet, the trend and their interaction control for changes in the size of the E100 car fleet as well as other factors correlated with time. Overall, as the E100 car fleet has been declining, I expect the total effect from these variables to be negative.

The demand for fuel by FFVs in State k at time t takes the same form as the demand by E100 cars:

$$(11) \quad Q_{kt}^{ffv} = \alpha_f + \beta_f p_{lkt} + \gamma_f fleet_{kt} + \lambda_f fleet_{kt} trend_{kt} + \tau_f trend_{kt} + \xi_f GDP_{kt} + \delta_{\mathbf{f}}' \mathbf{X_{kt}},$$

where the subscript l on the price variable stands for either alcohol a or gasoline g depending on the type of fuel that a FFV owner selects. That is, the expression for the demand by FFV owners is the same for ethanol and gasoline, with no difference in the coefficient for the price variable. The difference in the demand for the two types of motor fuel is captured by the function $H(p)$ that describes the distribution of preference for alcohol and gasoline. Variables for the car fleet, the trend and their interaction control for changes in the size of the FFV car fleet as well as other factors correlated with time. As the fleet of FFVs has been increasing, I expect the total effect from these variables to be positive.

Lastly, the same variables enter linearly in the demand for gasoline by gasoline cars in State k at time t:

(12) $$Q_{kt}^{gas} = \alpha_g + \beta_g p_{gkt} + \gamma_g fleet_{kt} + \lambda_g fleet_{kt} trend_{kt} + \tau_g trend_{kt} + \xi_g GDP_{kt} + \delta_{\mathbf{g}}' \mathbf{X_{kt}}.$$

Again, variables for the car fleet, the trend and their interaction are meant to control for changes in the size of the gasoline car fleet as well as other factors correlated with time. The fleet of gasoline cars , as well as the share of gasoline cars in the car fleet, has been decreasing. Thus, I expect the total effect of the fleet size, the trend, and their interaction, to be negative in the equation for the demand by gasoline cars.

Together, expressions (9)-(12) form all the building blocks to estimate the system of demand in equations (7) and (8). I estimate these equations in a nonlinear SUR framework, which allows for the identification of the parameters of the three demand expressions and the distribution function $H(p)$.

Identification

Prices and quantities of alcohol and gasoline in each State are determined by the intersection of the supply and the demand. The potential for bias from endogenous prices is non-negligible, especially from the price of alcohol. As Petrobras fixes the price of gasoline, responding to governmental objectives that are difficult to define, assuming that the price of gasoline is determined exogenously would be reasonable. Still, I approach the endogeneity problem cautiously by instrumenting both the price of alcohol and the price of gasoline.

I estimate the model using two-stage least-squares. I instrument prices by interacting State dummies with fleet size, the product of fleet size and a trend, a trend, GDP, monthly dummies, State total production of ethanol, the West Texas price of oil and the world price of sugar. That is, the first stage requires regressing prices of alcohol and gasoline for each State individually.

The exogeneity assumption of fleet size and the production of ethanol is worth discussing. When purchasing a vehicle, motorists factor in their expectation regarding future gasoline and alcohol prices (Ferreira, de Almeida Prado, and da Silveira 2009). However, at any given time, the price of gasoline and alcohol clears the market given the short-run conditions on demand and supply. Thus, as the car fleet adjusts only in the long-run, the size of the car fleet can be considered as exogenous in the short-run. The production of ethanol within a State directly depends on the production of sugar within that State. Sugar production responds to expectations regarding the price of sugar, which is determined on the world market. As many plants can switch production between ethanol and sugar depending on their relative prices, the price of sugar determines how much ethanol is produced. In addition, within a crop year, production of sugar is stochastic as sugar cane yields depend on weather conditions. Thus, as production of ethanol responds to world price of sugar and that yields are stochastic, it is reasonable to assume that the production of ethanol is exogenous to gasoline and alcohol prices.

Data

The monthly data are from January 2002 to December 2012, for a total of 132 months, and are collected for each of Brazil's 27 States. After removing missing observations, the dataset contains 3,310 observations, beginning in January 2002 and ending in March 2012.

Monthly data on prices and consumption of alcohol and gasoline by States were collected from ANP, the National Agency of Petroleum, Natural Gas and Biofuels (ANP 2013).[4] Consumption data are the monthly quantities of gasoline and alcohol

[4]Prices and consumption data were graciously provided by professors Luciano C. de Freitas and Shinji Kaneko.

