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Flex Cars and Competition in Ethanol and Gasoline Retail Markets

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Abstract
In Brazil, gasoline and ethanol coexist as automotive fuels and are becoming closer substitutes as flex cars become more widely adopted. We employ this source of variation in a large panel of weekly prices at the station level to show that fuel prices have fallen in response to this change. This finding is evidence of market power in fuel retail and indicates that innovations that increase consumer choice benefit even those who choose not to adopt them. We also propose a model of price competition in this market and use it to estimate demand from price response functions.

Key words: Flex-fuel vehicles; Gasoline; Ethanol; Price competition; Spatial Competition; Discrete equilibrium price dispersion.

JEL Classifications: L11, L13, L62, L71

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1 Introduction

The key aspect underlying the identification of conduct in empirical studies in industrial organization is the relationship connecting changes in the price elasticity of demand and firms' pricing decisions. In this paper, we explore two features of the automotive fuel retail market in Brazil that allow us to directly document this relationship. First, Brazil is a dual fuel market: both gasoline and ethanol have been available for automobiles at virtually every fuel station in the country since the 1980s. Second, since 2003, flex cars have been available and have allowed some of the consumers to treat these two fuels as nearly perfect substitutes at the pump. This technological innovation provides a source of change in the cross-price elasticity between two products that allow us to directly identify its effect on pricing.

Our results show that, consistent with the prediction of standard oligopoly models, fuel stations have significantly reduced the price of both products. The absolute effect is stronger for ethanol, which is consistent with the fact that it has a smaller market share in the automotive fuel market in Brazil. We believe that our results provide evidence of market power in fuel retail and that innovations that increase consumer choice may benefit even those that choose not to adopt them.

Flex, or bi-fuel, vehicles are able to run on any mix of gasoline and ethanol fuel; electronic sensors identify the mix at the fuel tank and adjust the fuel injection accordingly. Flex cars have been made commercially available in Brazil in 2003 and have become a commercial success: in 2008, 94% of the new cars registered in the country were flex cars. Because the speed of penetration of this technology has been unequal across localities (roughly driven by the pace of car fleet renewal), we have been able to employ panel data methods to control for aggregate time-varying effects and local fixed effects, using a detailed sample of weekly prices at the gas station level.

In Brazil, both gasoline and ethanol are distributed through the same retail network; virtually every fuel station supplies both products. Therefore, the setting is not the typical one studied in differentiated-goods oligopoly models, where each competitor supplies a different variety. To account for this difference, we propose a model where stations compete by each setting the price of both products. In the model, we allow consumers to treat fuel from different stations as imperfect substitutes due to location or other idiosyncratic preferences. We only impose that for flex car owners, gasoline and ethanol within the same station are perfect substitutes.

Our theory shows that our prediction continues to hold in this setting: in equilibrium, firms strategically respond to an increase in flex car penetration (that is, an increase in substitutability between products within its own product line) by reducing markups. A key difference remains: in our setting, the law of one price has no bite; our theory does not predict that the price of the two fuels should move closer as they become perfect substitutes to a growing share of the consumers. Because both prices are set by the same firm, it is generally optimal to keep prices apart to price discriminate consumers that cannot freely switch. In our empirical analysis, we also provide evidence that the data support this prediction of the model as well.

Our third contribution in this paper is to propose a method to empirically identify demand for fuel based on estimated price response functions (Pinkse, Slade and Brett, 2002), exploring the observed variation in the sizes of the three fleets (flex cars, gasoline-only cars, and ethanol-only cars). In spite of our use of only minimal information about the car fleet (namely, only the fraction of the fleet using each type of fuel) and our adoption of a crude market definition, our estimates seem reasonable: for example, they predict that pass-through from costs to prices in fuel retail is near 0.5, as predicted by oligopoly theory for the case of constant marginal costs.

Our paper contributes to a small but increasing literature on the industrial organization of ethanol as automotive fuel and its relation to the gasoline market. Anderson (2010), Corts (2009) and Shriver (2010) are examples of recent studies that investigate the ethanol market in the US.[1] Anderson (2010) studies the demand for the product. Shriver (2010) studies the network effect that arises due to spatially dependent complementarities between the availability of stations supplying ethanol fuel and the local number of flex cars. Corts (2009) also analyzes the decision to supply ethanol by local stations, using as a source of variation purchases of flex cars by government agencies.

This emphasis on the issue of expanding the distribution network reflects the incipient nature of ethanol as automotive fuel in the US. In Brazil, by contrast, the challenge of building an extensive distribution network has been completed in the 1980s with the Pró-álcool program, further discussed in section 2 below. The Brazilian market provides a setting where it is possible to study a mature dual-fuel industry.

Most existing studies employing Brazilian data (Ferreira, Prado and Silveira, 2009; Salvo and Huse, 2010*b*; Boff, 2011) use time series of average price data to look for evidence of convergence toward the law of one price between the fuels[2]. In contrast to this literature, we employ much more detailed data, which allows us to document the importance of price dispersion across stations (an important feature of automotive fuel markets; see, e.g., (Lewis, 2008)).In addition, we argue in this paper that because of the structure of the retail market for fuel in Brazil, price convergence should not necessarily occur.

The paper is organized as follows: section 2 provides a brief summary of the general characteristics of the Brazilian fuel market. Section 3 presents a model of oligopolistic competition among fuel stations supplying both types of fuel. Section 4 describes the data we use and also shows some descriptive statistics. We present the empirical results in two parts: In section 5 we employ panel data methods to establish some relationships between flex car penetration and fuel retail pricing. In section 6, we exploit these relationships to estimate demand functions for fuel. We make some concluding remarks in section 7.

[1] More precisely, E85; in the US, retail stations supply a composition of 85% of ethanol and 15% of gasoline called E85 instead of pure ethanol (E100) supplied in Brazil.

[2] Representing an exception are Salvo and Huse (2010*a*), who employ an opinion poll among flex car owners to document the relevance of motives other than price to choose between fuels.

2 Flex Cars and the Automotive Fuel Market in Brazil

2.1 Ethanol-Powered and Flex Cars

Brazil has a long history of using ethanol as a vehicular fuel. In the 1970s, in response to the first oil crisis, the military government launched the Pró-álcool program to favor the production of ethanol from sugarcane and stimulate the adoption of ethanol-fueled cars. The program included the use of credit subsidies for ethanol production and setting favorable fuel prices at the pump to stimulate adoption of the new technology. Consumers responded to the Pró-álcool program - from 1983 to 1989, most new cars purchased were ethanol-fueled vehicles. This finding may be seen in figure 1, which presents shares of new car registrations in Brazil per year by fuel type.

In response to a sharp increase in the global price of sugar, which tripled from 1985 to 1990 (USDA (2010), table 3a), domestic ethanol production sharply declined, and the ensuing supply crisis led to a plunge in the sales of ethanol-powered vehicles. Since 1995, sales of ethanol-powered cars have represented only a small fraction of new vehicle sales in Brazil. However, ethanol-fueled cars continue to represent over 10% of the current fleet.

In the first quarter of 2003, flex cars (or bi-fuel cars) became commercially available in Brazil. Flex cars may run on any mixture of gasoline and ethanol. Because a liter of ethanol contains roughly as much energy as 0.7 liters of gasoline (Marjotta-Maistro and Asai, 2006), a flex car owner may save money if the price ratio drifts away from that threshold.[3] As figure 1 shows, flex car penetration has been dramatic: In 2008, 94% of new cars registered in Brazil were flex cars.

[3] There are other facts that might lead consumers to choose one fuel over the other. A car running on ethanol is less hazardous to the environment, as it does not create net emissions of carbon dioxide. A car powered by gasoline demands less fuel per volume, thus allowing for less frequent refueling.

2.2 The Automotive Fuel Market in Brazil

In Brazil, ethanol, or ethyl alcohol, is made from sugarcane. Two types of ethanol play a role in the automotive fuel market: anhydrous and hydrated. Anhydrous ethanol is mixed with gasoline fuel in the proportion of one unit of ethanol to three units of gasoline. Hydrated ethanol, a mixture that contains 5% water, is the version of alcohol readily available in drugstores and pumps at fuel stations in Brazil.

Brazil is the largest producer of sugarcane in the world, the second-largest producer of ethanol, and a net exporter of ethanol. Brazil was a net importer of oil until 2006 but has been a net exporter of gasoline since 1976.

Before the passage of Law 9478 in 1997 ("Lei do Petróleo"), the Brazilian oil industry was a monopoly in the hands of state-owned Petrobras. The law created the Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP), the sector regulatory body, and broke Petrobras' monopoly on exploration, refining, international trade, and the sea transport of oil and its main byproducts. Since January 2002, retail fuel prices are freely set by the market. Petrobras continues to be a major player in the domestic refining, distribution and retail of gasoline, currently holding market shares in these markets of 96.6%, 28.9% and 17.8%, respectively (ANP, 2010, tables 2.34, 3.6 and 3.17).

3 Model: Price formation in the retail fuel market in the presence of flex cars

In this section, we present a model of strategic price formation in the retail fuel market and use it to investigate theoretically the effect of a larger flex car fleet on equilibrium fuel prices.

The model we propose has a number of features that are relevant for the automobile fuel market, particularly in areas where multiple fuels are offered through the same distribution network: i) aggregate demand for fuel (adding up different types of fuel) is proportional to the size of the automobile fleet and thus is inelastic in the short run; ii) location differences allow fuel stations to have a degree of market power; iii) every fuel station supplies both types of fuel and selects both prices to maximize joint profits; iv) for flex car owners, ethanol and gasoline are perfect substitutes.

In the model, there is (imperfect) competition across fuel stations, but between different types of fuel within a location, there is no competition at all: each station provides both ethanol and gasoline and internalizes the effect of a price change over the sales of the other product. The effect of an increase in the flex car fleet is to change the degree of substitutability between fuels and not across stations. One may tend to suppose that because competition and the direct effect of flex cars penetration operate in different dimensions of product differentiation, there would be no effect of the latter on the former. This supposition is not true: we find that in equilibrium, flex car penetration leads to more competition across fuel stations.