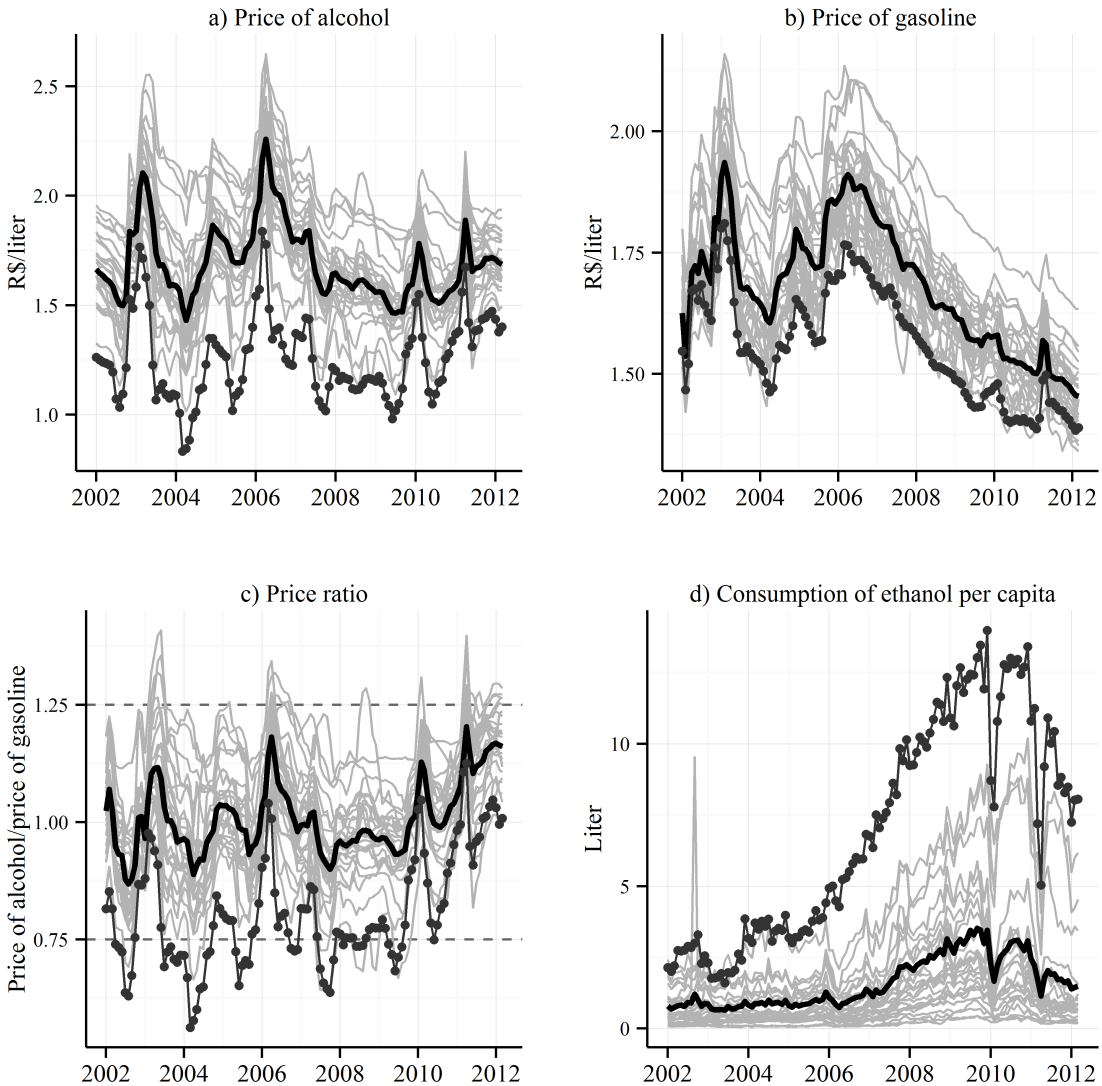
sold within a State. The price data were collected by ANP auditing division through a survey of fueling stations. The price data include the average price paid by motorists for alcohol and gasoline, including taxes.

All prices and quantities of alcohol are reported in energy equivalent to gasoline. Equivalency is calculated by the author using information from Brazil's Ministry of Mines and Energy (page 216 in Empresa de Pesquisa Energética 2012) and the share of ethanol in gasoline reported in table 1.

Figure 3 shows time series by States for a) the price paid by consumers for alcohol, b) the price paid for consumers for gasoline, c) the ratio of alcohol and gasoline prices and d) the total consumption of ethanol per capita (hydrous and anhydrous ethanol). Each gray line shows data for a States. All prices are in 2002 R$ as calculated using the CPI published by Brazil Central Bank (2013). In figure 3, the thick black lines are the un-weighted averages across States and the dots emphasize data for the State of Sao Paulo. Observe that, as figure 1 shows, Sao Paulo is quite distinct from any other States.

The price of alcohol does not appear to follow any trend between 2002 and 2012. This contrasts with the price of gasoline that has been in constant decline since 2006. The decline reflects a general increase in prices while the price of gasoline has been relatively constant in nominal value.[5] The ratio of prices varies greatly across States. Between 2002 and 2009, the relative prices of alcohol and gasoline have varied around 1, with notable positive shocks to the ratio in 2003 and 2006. The price ratio has increased starting in 2010 in response to the decline in the price gasoline. The total consumption per capita of ethanol varies much by State. In some State, the consumption per capita is near zero while in Sao Paulo it was more than 10 liters between 2008 and 2011.

[5] Recall that the price of gasoline is set by Petrobras, which is largely controlled by Brazil federal government.



Notes: Each gray line shows data for a State. The price and the quantity of alcohol are reported in energy equivalent unit to gasoline. The thick black lines are the unweighted averages across States and the dots emphasize data for the State of Sao Paulo.

Figure 3. Prices and quantities of alcohol and gasoline by State

Data on the total production of ethanol (hydrous and anhydrous) by State are from the United Cane-Sugar Industry (Unica 2013). The production data are expressed in liter per month by dividing annual production by 12. Annual production is adjusted for the crop year according to the region of production.[6]

I obtained data on the car fleet by State from Denatran (2013), Brazil's National Department of Transportation. The data represent the monthly size of the car fleet by State. The data do not distinguish cars by their fuel system. Data on Brazil's population by States are from Brazil's Institute of Geography and Statistics (IBGE 2013). Population data are only available on an annual basis for 2000, 2010 and 2012. I constructed monthly population data by assuming linear increase in population between 2000 and 2010 and between 2010 and 2012. I also obtained from IBGE (2013) the monthly GDP per State. The GDP is expressed in real R$ using the CPI published by Brazil Central Bank (2013).

The monthly price of sugar is from FAO (2013). This price is an index of the international price of sugar compiled by the Food and Agriculture Organization of the United Nations. The price of crude oil is the West Texas Intermediate 40 API, Midland Texas as compiled by the International Monetary Fund (IMF 2013). The price of oil is converted from US$ to R$ using the monthly exchange rate published by Federal Reserve Bank of St-Louis (2013).

Results

I estimate the system of equations in (7) and (8) by non-linear least squares. I present two sets of estimations. In the least-square (LS) estimates, I assume that all variables are exogenous. In the two-stage least-square estimates (2SLS), I instrument the price

[6]Crop year pertains to the production of sugar cane, the feedstock in the production of ethanol. In the Center-South, the crop covers the period from April to March of the following year. In the North-East, the harvest period varies between States: from May to April for the States of Amazonas, Bahia, Ceará, Maranhão, Pará, Piauí and Tocantins, and from September to August to Alagoas, Paraíba, Pernambuco, Rio Grande North and Sergipe.

of alcohol and the price of gasoline, and hence the ratio of prices, to control for potential endogeneity problem.

Regression results

Table 2 shows coefficient estimates. The table excludes coefficients estimates for State dummies and weekly dummies. Models numbered 1, 2 and 3 differ in the variables they include in the distribution of consumers' preference for alcohol.

In the interest of space, I will focus the discussion of the results on the coefficients for the price variable and for the coefficient of the distribution of preferences. I will not discuss the statistical significance of the coefficients as the calculation of the standard errors could be improved by calculating cluster standard errors that are robust to autocorrelation and heteroscedasticity.

The demands should slope down with respect to fuel prices. In the equation for the demand for alcohol by E100 cars, the coefficient for alcohol takes positive and negative values, but is very small when taking a positive value. This may reflect that the fleet of E100 cars is composed of old vehicles and that these cars are a necessity good. That is, these old cars are mostly owned by the least wealthy segment of the population and respond to their minimal need for transportation. As such, the demand for alcohol from these cars is very insensitive to changes in the price alcohol. The demand by FFVs and the demand by gasoline car both respond negatively, as expected, to an increase in the price of gasoline, or alcohol in the case of the demand by FFVs.