The model also predicts price dispersion across stations and among fuels within a station. In equilibrium, a gas station generally finds it optimal to charge prices that do not conform to the technical substitution ratio of 70%, even when flex car penetration approaches 100%; therefore, this theory may help explain why this relationship is not observed in practice.

3.1 Basic structure

We consider an oligopoly model where N gas stations compete by setting prices for gasoline and ethanol. The population of consumers, which we normalize to 1, is divided into three groups: gasoline-fueled car owners, ethanol-fueled car owners, and flex car owners. We call ? the fraction of flex car owners, and to maintain symmetry in the model, we assume that the rest of the fleet is equally divided between gasoline and ethanol. The type of fuel generally has no effect on consumption, but for flex car owners, gasoline and ethanol within the same gas station are perfect substitutes. (We measure fuel in terms of energy content, so flex car owners always buy the cheaper fuel).

There is differentiation across fuel stations. For a given fuel price profile, let $p_{if} = \min\{p_{ig}, p_{ia}\}$ (the price effectively faced by a flex type in station i). Using this notation, we assume that the demand for fuel from station i from a consumer with car type $j = g$ (gasoline-powered), a (alcohol-powered) or f (flex) is

$$q_{ij} = \alpha - \beta p_{ij} + \gamma \bar{p}_{-ij},$$

where α, β and γ are positive constants, p_{ij} is the price of fuel j in station i, and $\bar{p}_{-ij}$ is the average price of fuel j in all stations except i.

We adopt the same functional form for all fuel types. This procedure is followed for simplicity and to isolate the effect on substitutability across fuels as the car fleet changes.[4] For consumers within each car group, we assume that demand across stations exhibits a simple linear form of symmetric product differentiation. This demand system may be justified by Carlson and McAfee (1983), who model consumer choice by a process of costly search among identical products sold by different firms at (potentially) different prices Carlson and McAffe show that if the distribution of search costs in the consumer population is uniform, then aggregate demand for firm i exhibits the form postulated above, with $\alpha = 1/N$ and $\beta = \gamma = (N-1)/N$, where N is the number of firms in the market.

We seek to obtain a prediction regarding Bertrand-Nash equilibrium prices for firms that face demand arising from this process and have a cost function as follows:

$$C_i(q_{ig}, q_{ia}) = c_{ig} q_{ig} + c_{ia} q_{ia} + F_i,$$

where q_{ig} and q_{ia} are the quantities sold of gasoline and ethyl alcohol in station i, c_{ig} and c_{ia} are marginal costs, and F_i is a fixed cost component. We assume that marginal costs are constant and exogenous, but different across fuels and stations. We believe that assuming that marginal costs differ across stations is reasonable, given that the according to our data, there is substantial variation

[4] We relax this assumption in the model we estimate structurally in section 6.

on wholesale price for fuel faced by each station.

3.2 Properties of equilibrium prices

To obtain a characterization of equilibrium prices, we must first integrate the demand over the mass of consumers with each car type. If $p_{ig} \neq p_{ia}$, station i will sell Q_{ig} of gasoline and Q_{ia} of ethanol, where

$$\begin{aligned} Q_{ig} &= \left(\frac{1-\theta}{2}\right)(\alpha - \beta p_{ig} + \gamma \bar{p}_{-ig}) \\ &\quad + \mathbb{1}\{p_{ig} < p_{ia}\}\theta(\alpha - \beta p_{ig} + \gamma \bar{p}_{-if}) \end{aligned}$$

and

$$\begin{aligned} Q_{ia} &= \left(\frac{1-\theta}{2}\right)(\alpha - \beta p_{ia} + \gamma \bar{p}_{-ia}) \\ &\quad + \mathbb{1}\{p_{ig} > p_{ia}\}\theta(\alpha - \beta p_{ia} + \gamma \bar{p}_{-if}). \end{aligned}$$

($\mathbb{1}\{A\}$ represents the indicator function, with value one if A is true and zero otherwise.) If $p_{ig} = p_{ia}$, flex car owners are indifferent between the two types of fuel, and we must specify a sharing rule $\tau \in [0,1]$. Formally, we follow the approach of Simon and Zame (1990) and adopt an endogenous sharing rule, although the specifics of the tie-breaking do not affect the equilibrium determination in this model.

The profit of station i is simply $\pi_i = (p_{ig} - c_{ig})Q_{ig} + (p_{ia} - c_{ia})Q_{ia} - F_i$. Maximizing this expression with respect to p_{ig} and p_{ia} yields this firm's best-response function. Whenever θq_{if} is positive, π_i is discontinuous at the point $p_{ig} = p_{ia}$ (and the profit at the discontinuity point depends on the tie-breaking rule).

In any pure-strategy equilibrium, we may classify stations into those that choose to charge $p_{ig} > p_{ia}$, $p_{ig} < p_{ia}$ or $p_{ig} = p_{ia}$. In the first two cases, profits are continuously differentiable around the chosen prices, and the latter may be characterized by the first-order conditions $\frac{\partial}{\partial p_{ig}}\pi_i = 0$ and $\frac{\partial}{\partial p_{ia}}\pi_i = 0$.

In the next proposition, we show that the last alternative is never optimal: In equilibrium no fuel station elects to charge $p_{ig} = p_{ia}$:

Proposition 1 *If $\theta > 0$ then any firm i will post $p_{ig} \neq p_{ia}$ in equilibrium.*

Proof:

If some of the other fuel stations charge a different price for each fuel, $\bar{p}_{-if} < \bar{p}_{-ig}$ or $\bar{p}_{-ia}$. Without loss of generality, suppose that $\bar{p}_{-if} < \bar{p}_{-ig}$.

The profit of firm i, as a function of p_{ig}, exhibits a kink at the point $p_{ig} = p_{ia}$. Let x and y be the right and left derivatives, respectively, at that point:

$$x = \frac{\partial}{\partial p_{ig}} \pi_i^+ = (1 - \theta/2)[q(p_{ig}, \bar{p}_{-ig})) - \beta(p_{ig} - c_{ig})]$$

and

$$y = \frac{\partial}{\partial p_{ig}} \pi_i^- = x + (\theta)[q(p_{ig}, \bar{p}_{-if})) - \beta(p_{ig} - c_{ig})]$$

For firm i to find it optimal to charge $p_{ig} = p_{ia}$, it must be the case that $y \geq 0 \geq x$. However, such a case is impossible as $x \leq 0 \Rightarrow y < 0$.

If *all* other stations charge the same price for both fuels, $\bar{p}_{-if} = \bar{p}_{-ia} = \bar{p}_{-ig} = \bar{p}$. Evaluating the left and right derivatives around a point $p_{ig} = p_{ia} = p$, we define as before $x = \frac{\partial}{\partial p_{ig}} \pi_i^+$, and $y = \frac{\partial}{\partial p_{ig}} \pi_i^-$ and, analogously, $x' = \frac{\partial}{\partial p_{ia}} \pi_i^+$, and $y' = \frac{\partial}{\partial p_{ia}} \pi_i^-$. As we argued above, $x < 0 \Rightarrow y < 0$ and $x' < 0 \Rightarrow y' < 0$. For the first-order condition to be satisfied, we need $x = 0$, $x' = 0$ at this point. However, this condition is impossible because

$$x = (1 - \theta/2)[q(p, \bar{p})) - \beta(p - c_{ig})] \neq x' = (1 - \theta/2)[q(p, \bar{p})) - \beta(p - c_{ia})],$$

as $c_{ig} \neq c_{ia}$. $\square$

Considering the two possible first-order conditions that must be satisfied by p_{ij}, we obtain the following expressions:

$$p_{ig} = \frac{1}{2}\left[c_{ig} + \frac{\gamma}{\beta}\bar{p}_{-ig} + \frac{\alpha}{\beta}\right] - \mathbb{1}\{p_{ig} < p_{ia}\}\frac{\theta}{1+\theta}\frac{\gamma}{\beta}(\bar{p}_{-ig} - \bar{p}_{-if})$$

and

$$p_{ia} = \frac{1}{2}\left[c_{ia} + \frac{\gamma}{\beta}\bar{p}_{-ia} + \frac{\alpha}{\beta}\right] - \mathbb{I}\{p_{ig} > p_{ia}\}\frac{\theta}{1+\theta}\frac{\gamma}{\beta}(\bar{p}_{-ia} - \bar{p}_{-if})$$

Note that $\bar{p}_{-if} \leq \bar{p}_{-ig}$ and $\bar{p}_{-if} \leq \bar{p}_{-ia}$, so the right-hand sides of the expressions above are decreasing in θ. Because prices across stations are strategic complements, we conclude that prices are decreasing in θ. This result is summarized in the proposition below.

Proposition 2 *Ethanol and gasoline prices are decreasing with respect to the fraction of flex cars.*

A larger fleet of flex cars pulls prices down because flex cars provide an option value to their owners: if fuel prices are dispersed, flex car owners expect to find lower prices than other drivers because they can always pick the cheapest alternative. For this reason, flex car owners are willing to pay less, and fuel stations respond to lower demand by lowering prices.

Let us turn to the analysis of the difference between gasoline and ethanol prices. The effect of flex car penetration on the difference between gasoline and ethanol prices is ambiguous and depends on the competition pressures from other station in the market. More precisely, we have the following:

$$\begin{aligned} p_{ig} - p_{ia} &= \frac{1}{2}\left[c_{ig} - c_{ia} + \frac{\gamma}{\beta}\left(\bar{p}_{-ig} - \bar{p}_{-ia}\right)\right] \\ &\quad - \frac{\theta}{1+\theta}\frac{\gamma}{\beta}\left[\mathbb{I}\{p_{ig} < p_{ia}\}(\bar{p}_{-ig} - \bar{p}_{-if}) - \mathbb{I}\{p_{ia} < p_{ig}\}(\bar{p}_{-ia} - \bar{p}_{-if})\right]. \end{aligned}$$

Therefore, the price difference $p_{ig} - p_{ia}$ does not necessarily decrease with θ. This fact may help explain why we do not observe the price of ethanol to approach that of gasoline as the flex car fleet grows.

4 Data

4.1 Data sources

This study combines data from different sources. The first source is the *Levantamento de Preços e de Margens de Comercialização de Combustíveis*, a weekly survey conducted by ANP, the Brazilian regulatory agency covering the oil, gas and biofuel industry. ANP collects data on retail prices for ethanol and gasoline prices, as well as prices paid to fuel distributors, at individual fuel stations in 10% of the municipalities in Brazil. There is also information on the brand of the station (or whether it has no brand), the date on which prices were collected and the address of the station. Our sample contains weekly prices from January 2002 to March 2008 for stations located in 36 municipalities in the Rio de Janeiro state. Not all fuel stations are surveyed every week. Coverage is 100% in small municipalities, whereas for larger markets, the survey adopts a rotating sample (with random selection) that eventually covers all fuel stations in the location. Table 1 provides information on the number of stations sampled, as a proportion of the overall population of stations, in the 38 municipalities used in this study.

The second data source is a monthly data set on the number of cars with license plates from each municipality in the state of Rio de Janeiro, classified according to fuel type (gasoline, ethanol, flex, gasoline + CNG[5], ethanol + CNG, flex + CNG). The time period is the same considered in the ANP's survey (from January 2002 to March 2008). This data set was provided by the department of motor vehicles of the state of Rio de Janeiro (Detran - RJ). Although ANP verifies the price charged by fuel stations in all Brazilian states, we are unable to expand our analysis to the entire Brazilian territory because we do not have access to data on the number of cars by fuel type in other states.

We included annual municipal GDP per capita as a regressor (obtained from the Brazilian institute of geography and statistics - IBGE). We also included annual data on number of hotels per square km in each municipality (provided

[5]CNG stands for compressed natural gas. In Brazil, it is possible to convert vehicles to run on natural gas.

by the data and information center of Rio de Janeiro - CIDE RJ) as a proxy for markets where a large fraction of drivers are not local. The former series is available from 2002 to 2006, and the latter is available from 2002 to 2004. Because we are analyzing the period between 2002 and 2008, in both cases the missing years were replaced by the most recent available ones.

4.2 Descriptive statistics

Table 1 shows how the percentage of flex cars changed between 2004 and 2007 in the 38 municipalities in our sample. Figure 2 presents a map of the Rio de Janeiro state with a bullet for each municipality in our sample. The size of the bullet is proportional to (the log of) the local car fleet, and the color is coded according to flex car penetration in 2007. As we can see, the flex car fleet grew considerably across time in all locations, reaching a maximum value of 14.1% in the city of Mangaratiba in 2007. There is variation both in the time series and the cross-section/geographic dimensions.

Figure 2 strongly suggests that flex car adoption is closely related to local income, growing the most in the capital (the Rio de Janeiro city), tourist resort towns (Armação de Búzios, Parati, Angra dos Reis) and rapidly developing areas (Macaé, Mangaratiba). The municipalities with the lowest adoption rates are located in the northeastern part of the state, the traditional region of sugarcane production in Rio de Janeiro.

Table 2 provides basic statistics on wholesale prices, retail prices and margins in our data. Table 3 presents the evolution of retail prices for each type of fuel. Ethanol average retail prices have been below the 70% threshold of gasoline average retail prices except in 2006. Therefore, it is reasonable to infer that most owners of flex cars in our sample are choosing to fill their tanks with ethanol.

Although we do not have access to data on gasoline and ethanol sales at stations, ANP publishes the distributors' consolidated sales volume in the state of Rio de Janeiro, as shown in table 4. In this table, we also present the aggregate size of the fleet in our data set. We have also computed sales per car, in cubic meters, in the last two columns. (For ethanol, we added the fleet of ethanol-powered and flex cars in the denominator, under the assumption that in this period flex car owners were mostly buying this fuel.)

5 Empirical Results

In this section, we document three effects of flex car penetration on the distribution of fuel prices. First, we estimate the effect of the penetration of the flex cars θ on the level of retail prices and margins for both ethanol and gasoline. Second, we investigate and fail to find evidence that the price spread between gasoline and ethanol is reduced by flex car penetration. Finally, we document that flex car penetration has made gasoline and ethanol prices more highly correlated within each station.

All the results presented in this and the following section consider the price of gasoline multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels.

5.1 Effect of flex cars on retail prices and margins

According to proposition 2, the penetration of flex cars tightens the competition in fuel market, decreasing gasoline and ethanol prices as well margins. Tables 5 and 6 present a reduced-form analysis of the impact of flex cars on prices and margins. Columns (1)-(4) of both tables consider retail prices, whereas columns (5)-(8) consider retail margins (i.e., the gap between wholesale and retail prices). Each column adopts a different set of controls: monthly dummies, individual station fixed effects and brand fixed effects. This approach allows us to flexibly control for both aggregate effects over time and site-specific effects. In specifications (4) and (8) we also include municipal GDP per capita, the number of stations per car and the number of hotels per square km to control for the effect of income growth, variation in relative fuel station scarcity and the intensity of local tourist activity.

Table 5 analyzes the effect of flex cars on the gasoline market. Column (1) suggests that, contrary to the prediction of the model, the estimated coefficient is positive. However, this is a result drawn by a common upward trend of prices due to inflation and flex car penetration. In fact, when we introduce time dummies, in column (2), the coefficient becomes negative. The point estimate implies that an increase of 10 percentage points in flex car penetration reduces the gasoline price by $3.84/0.7 = 5.49$ cents (of Brazilian Reais) per liter. Considering station and flag/brand fixed effects, this impact reduces to $2.74/0.7 = 3.91$ cents per liter. Finally, controlling for municipal GDP per capita, stations per car and hotel density, this impact becomes $2.05/0.7 = 2.93$ cents per liter. The effect on gasoline margin presents the same pattern and has a similar magnitude, suggesting that the competitive pressure is wholly absorbed by the retail layer of the gasoline supply chain.

Table 6 presents the same analysis for the ethanol market. The effects on ethanol prices are similar but more pronounced. In our preferred specification (column 4), a 10 percentage-point increase in flex car penetration reduces the ethanol price by 7.8 cents (of Brazilian Reais) per liter. We estimate a negative, but significantly smaller, effect on ethanol retail margins: a reduction of 3.7 cents per liter. This finding suggests that unlike the gasoline case, flex car penetration may have affected mark-ups in the ethanol upstream markets as well.

5.2 Effect of flex cars on the spread between gasoline and ethanol prices

We now investigate the empirical relationship between flex cars (θ) and the spread between gasoline and ethanol prices ($p_g - p_a$). Figure 3 shows the scatter plot between the spread $p_g - p_a$ and θ, with a spline trend estimated with bandwidth 8. The relationship depicted in the figure is clearly non-monotonic. The spread is larger for values of θ greater than 6%.[6]

[6] Figure 4 plots the spread against time. There are substantial seasonal effects that affect the affect relative prices of the fuels, but there is no evidence of a reduction of the spread over

Although figure 3 suggests a non-monotonic effect of flex cars on the spread, it might be contaminated by other undesired sources of variation. To consider this factor, table 7 presents regressions of the absolute value of the spread $|p_g - p_a|$ on θ, controlling for different sets of fixed effects and other variables.

In columns (1) and (2), the coefficient on the penetration of flex cars is negative and statistically significant. However, after controlling for cross-section variation, the coefficient becomes positive. We conclude that there is no evidence that flex car penetration has reduced price spreads across fuels.

5.3 Fuel price correlation

Although we do not find evidence that the spread of fuel prices has decreased, we have found that in markets with more flex penetration, fuel prices tend to be more correlated, which is consistent with the hypothesis that fuel stations make the pricing decisions of both fuels jointly.

In this section, we provide evidence that the correlation between fuel prices has increased with flex car penetration using two different methods.

In the first method, we assume that fuel prices are jointly distributed with flex car penetration affecting both the expectation and the covariance of prices. Put another way, we assume that the equations estimated in tables 5 and 6 form a system of seemingly unrelated regressions (SUR) and that the residuals are heteroskedastic, with the residuals' covariance being a function of flex car penetration.

To estimate this relationship, we regress the product of the residuals from regressions in tables 5 and 6 on flex car penetration, which is the same as the second stage in the standard feasible GLS procedure to estimate a SUR model. Coefficients in this regression show how the conditional covariance of fuel prices depends on the regressor.

Table 8 presents the results of this regression. We consider three specifications: the first one is a regression involving flex car penetration and station fixed

time.

effects; in the second, brand effects are added; and in the third, month effects are added. In all specifications, we find that flex car penetration has a positive and significant effect on price covariance.

In the second method, we introduce interactions of flex fuel penetration with the price of the other fuel on the original price regressions. If our hypothesis is correct, in markets with more flex fuel cars, the price of a given fuel should respond more sharply to shifts in the price of the other fuel, which would lead to a positive coefficient for this interaction term.

The results of the second method are presented in table 9. We find that all interaction terms are positive as predicted, and all but one are statistically significant.

6 Structural Estimation of the Model

In this section, we employ the theory of price formation that we proposed in section 3 to investigate the demand for fuel from the information contained in stations' price response functions.

To bring the theory to the data, we change two aspects of the basic model presented in section 3. First, we recognize that the gasoline fleet is much larger than the ethanol fleet in our sample: let the fleet of gasoline, ethanol and flex vehicles at time t be θ_g^t, θ_a^t and θ_f^t, respectively. Second, we recognize that demand for fuel may differ systematically with car type, in response to differences in usage and fleet composition: let the demand for fuel from a vehicle of type j from station i in market m is

$$q_{ij}^t = \alpha_{mj}^t - \beta_j p_{ij}^t + \gamma_j \bar{p}_{ij}^t,$$

where $\alpha_{mj}^t = \alpha_m + \alpha_j$ represents the composition of a market-specific fixed effect and a fuel-specific intercept.