Estimates between 10 and 17 for the parameter β say that the distribution of preferences is bell-shaped. In model 1, the value of the parameter α is the median of the distribution of preferences for ethanol. In both the LS and 2SLS estimates, the median consumer discounts alcohol over gasoline as the value of α is below one. The discount is larger in the 2SLS estimates at near 6%. In model 2, the median

Table 2. Estimates of demands and preference distribution parameters

	Model 1 (LS)	Model 2 (LS)	Model 3 (LS)	Model 1 (2SLS)	Model 2 (2SLS)	Model 3 (2SLS)
			Demand by E100 cars			
Intercept	1.234***	1.775***	1.730***	1.871***	1.912***	2.021***
	(0.241)	(0.144)	(0.158)	(0.359)	(0.378)	(0.371)
Alcohol price	0.0149	-0.273***	-0.263***	0.057	0.042	-0.008
	(0.079)	(0.047)	(0.050)	(0.151)	(0.153)	(0.152)
Fleet	-0.084	-1.350***	-1.048**	-1.195	-1.285	-1.694*
	(0.540)	(0.370)	(0.355)	(0.769)	(0.753)	(0.826)
Fleet*Trend	0.002	0.007	0.003	0.010	0.011	0.010
	(0.008)	(0.006)	(0.006)	(0.011)	(0.011)	(0.011)
Trend	0.003***	0.004***	0.004***	0.002*	0.002*	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
GDP	-122.9***	-121.7***	-121.6***	-210.5***	-210.1***	-211.4***
	(25.51)	(20.56)	(21.17)	(34.25)	(33.69)	(33.98)
			Demand by FFVs			
Intercept	3.665***	-0.720	0.311	2.682**	2.432*	1.252
	(0.666)	(1.111)	(1.064)	(0.991)	(1.000)	(1.117)
Fuel price	-2.896***	-1.100***	-1.574***	-3.323***	-3.251***	-2.898***
(alcohol or gasoline)	(0.224)	(0.282)	(0.268)	(0.448)	(0.450)	(0.477)
Fleet	-21.15***	-15.92	-13.21	-14.86*	-14.48*	-9.703
	(4.855)	(9.007)	(8.442)	(6.659)	(6.732)	(7.905)
Fleet*Trend	0.310***	0.257***	0.262***	0.273***	0.269***	0.252***
	(0.027)	(0.046)	(0.045)	(0.038)	(0.038)	(0.043)
Trend	0.010***	0.027***	0.021***	0.022***	0.023***	0.029***
	(0.002)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
GDP	393.9***	478.5***	490.5***	510.9***	517.8***	578.4***
	(67.49)	(108.5)	(104.4)	(88.14)	(88.53)	(99.28)
			Demand by gasoline cars			
Intercept	13.07***	17.88***	16.74***	15.46***	15.71***	16.94***
	(0.633)	(1.112)	(1.049)	(0.880)	(0.879)	(0.978)
Gasoline price	-1.453***	-3.504***	-2.948***	-2.111***	-2.193***	-2.588***
	(0.236)	(0.306)	(0.294)	(0.391)	(0.404)	(0.426)
Fleet	15.91***	11.73	8.786	9.997	9.697	5.340
	(4.280)	(8.685)	(8.014)	(5.934)	(6.023)	(7.077)
Fleet*Trend	-0.155***	-0.125**	-0.121**	-0.126***	-0.124***	-0.111**
	(0.021)	(0.043)	(0.040)	(0.031)	(0.031)	(0.036)
Trend	0.018***	-0.001	0.005	0.005	0.004	-0.002
	(0.002)	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)
GDP	-225.7***	-262.4*	-286.4**	-256.9***	-261.9***	-310.2***
	(58.00)	(103.0)	(97.41)	(73.06)	(73.93)	(83.09)
			Distribution of preferences			
α	0.971***	0.796***	0.825***	0.942***	0.937***	0.909***
	(0.005)	(0.008)	(0.008)	(0.008)	(0.010)	(0.011)
β	15.84***	16.80***	15.64***	11.56***	11.54***	10.18***
	(0.984)	(1.155)	(1.071)	(1.031)	(1.048)	(1.050)
Trend		0.002***	0.001***		0.00005	0.0001
		(0.00008)	(0.0001)		(0.0001)	(0.0001)
Production			0.0008***			0.0008*
of ethanol			(0.0002)			(0.0003)
R-squared						
Alcohol equation	0.91	0.93	0.93	0.88	0.88	0.89
Gasoline equation	0.96	0.95	0.95	0.95	0.95	0.95
Number of observations	3,310	3,310	3,310	3,310	3,310	3,310