Retaking the same analysis performed in section 3, we obtain the following first-order conditions:

$$\begin{aligned}
p_{ig}^t &= \frac{1}{2}c_{ig}^t + \mathbb{1}\{p_{ig}^t > p_{ia}^t\}\left[\frac{\alpha_{mg}}{2\beta_g} + \frac{\gamma_g}{2\beta_g}\bar{p}_{ig}^t\right] \\
&+ \mathbb{1}\{p_{ig}^t < p_{ia}^t\}\left[\frac{\theta_g^t\alpha_{mg} + \theta_f^t\alpha_{mf} + \theta_g^t\gamma_g\bar{p}_{ig}^t + \theta_f^t\gamma_f\bar{p}_{if}^t}{2(\theta_g^t\beta_g + \theta_f^t\beta_f)}\right] + \epsilon_{ig}^t,
\end{aligned}$$

$$\begin{aligned}
p_{ia}^t &= \frac{1}{2}c_{ia}^t + \mathbb{1}\{p_{ia}^t > p_{ig}^t\}\left[\frac{\alpha_{ma}}{2\beta_a} + \frac{\gamma_a}{2\beta_a}\bar{p}_{ia}^t\right] \\
&+ \mathbb{1}\{p_{ia}^t < p_{ig}^t\}\left[\frac{\theta_a^t\alpha_{ma} + \theta_f^t\alpha_{mf} + \theta_a^t\gamma_a\bar{p}_{ia}^t + \theta_f^t\gamma_f\bar{p}_{if}^t}{2(\theta_a^t\beta_a + \theta_f^t\beta_f)}\right] + \epsilon_{ia}^t.
\end{aligned}$$

ϵ_{ij}^t may be interpreted as an unobserved (to the econometrician) i.i.d. cost shock that is fuel-station-time specific. [7]

Our objective in this section is to identify the demand parameters by estimating price best response functions (Pinkse, Slade and Brett, 2002).

Because we do not observe quantities directly, we cannot identify the absolute scale of the demand coefficients only from pricing responses, and a normalization must be made. For convenience, we normalize $\beta_f = 1$.

If we further assume that $\beta_g = \beta_a = \beta_f = 1$, we obtain best responses that are linear in the remaining parameters:

$$\begin{aligned}
p_{ig}^t &= \frac{1}{2}c_{ig}^t + \mathbb{1}\{p_{ig}^t > p_{ia}^t\}\left[\frac{\alpha_{mg}}{2} + \frac{\gamma_g}{2}\bar{p}_{ig}^t\right] \\
&+ \mathbb{1}\{p_{ig}^t < p_{ia}^t\}\left[\frac{\theta_g^t\alpha_{mg} + \theta_f^t\alpha_{mf} + \theta_g^t\gamma_g\bar{p}_{ig}^t + \theta_f^t\gamma_f\bar{p}_{if}^t}{2(\theta_g^t + \theta_f^t)}\right] + \epsilon_{ig}^t,
\end{aligned}$$

[7] More precisely, we assume that total marginal cost for a given fuel j in station i is equal to $c_{ij}^t + 2\epsilon_{ij}^t$, where the number 2 multiplying the error is simply a normalization that does not affect the results. The two estimating equations follow by plugging this in our profit equation and deriving the optimal solution.

$$
\begin{aligned}
p_{ia}^t &= \frac{1}{2}c_{ia}^t + \mathbb{I}\{p_{ia}^t > p_{ig}^t\}\left[\frac{\alpha_{ma}}{2} + \frac{\gamma_a}{2}\bar{p}_{ia}^t\right] \\
&+ \mathbb{I}\{p_{ia}^t < p_{ig}^t\}\left[\frac{\theta_a^t\alpha_{ma} + \theta_f^t\alpha_{mf} + \theta_a^t\gamma_a\bar{p}_{ia}^t + \theta_f^t\gamma_f\bar{p}_{if}^t}{2(\theta_a^t + \theta_f^t)}\right] + \epsilon_{ia}^t.
\end{aligned}
$$

We report estimates both for the case where β coefficients are assumed to be identical and for the more general, nonlinear case.

To estimate these models, we must address two additional issues. First, we must define the relevant market for each fuel station. One possible approach is to define a market as a municipality; however, in the case of large cities, this definition appears to be inappropriate. Rio de Janeiro, the state capital, has 805 fuel stations spread over 12,000 squares; it is unreasonable to assume that they are all competing in the same market. To account for local competition in a simple manner, we define a market to consist of all stations that share the same four-digit postal code (CEP). We also experiment with narrowing the market definition to five-digit CEP areas.[8]

Representing a second challenge is endogeneity. If there are stochastic unobserved components in the demand function or in the marginal cost, because all prices are determined in equilibrium, all terms on the right-hand side of the form $\bar{p}_{ij}$ or $\mathbb{I}\{p_{ij} < p_{ik}\}$ are endogenous. Throughout, we still maintain the assumptions that the fleet composition and the marginal costs are exogenous.

To address this problem, we follow Pinkse, Slade and Brett (2002) and instrument each endogenous regressor by the analogous term involving costs: that is, we substitute $\mathbb{I}\{c_{ij}^t < c_{ik}^t\}$ for $\mathbb{I}\{p_{ij}^t < p_{ik}^t\}$, etc.

In addition, we estimate the model with and without market fixed effects to account for unobserved variation across markets. In the linear case, we may add

[8]In Brazil, the postal code has 8 digits, with the first five dividing the country into increasingly fine partitions. The four-digit level corresponds to neighborhoods in large cities and to small municipalities; at the five-digit level, neighborhoods of larges cities are divided into several areas. Three-digit areas are too coarse for the purposes of our model, as some of these areas cover different municipalities in our sample; conversely, eight-digit areas are too narrow, as most gas stations in the sample would be considered monopolies.

fixed effects for each market (postal code) separately. In the nonlinear case, we use municipality-specific fixed effects.

We must also account for inflation; otherwise, our estimates may be affected by the spurious correlation between the upward trends in prices and flex car penetration over time (as in tables 5 and 6). Because adding monthly fixed effects would overburden the computation of the nonlinear model, we opted to deflate fuel prices using a standard consumer price index (IPCA).

Finally, we may estimate price reaction functions separately for each fuel type (which will yield two different sets of estimates for the demand from flex car owners) or stack the data to impose the restriction that α_f and γ_f must be the same in both regressions.

Tables 10 and 11 present the results of estimating the linear model separately and jointly, respectively. Table 12 presents the results of the nonlinear model.

In tables 10 and 11 and in columns 1, 2 and 3 of table 12 we do not impose the theoretical restriction that the coefficients on cost should be 0.5. A remarkable finding is that our estimates of this effect are near this figure; they fluctuate between 0.4 and 0.53 among all specifications that control for price endogeneity (however, because these effects are precisely estimated, they *are* statistically different from 0.5). This fact suggests that pricing in this market does indeed comply with the logic of a price-setting oligopoly game. This coefficient is also of independent interest; the fact that is less than unity means that demand is *cost-absorbing*; according to Weyl and Fabinger (2009), a number of comparative statics predictions may be derived from that fact. For example, the entry of a new station will necessarily reduce prices, and a merger (without synergies) will raise prices of all firms (Weyl and Fabinger, 2009, theorem 4).

In column 4, we present estimates of the model obtained when we impose the theoretical restriction that the coefficients on costs should be 0.5. This is our preferred specification.

In our model, the elasticity of demand is proportional to the difference between β_j and γ_j. We estimate that γ_F is 16% smaller than β_F, γ_A is 13% smaller than β_A and γ_G statistically equal to β_G; our estimated demands are inelastic. We find estimates for β_G and β_A of approximately 0.3 and 0.27, substantially smaller than the values assumed in the linear model. This finding suggests that gasoline and ethanol car owners are less responsive to fluctuations in prices across fuel stations within the market.

Tables 13, 14 and 15 present the results we obtain if we use the narrow market definition. Our findings with respect to pass-through are similar in this case. We also find that the demand coefficients in our preferred specification (column 4 in tables 12 and 15) are also robust to the market definition we employ.

6.1 Exploring the demand estimates

In this section, we report two counter-factual simulations that exploit our demand estimates.[9] First we simulate how aggregate sales of ethanol and gasoline would change in response to a shift in the average price of ethanol, holding constant the price dispersion observed in the data. This exercise is a simple way to trace out the demand curves for fuel and illustrates how in our model the demand from flex car owners is substantially more elastic due to the possibility of substituting across fuels. In the second exercise, we simulate how the equilibrium price distribution would change in response to an increase in the flex car fleet. In line with our empirical findings, we find that the increase would mostly affect ethanol prices.

Figures 7 and 8 present the results of our first experiment. These figures show how the average demand (per car, per station, per week) changes in response to a change in the average ethanol price, holding price dispersion fixed. Figure 7 is a standard demand curve, plotting the price and demand for ethanol, while figure 8 presents the effect of the price of ethanol on the demand for gasoline.

[9] To obtain predictions for demand in terms of volume, we must de-normalize our coefficients; because our estimation method does not involve any information about the quantity sold at each station, it does not identify the absolute scale of the coefficients. To proceed, we multiply our coefficients by a constant that makes the model match the total fuel sales in the state of Rio de Janeiro in 2007, assuming that the sample of stations in our data set is representative of the overall market.

By assumption, the demand by ethanol car owners is linear, and the demand by gasoline car owners is completely inelastic with respect to the price of ethanol. If the price of ethanol is very high, flex car owners substitute entirely away to gasoline; the model estimates that their average demand is substantially higher that gasoline car owners, which is compatible with the fact that the flex car fleet is newer and presumably used more intensively. For intermediate prices, some of the flex car owners use ethanol and some use gasoline, depending on which fuel is cheaper at each particular station. The figures illustrate how, due to the price dispersion in these data, the flex car owners' aggregate demand curve for fuel is elastic but continuous in this range. Finally, if ethanol prices are very low, flex car owners consume only ethanol. Their demand in this range is predicted to be both larger and more elastic than the demand by ethanol car owners.

We also perform a counterfactual exercise to evaluate the impact of a hypothetical increase in the number of flex vehicles. As stated in Proposition 2, we should expect an increase in the number of flex cars to lead to a higher competitive pressure and thus to a fall in prices. In the counterfactual exercise, we assume that the number of flex cars triples in all municipalities (and that the rest of the market is split between gasoline and ethanol in the same proportion that we observe in the data). We then find the new equilibrium prices by numerically solving the system of best reply equations estimated above.

Figures 7 and 8 show our counterfactual, predicted and observed prices for ethanol and gasoline, respectively. In the ethanol case, it is clear that an increase in flex cars shifts the distribution to the left. In contrast, the gasoline distributions appear relatively similar. This finding reflects the fact that the introduction of flex cars had a much larger effect on the ethanol market than on the gasoline market. These figures also illustrate the fact that although our model predicts substantial price dispersion (given that there is substantial cost dispersion as measured by distributors' prices), the retail price dispersion in the data is larger than in our simulations.

7 Concluding Remarks

In this work, we investigate how the penetration of flex cars has affected the fuel retail market in the state of Rio de Janeiro. Our main hypothesis was that flex car penetration has increased the degree of substitution between gasoline and ethanol and that fuel stations would respond strategically to this shock, reducing retail prices in equilibrium.

Our estimates suggest that the model prediction is correct and that as the percentage of flex cars increase by 10%, ethanol and gasoline energy equivalent prices per liter fall by approximately 8 cents and 2 cents, respectively. Considering the volume of sales and the size of the flex car fleet in 2007, a rough estimate suggests consumer savings to the order of 70 million Reais in the Rio de Janeiro state that year. Our estimates also show that the price gap as well as the price correlation between the two fuels has increased with the increased penetration of flex cars.

We also propose a method to structurally identify fuel demand parameters from the estimation of best reply price response functions, which does not require sales data. In spite of using only minimal information about the car fleet (namely, only the fraction of the fleet using each type of fuel) and adopting a crude market definition, our estimates appear reasonable: they predict that pass-through from costs to prices in fuel retail is near 0.5, as predicted by oligopoly theory for the case of constant marginal costs.

In future work, we plan to extend our analysis of pricing best reply functions to use information on the exact geographic location of each fuel station. As in Pinkse, Slade and Brett (2002), we believe that this extension would allow us to better understand how geography affects competition in the fuel retail market.

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Table 1: Stock of Vehicles, Percentage of Flex Cars and Number of Fuel Stations, by City

	2004		2007		Number of fuel stations		
	Number of vehicles	% flex	Number of vehicles	% flex	In the sample	Total (2010)	% sampled weekly
Mangaratiba	3 090	1.2%	4 812	14.1%	10	11	91%
Niterói	176 647	1.0%	194 511	12.4%	34	85	40%
Macaé	41 048	1.1%	57 261	11.1%	14	23	61%
Rio de Janeiro	1 800 614	0.8%	1 969 128	10.5%	190	805	24%
A. de Búzios	4 340	1.4%	6 703	10.5%	7	7	100%
Angra dos Reis	21 503	0.9%	27 030	10.0%	13	23	57%
Parati	2 937	0.6%	3 675	9.1%	7	11	64%
Maricá	14 193	0.7%	24 120	9.0%	11	22	50%
Resende	26 085	0.8%	33 368	8.9%	14	26	54%
Cabo Frio	32 315	1.0%	46 371	8.6%	10	23	43%
Nilópolis	24 305	0.5%	29 579	7.4%	9	10	90%
Três Rios	14 792	0.9%	18 246	7.3%	10	15	67%
Araruama	20 290	0.6%	28 037	7.2%	16	23	70%
Saquarema	9 955	0.6%	13 771	7.1%	9	13	69%
Barra Mansa	31 788	0.8%	36 420	6.9%	21	31	68%
Vassouras	7 297	1.0%	8 319	6.9%	6	10	60%
Volta Redonda	68 441	0.7%	81 203	6.7%	21	30	70%
Paraíba do Sul	6 101	0.8%	7 427	6.5%	7	7	100%
São Gonçalo	107 977	0.4%	134 860	6.5%	35	88	40%
Petrópolis	86 912	0.6%	97 177	6.3%	18	54	33%
Sapucaia	1 381	0.9%	1 508	6.2%	10	13	77%
Belford Roxo	26 574	0.3%	37 744	6.1%	11	19	58%
Teresópolis	42 920	0.5%	50 787	5.6%	23	31	74%
Queimados	9 278	0.3%	13 612	5.6%	7	7	100%
Nova Iguaçu	115 523	0.4%	137 337	5.5%	25	65	38%
Magé	21 034	0.4%	27 495	5.5%	10	13	77%
Duque de Caxias	128 426	0.3%	151 257	5.3%	30	88	34%
Nova Friburgo	60 539	0.4%	68 588	5.3%	21	38	55%
Itaguaí	28 016	0.2%	31 609	4.6%	8	13	62%
Valença	10 297	0.3%	11 540	4.5%	10	15	67%
S. J. de Meriti	64 607	0.2%	76 891	4.4%	20	33	61%
Rio Bonito	22 251	0.5%	35 453	4.4%	11	17	65%
Itaboraí	27 800	0.3%	37 075	4.3%	20	34	59%
Barra do Piraí	18 436	0.5%	21 239	4.3%	10	16	63%
S. Ant de Padua	9 234	0.7%	10 540	4.2%	10	16	63%
Itaperuna	18 810	0.6%	22 123	3.8%	16	20	80%
Campos dos Goit.	91 651	0.3%	109 388	2.6%	38	109	35%
S. Fr. de Itabapoana	3 395	0.3%	4 204	2.3%	8	10	80%
Total	3 200 802	0.7%	3 670 408	8.8%	750	1874	40%

Table 2: Fuel wholesale and retail prices and margins (in R$)

	Observations	Mean	St. Deviation	Min	Max
Ethanol retail price	266,030	1.510	0.331	0.600	2.879
Ethanol wholesale price	154,185	1.253	0.338	0.278	2.527
Ethanol margin	154,185	0.249	0.133	-0.927	0.964
Gasoline retail price	286,126	2.279	0.332	1.299	3.119
Gasoline wholesale price	198,866	2.015	0.298	1.140	2.846
Gasoline margin	198,866	0.258	0.104	-0.747	1.469

Table 3: Gasoline and Ethanol Average Prices by Year in the State of Rio de Janeiro (in R$)

	Ethanol Price	Gasoline Price	Ethanol Price/ Gasoline Price	Frequency of Ethanol pr. < 0.7 Gasoline pr.
2002	1.06	1.71	0.62	0.78
2003	1.40	2.12	0.66	0.60
2004	1.30	2.11	0.61	0.76
2005	1.56	2.37	0.66	0.71
2006	1.88	2.60	0.72	0.37
2007	1.70	2.57	0.66	0.66

Table 4: Distributors' Fuel Sales, in cubic meters, and size of fleet in the State of Rio de Janeiro

	Gasoline Sales (a)	Ethanol Sales (b)	Gasoline Fleet (c)	Ethanol Fleet (d)	Flex Fleet (e)	(a)/(c)	(b)/[(d)+(e)]
2001	1,772,337	155,572	2,424,674	471,053	-	0.73	0.33
2002	1,971,934	157,567	2,606,238	473,434	-	0.76	0.33
2003	1,764,595	98,178	2,775,071	478,060	-	0.64	0.21
2004	1,848,172	109,817	2,879,902	476,632	23,561	0.64	0.22
2005	1,739,319	180,528	2,958,560	475,307	84,297	0.59	0.32
2006	1,660,803	224,255	3,016,335	473,880	188,271	0.55	0.34
2007	1,635,152	359,404	3,098,499	472,670	335,629	0.53	0.44

Table 5: Effect of flex car penetration on gasoline price and margin

	Gasoline price (p_g)				Gasoline margin ($p_g - c_g$)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
% flex cars (θ)	5.270***	-0.384***	-0.274***	-0.205***	0.458***	-0.428***	-0.305***	-0.279***
	(0.162)	(0.0744)	(0.0263)	(0.0294)	(0.0379)	(0.0518)	(0.0216)	(0.0262)
gdp per capita				0.00109***				0.000411***
				(0.000138)				(0.000124)
stations/car				-0.000211***				-0.000105***
				(0.0000213)				(0.0000167)
hotels/km2				0.0545*				0.0434*
				(0.0243)				(0.0206)
constant	1.480***	1.103***	1.097***	1.100***	0.171***	0.143***	0.141***	0.140***
	(0.00431)	(0.00679)	(0.00551)	(0.00736)	(0.00105)	(0.00407)	(0.00328)	(0.00578)
Month fixed effects	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Station fixed effects	No	No	Yes	Yes	No	No	Yes	Yes
Brand fixed effects	No	No	Yes	Yes	No	No	Yes	Yes
N	280827	280827	280798	272243	195528	195528	195501	189942
R^2	0.388	0.876	0.975	0.975	0.031	0.120	0.701	0.697

Robust standard errors in parentheses, clustered by city-week.
Regressions include month, brand and station fixed effects.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6: Effect of flex car penetration on ethanol price and margin

	Ethanol price (p_a)				Ethanol margin ($p_a - c_a$)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
% flex cars (θ)	5.847***	0.396***	-0.795***	-0.780***	0.0608	-0.000272	-0.351***	-0.370***
	(0.242)	(0.118)	(0.0756)	(0.0901)	(0.0413)	(0.0808)	(0.0632)	(0.0782)
gdp per capita				-0.00183***				0.000601*
				(0.000365)				(0.000290)
stations/car				-0.000175***				0.000162***
				(0.0000364)				(0.0000351)
hotels/km2				0.0637				-0.0532
				(0.0455)				(0.0372)
constant	1.381***	1.036***	1.033***	1.056***	0.248***	0.209***	0.218***	0.205***
	(0.00624)	(0.00898)	(0.00530)	(0.0127)	(0.00116)	(0.00572)	(0.00531)	(0.0110)
Monthly fixed effects	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Station fixed effects	No	No	Yes	Yes	No	No	Yes	Yes
Brand fixed effects	No	No	Yes	Yes	No	No	Yes	Yes
N	261048	261048	261023	252695	151687	151687	151665	146841
R^2	0.236	0.795	0.928	0.928	0.000	0.067	0.358	0.357