Notes: The numbers in parentheses are standard errors. The asterisk indicate statistical significance with * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors should be taken cautiously as they could be improved by calculating cluster standard errors that are robust to autocorrelation and heteroscedasticity.

of the distribution shifts with respect to time. In the LS estimates, the value of α declines when adding the trend. The positive coefficient for the trend implies than between January 2002 and December 2011 (120 months), the median willingness to pay for alcohol increase by FFV motorists increased by 0.24. Adding the trend to the distribution of preferences has small effect on the 2SLS estimate of α. The coefficient for the trend is small and implies that the median willingness to pay for alcohol increased only by 0.006 between January 2002 and December 2011. The estimates for the effect of within State production of ethanol are the same for the LS and the 2SLS estimates. The value of the coefficient is small. The State of Sao Paulo, a large producer of ethanol, produced 30.56 liters of ethanol per capita in December 2011. This means that the median consumer in Sao Paulo was willing to pay 0.02 more for ethanol relative to gasoline compared to a the median consumer in a State with no ethanol production.

Distribution of preferences for alcohol

Recall that, as illustrated in figure 2, the variance on the distribution of preferences for alcohol determines the shape of the total demand for alcohol. The mean of the distribution determines at what price ratio consumers on average switch between fuels.

Table 3 summarizes estimates of the distribution of willingness to pay for alcohol for the State of Sao Paulo in December 2011. At that time, Sao Paulo was the third largest ethanol producing State on a per capita basis. Thus, as the coefficient for production of ethanol is positive in model 3, the mean willingness to pay for ethanol reported in table 3 is the third largest willingness to pay estimate among Brazil's States.

In least-squares model estimates, the mean willingness to pay is near one. In contrast, the 2SLS estimates show that consumers on average tend to discount

Table 3. Distribution of willingness to pay for alcohol

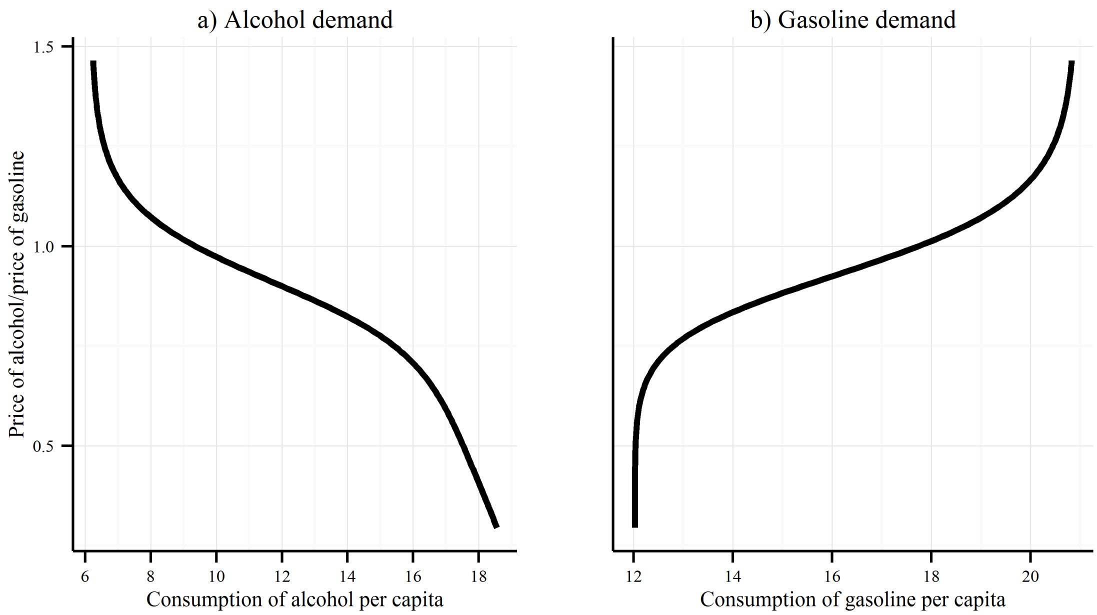
	Model 1 (LS)	Model 2 (LS)	Model 3 (LS)	Model 1 (2SLS)	Model 2 (2SLS)	Model 3 (2SLS)
Mean	0.978	0.997	1.003	0.954	0.954	0.960
Standard deviation	0.113	0.108	0.117	0.152	0.152	0.174
Share premium	0.387	0.461	0.484	0.335	0.336	0.359
20% quantile	0.890	0.912	0.912	0.836	0.836	0.824
80% quantile	1.060	1.076	1.088	1.062	1.063	1.083