Robust standard errors in parentheses, clustered by city-week.
Regressions include month, brand and station fixed effects.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7: Effect of flex car penetration on spread between gasoline and ethanol prices

	Absolute spread ($\lvert p_g - p_a \rvert$)			
	(1)	(2)	(3)	(4)
% flex cars (θ)	-0.351***	-0.509***	0.192***	0.183***
	(0.0602)	(0.0524)	(0.0542)	(0.0543)
gdp per capita				-0.00214***
				(0.000536)
stations/car				-0.000102***
				(0.0000271)
hotels/km2				-0.0598
				(0.0346)
Constant	0.160***	0.0974***	0.0855***	0.129***
	(0.00190)	(0.00333)	(0.00394)	(0.00945)
Month fixed effects	No	Yes	Yes	Yes
Station fixed effects	No	No	Yes	Yes
Brand fixed effects	No	No	Yes	Yes
N	260472	260472	260447	259098
R^2	0.007	0.394	0.529	0.529

Robust standard errors in parentheses, clustered by city-week.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8: The effect of flex cars penetration on fuel prices correlation, I

	product of residuals from tables 5 and 6 (specification 4)		
	(1)	(2)	(3)
% flex cars	0.0000552***	0.0000561***	0.0000712**
	(0.0000115)	(0.0000115)	(0.0000266)
constant	0.00163***	0.00142***	0.00137***
	(0.0000380)	(0.000151)	(0.000323)
Month fixed effects	No	No	Yes
Station fixed effects	Yes	Yes	Yes
Brand fixed effects	No	Yes	Yes

Robust standard errors in parentheses, clustered by city-week.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 9: The effect of flex cars penetration on fuel price correlation, II

	Gasoline price			Ethanol price		
	(1)	(2)	(3)	(4)	(5)	(6)
% Flex	-0.0243***	-0.0198***	-0.0174***	-0.00614	-0.0519***	-0.0217***
	(0.00135)	(0.00132)	(0.00134)	(0.00557)	(0.00490)	(0.00511)
% Flex×Ethanol price	0.0133***	0.0103***	0.00955***			
	(0.000713)	(0.000702)	(0.000699)			
Ethanol price	0.186***	0.165***	0.166***			
	(0.00331)	(0.00320)	(0.00320)			
Gas wholesale price		0.297***	0.297***			
		(0.00751)	(0.00750)			
Gasoline fleet			-0.00447***			
			(0.00110)			
% Flex×Gasoline price				0.000220	0.0185***	0.00910***
				(0.00209)	(0.00184)	(0.00186)
Gas price				0.617***	0.502***	0.522***
				(0.0115)	(0.00968)	(0.00996)
Ethanol wholesale price					0.316***	0.315***
					(0.00418)	(0.00411)
Ethanol fleet						-0.0329***
						(0.00336)
gdp per capita	0.00187***	0.00136***	0.00135***	-0.00277***	-0.00197***	-0.00173***
	(0.000183)	(0.000170)	(0.000171)	(0.000335)	(0.000286)	(0.000284)
stations/car	-0.000241***	-0.000210***	-0.000182***	-0.00000814*	0.0000105**	0.0000188***
	(0.0000272)	(0.0000254)	(0.0000250)	(0.00000381)	(0.00000393)	(0.00000395)
hotels/km2	0.107***	0.101***	0.122***	-0.0139	-0.0407	0.00654
	(0.0321)	(0.0275)	(0.0302)	(0.0390)	(0.0301)	(0.0312)
_cons	1.364***	0.979***	0.992***	0.0997***	0.0132	-0.00481
	(0.0106)	(0.0138)	(0.0138)	(0.0206)	(0.0175)	(0.0179)
N	252145	175424	175424	252145	146543	146543

Robust standard errors in parentheses, clustered by city-week. Regressions include month, brand and station fixed effects.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 10: Structural regressions, separate equations

	Gasoline price				Ethanol price			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	OLS	IV	IV	OLS	OLS	IV	IV
c_G	0.314***	0.455***	0.510***	0.472***				
	(0.00216)	(0.00242)	(0.00376)	(0.00355)				
c_A					0.474***	0.512***	0.538***	0.529***
					(0.00169)	(0.00171)	(0.00230)	(0.00219)
α_F	2.368***	3.510***	0.238	2.635***	0.114***	0.588***	0.0493	0.371***
	(0.122)	(0.118)	(0.343)	(0.323)	(0.0309)	(0.0310)	(0.0610)	(0.0611)
γ_G	1.504***	1.086***	1.105***	1.053***				
	(0.00349)	(0.00469)	(0.00744)	(0.00783)				
γ_A					0.981***	0.822***	0.784***	0.764***
					(0.00411)	(0.00435)	(0.00623)	(0.00612)
γ_F	-0.365***	-1.665***	0.738**	-1.046***	0.713***	0.118***	0.710***	0.390***
	(0.0994)	(0.0963)	(0.275)	(0.259)	(0.0263)	(0.0268)	(0.0538)	(0.0545)
Constant	-0.0347***	0.0655***	-0.00308	0.0683***	0.142***	0.197***	0.187***	0.208***
	(0.00165)	(0.00172)	(0.00217)	(0.00224)	(0.00153)	(0.00161)	(0.00204)	(0.00206)
Market fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
N	175608	171563	166254	162209	135154	131967	122736	119549

Estimation method subsumes that $\beta_G = \beta_A = \beta_F$, normalized to 1.
Standard errors in parentheses. Prices and costs are deflated.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 11: Structural regressions, stacked equations

	(1) OLS	(2) IV	(3) OLS	(4) IV
c_G	0.410***	0.533***	0.535***	0.525***
	(0.00291)	(0.00304)	(0.00461)	(0.00470)
c_A	0.462***	0.496***	0.536***	0.526***
	(0.00126)	(0.00125)	(0.00172)	(0.00163)
α_F	0.0872***	0.625***	-0.00875	0.307***
	(0.0232)	(0.0227)	(0.0456)	(0.0443)
γ_G	1.369***	0.952***	1.071***	0.959***
	(0.00482)	(0.00562)	(0.00997)	(0.0109)
γ_A	1.015***	0.878***	0.790***	0.778***
	(0.00304)	(0.00310)	(0.00465)	(0.00448)
γ_F	0.789***	0.158***	0.770***	0.472***
	(0.0197)	(0.0195)	(0.0401)	(0.0392)
Constant	-0.240***	-0.0474***	-0.201***	-0.0611***
	(0.00509)	(0.00511)	(0.00617)	(0.00641)
Stack: (=1 if gas,	0.187***	0.113***	0.194***	0.131***
2 if ethanol)	(0.00274)	(0.00271)	(0.00336)	(0.00341)
Market fixed effects	No	Yes	No	Yes
N	310488	303265	288725	281502

Estimation method subsumes that $\beta_G = \beta_A = \beta_F$, normalized to 1.
Standard errors in parentheses. Prices and costs are deflated.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 12: Structural regressions, Nonlinear model

	(1) Gasoline price	(2) Ethanol price	(3) Joint equations	(4) Joint equations, restricted
	IV	IV	IV	IV
c_G	0.466***		0.408***	0.5
	(0.00496)		(0.00385)	
c_A		0.527***	0.417***	0.5
		(0.00354)	(0.00241)	
α_G	-0.0272		0.0754	0.0438***
	(0.0254)		(0.0407)	(0.00300)
α_A		0.307	1.576	0.105***
		(0.238)	(0.845)	(0.00944)
α_F	2.480	0.711	1.365*	0.354***
	(2.045)	(0.380)	(0.600)	(0.0250)
β_G	0.998		1.252	0.301***
	(0.935)		(0.657)	(0.0301)
β_A		1.046	4.047	0.270***
		(0.803)	(2.173)	(0.0288)
β_F	1	1	1	1
γ_G	0.980		1.563	0.305***
	(0.918)		(0.818)	(0.0308)
γ_A		0.891	4.036	0.233***
		(0.684)	(2.168)	(0.0248)
γ_F	-1.238	0.424	0.0991	0.838***
	(2.032)	(0.383)	(0.527)	(0.0229)
N	118571	118571	118571	118571

Standard errors in parentheses. Prices and costs are deflated.
All specifications include city fixed effects.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 13: Structural regressions, separate equations, narrow market definition

	Gasoline price				Ethanol price			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	OLS	IV	IV	OLS	OLS	IV	IV
c_G	0.350***	0.519***	0.535***	0.493***				
	(0.00239)	(0.00261)	(0.00425)	(0.00401)				
c_A					0.496***	0.537***	0.555***	0.544***
					(0.00185)	(0.00185)	(0.00263)	(0.00248)
α_F	2.940***	4.109***	1.008**	3.257***	0.0982**	0.657***	0.0999	0.419***
	(0.133)	(0.126)	(0.374)	(0.348)	(0.0349)	(0.0349)	(0.0729)	(0.0729)
γ_G	1.433***	0.945***	1.054***	1.003***				
	(0.00382)	(0.00496)	(0.00847)	(0.00884)				
γ_A					0.908***	0.741***	0.730***	0.718***
					(0.00442)	(0.00462)	(0.00706)	(0.00686)
γ_F	-0.909***	-2.289***	0.0938	-1.541***	0.656***	-0.0235	0.620***	0.311***
	(0.108)	(0.103)	(0.299)	(0.278)	(0.0296)	(0.0300)	(0.0641)	(0.0648)
Constant	-0.0307***	0.0828***	0.000767	0.0752***	0.163***	0.219***	0.202***	0.219***
	(0.00184)	(0.00188)	(0.00246)	(0.00253)	(0.00167)	(0.00175)	(0.00232)	(0.00233)
Market fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
N	150636	146591	136640	132595	114535	111348	97857	94670