Notes: All values are calculated for the State of Sao Paulo in December 2011, assuming that the price of gasoline is R$ 1.7 per liter and that the price of alcohol is R$ 1.7 per liter as well. The row labeled "Share premium" is the share of consumers that are willing to pay a premium for alcohol.

alcohol by slightly more than 4% on average. Estimates of the standard deviation of the distribution are larger in the 2SLS. Less than half of consumers are willing to pay a premium for alcohol. Observe in model 3 of the least-squares estimates that even though consumers on average value alcohol and gasoline the same, still less than half of consumers are willing to pay premium for gasoline. In the 2SLS estimates of the same model, about 34% of consumers are willing to pay a premium for ethanol.

Figure 4 shows graphs of the per capita demands for alcohol and gasoline in Sao Paulo in December 2011 in function of the ratio of the price of alcohol and gasoline. The figure uses the 2SLS estimate of model 3, which is the case where the standard deviation of the distribution of preferences is the widest. Observe in panel a) of figure 4 that the demand for alcohol is smooth which suggests that FFV motorists switch rather slowly from gasoline to alcohol as the price of alcohol declines relative to the price of gasoline. Panel b) shows that the demand for gasoline increases as the ratio of fuel prices increases. The figure shows that FFV motorists tend to switch slowly from alcohol to gasoline as the relative price of alcohol increases.

My results show a much narrower distribution of preferences than what Salvo and Huse (forthcoming) find. Salvo and Huse (forthcoming) find that about 20% of motorists still purchase gasoline when the price of gasoline is 20% above the parity



Notes: The predicted demands are plotted using 2SLS estimates of model 3. The prediction assumes that the price of gasoline is R$ 1.7 per liter.

Figure 4. Predicted per capita demands for alcohol and gasoline in the State of Sao Paulo in December 2011

price of alcohol. Symmetrically, there is roughly 20% of motorists that still purchase alcohol when the price of ethanol is 20% above parity. My results shows that 20% of consumers still purchase alcohol when its price is about 10% above the price of gasoline. The distribution of preferences is not symmetric as 20% of consumers still purchase gasoline when there is a 15% discount on the price of alcohol.

Summary and conclusion

The recent introduction of flex cars, that can run on fuel than contains a share between zero and one of ethanol, is shaping the demand for ethanol and gasoline in the United States and Brazil. Understanding the demand for fuel, as motorists are now able to arbitrage between motor fuels with varying quantities of ethanol, is crucial for analysis of energy policy in Brazil and the United States.

This paper describes the aggregate demand for alcohol (pure ethanol) and gasoline in Brazil. The model shows how motorists switch between fuels, given relative prices, depending on their preferences. If there is a small variance in motorists' preferences, then most motorists switch fuel at around the average willingness to pay, creating a flat segment in the aggregate demand for alcohol. Otherwise, if the variance on the distribution of consumers is large, then aggregate demand for fuel is smoother, without any apparent flat segment.

I estimate in a system of equations the demand for alcohol and gasoline in Brazil, and FFV motorists preference for alcohol. I find that on average, FFV motorists in Brazil slightly discount alcohol over gasoline, even when accounting for the relative energy contents of the two fuels. That is, most motorists switch between fuels when their relative prices are slightly below one. I find that 20% of consumers still purchase alcohol when its price is about 10% above the price of gasoline. The distribution of preferences is not symmetric as 20% of consumers still purchase gasoline when there is a 15% discount on the price of alcohol. This is a narrower distribution of preference for alcohol then what Salvo and Huse (forthcoming) find.

This paper is an early effort in estimating the FFV motorists in Brazil preferences for alcohol and gasoline and motor fuel. Future work will estimate cluster standard errors that are robust to autocorrelation and heteroscedasticity. Upcoming work will show estimates of demand elasticities derived from the model. In addition, I will derive an estimate of the demand for alcohol for all of Brazil. This demand will use the bases for fuel prices across States to plot a demand curve that is conditional on the price observed in Sao Paulo. In this aggregate demand, I do not expect to observe much flattening of the demand at near parity for the price of alcohol and gasoline. The reason is that the price bases for alcohol and gasoline may differ. As such, in some States, the price ratio may be above one when the price ratio in Sao Paulo is below one. The opposite case may occur as well. This implies that FFV motorists across States will switch between motor fuel at a price ratio, measured in Sao Paulo, that does not equal one, thus making the aggregate demand smoother.

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