Estimation method subsumes that $\beta_G = \beta_A = \beta_F$, normalized to 1.
Standard errors in parentheses. Prices and costs are deflated.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 14: Structural regressions, stacked equations, narrow market definition

	(1) OLS	(2) IV	(3) OLS	(4) IV
c_G	0.444***	0.585***	0.563***	0.554***
	(0.00319)	(0.00331)	(0.00517)	(0.00528)
c_A	0.485***	0.521***	0.552***	0.540***
	(0.00138)	(0.00135)	(0.00195)	(0.00184)
α_F	0.0860**	0.697***	0.0357	0.342***
	(0.0262)	(0.0254)	(0.0543)	(0.0523)
γ_G	1.300***	0.835***	1.011***	0.898***
	(0.00523)	(0.00603)	(0.0112)	(0.0122)
γ_A	0.940***	0.797***	0.737***	0.732***
	(0.00328)	(0.00330)	(0.00526)	(0.00501)
γ_F	0.718***	0.0128	0.688***	0.404***
	(0.0221)	(0.0217)	(0.0476)	(0.0462)
Constant	-0.250***	-0.0389***	-0.206***	-0.0616***
	(0.00562)	(0.00560)	(0.00697)	(0.00719)
Stack: (=1 if gas,	0.202***	0.120***	0.203***	0.138***
2 if ethanol)	(0.00302)	(0.00296)	(0.00380)	(0.00382)
Market fixed effects	No	Yes	No	Yes
N	264904	257681	234240	227017

Estimation method subsumes that $\beta_G = \beta_A = \beta_F$, normalized to 1.
Standard errors in parentheses. Prices and costs are deflated.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 15: Structural regressions, Nonlinear model, narrow market definition

	(1) Gasoline price	(2) Ethanol price	(3) Joint equations	(4) Joint equations, restricted
	IV	IV	IV	IV
c_G	0.495***		0.423***	0.5
	(0.00571)		(0.00457)	
c_A		0.541***	0.417***	0.5
		(0.00405)	(0.00275)	
α_G	-0.0129		0.178	0.0459***
	(0.0173)		(0.124)	(0.00291)
α_A		0.325	2.333	0.0909***
		(0.276)	(1.653)	(0.00803)
α_F	3.039	0.949	2.055	0.367***
	(3.461)	(0.529)	(1.142)	(0.0269)
β_G	1.210		1.645	0.268***
	(1.538)		(1.142)	(0.0285)
β_A		1.016	5.484	0.224***
		(0.858)	(3.882)	(0.0255)
β_F	1	1	1	1
γ_G	1.103		1.950	0.268***
	(1.402)		(1.353)	(0.0287)
γ_A		0.817	5.309	0.191***
		(0.691)	(3.759)	(0.0218)
γ_F	-1.810	0.198	-0.465	0.830***
	(3.400)	(0.515)	(0.970)	(0.0244)
N	94152	94152	94152	94152

Standard errors in parentheses. Prices and costs are deflated.
All specifications include city fixed effects.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 1: Registration of new cars by fuel type — Share in percentage.

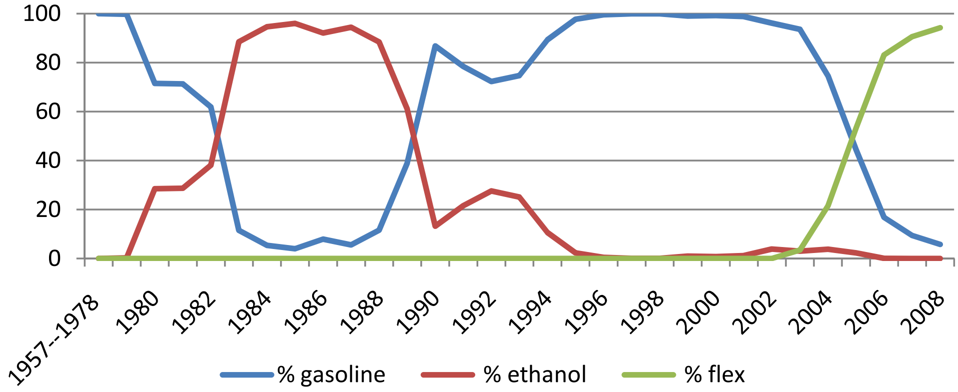


Figure 2: Geographic distribution of sample across Rio de Janeiro state.

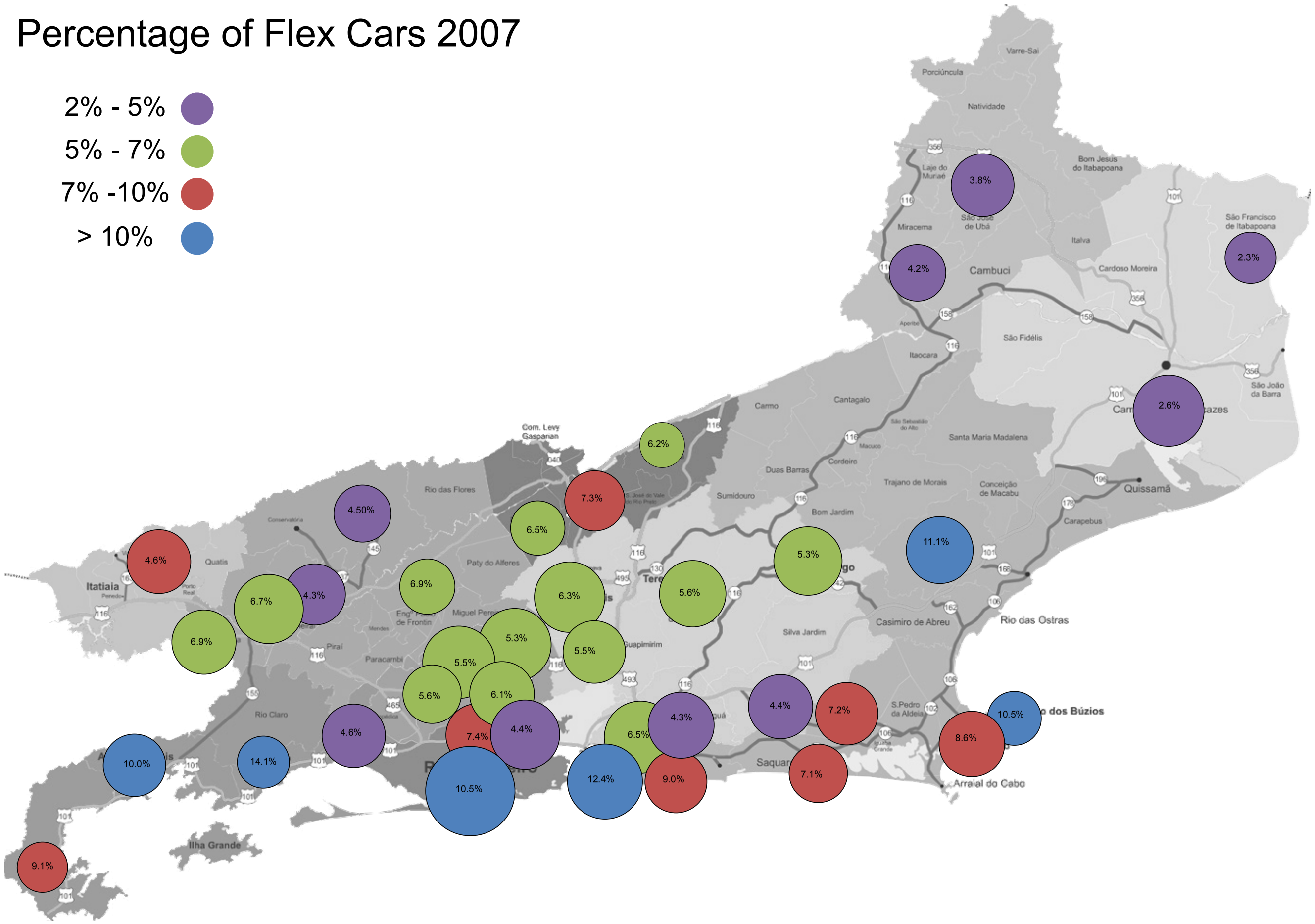


Figure 3: Flex cars and the spread between gasoline and ethanol prices

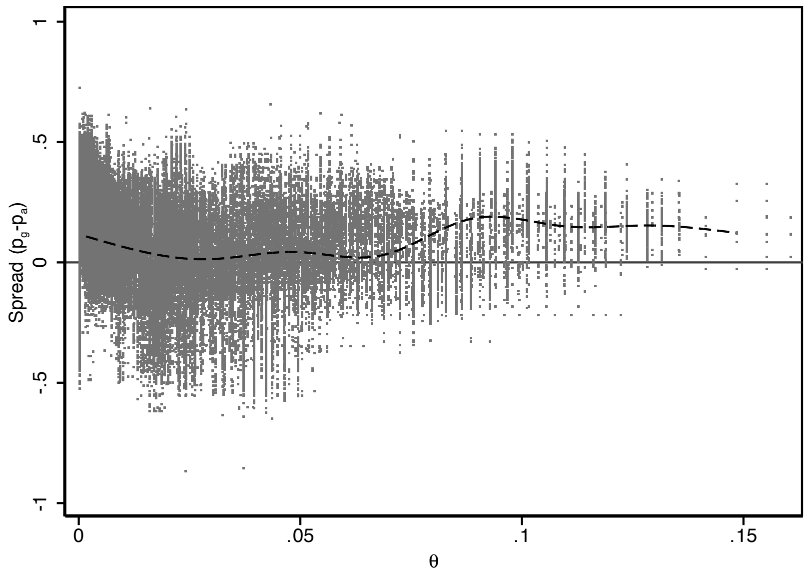


Figure 4: Spread between gasoline and ethanol prices over time

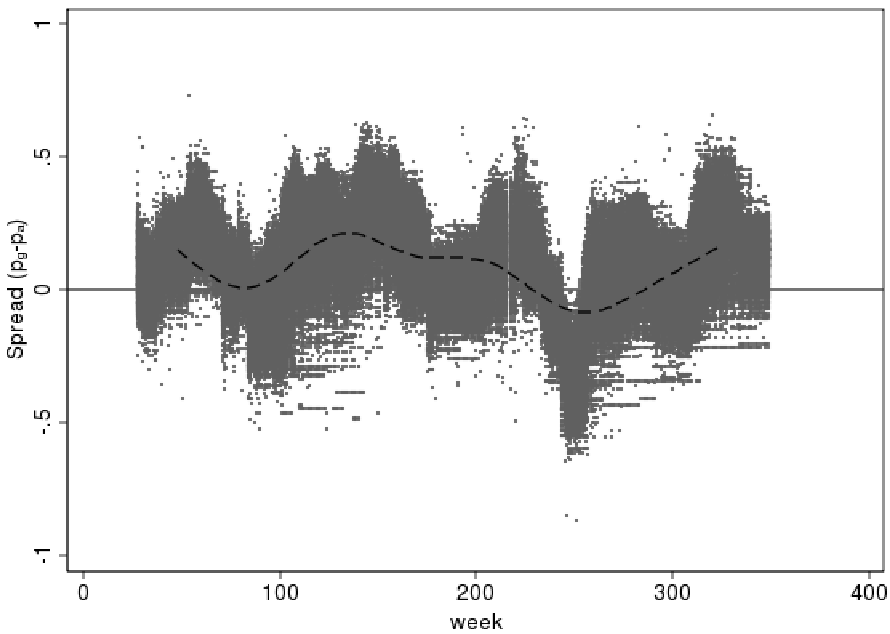


Figure 5: Effect of average ethanol price change in demand for ethanol

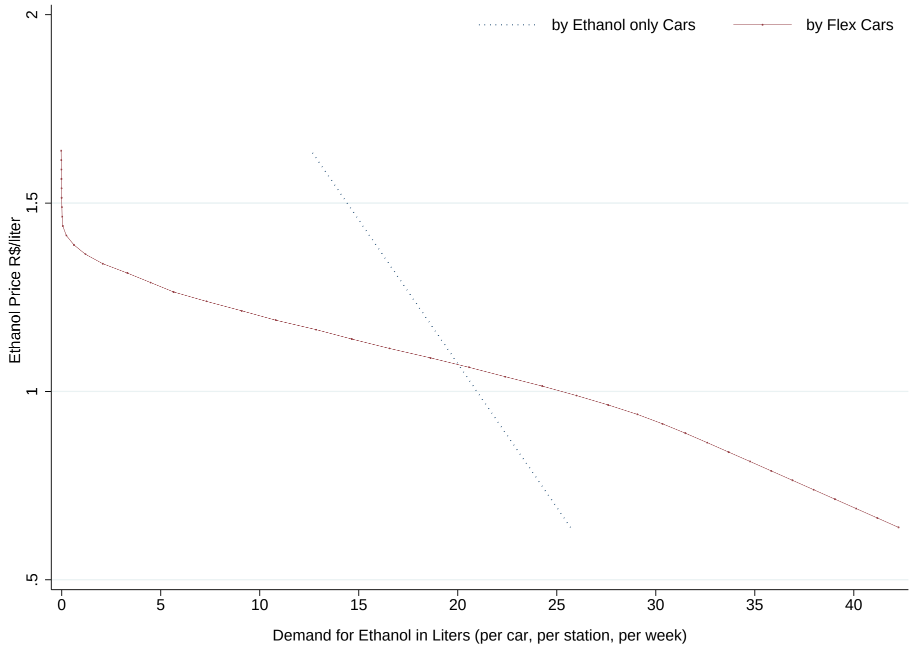


Figure 6: Effect of average ethanol price change in demand for gasoline

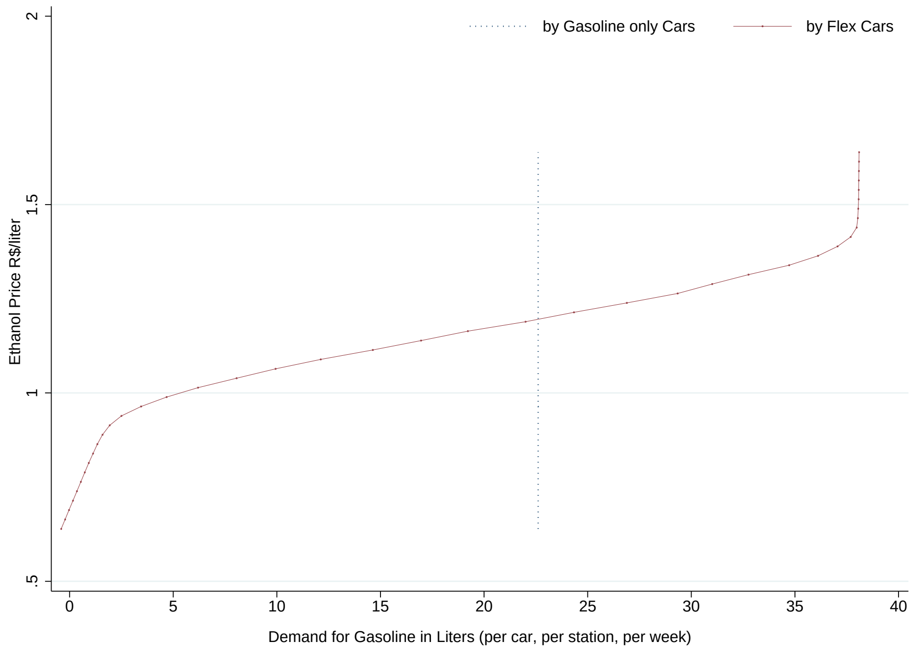


Figure 7: Counterfactual Ethanol Prices

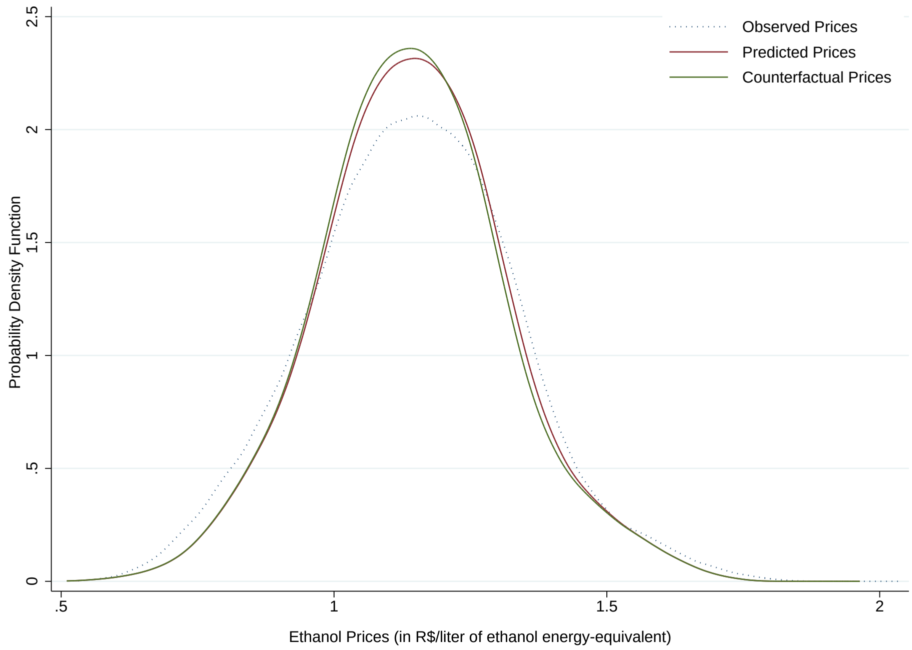
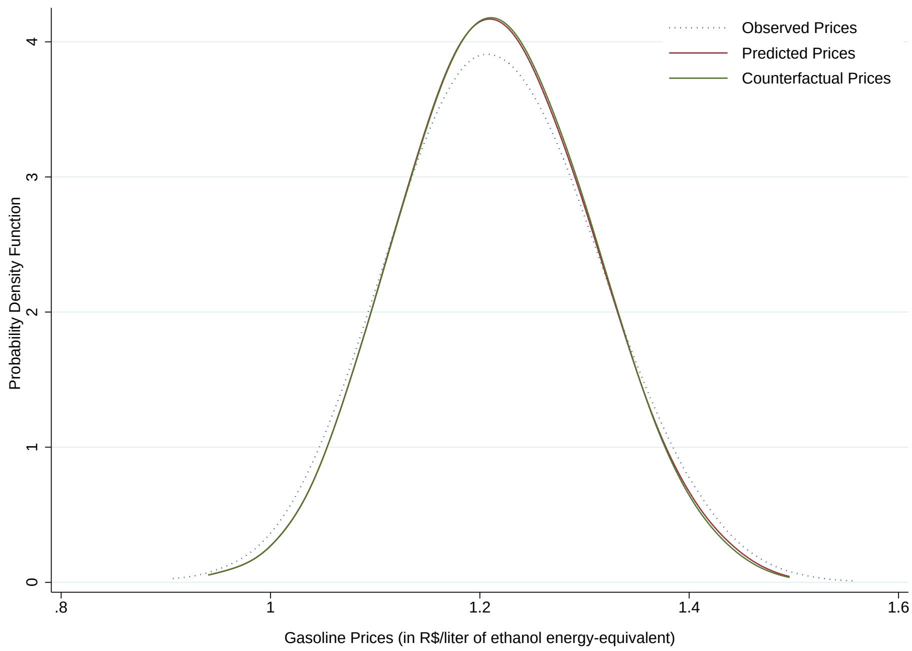


Figure 8: Counterfactual Gasoline Prices



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