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Flex Cars and Competition in Fuel Retail Markets

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Abstract

We study how the diusion of ex (bi-fuel) cars aected competition on ethanol and gasoline retail markets. We propose a model of price competition in which the two fuels become closer substitutes as flex cars penetration grows. We use a large panel of weekly prices at the station level to show that fuel prices and margins have fallen in response to this change. □ is finding is evidence of market power in fuel retail and indicates that innovations that increase consumer choice benfit even those who choose not to adopt them.

Keywords

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

JEL codes

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 (Bresnahan, 1982). 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, flex cars have been available in Brazil since 2003 and have allowed consumers to treat these two fuels as nearly perfect substitutes at the pump. 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. They have become a commercial success: in 2008, 94% of the new cars registered in the country were flex. This innovation provides a source of change in the cross-price elasticity between two products that allow us to directly identify its effect on pricing.

We build a model of strategic price formation to study the impact of the flex car fleet on equilibrium fuel prices. In the model, stations compete by choosing the price of gasoline and ethanol, and consumers treat fuel from different stations as imperfect substitutes, due to location or other idiosyncratic preferences. The model suggests that, in equilibrium, fuel retailers respond strategically to an increase in flex car penetration (that is, an increase in substitutability between products within its own product line) by reducing markups. There is a clear difference in comparison to other differentiated-goods oligopoly models: 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 for consumers who cannot freely switch.

We empirically assess the model using two approaches: the first documents the causal effect of flex-fuel penetration on fuel prices using reduced-form methods; the second provides estimates of the structural parameters of our theoretical model to investigate in more detail how fleet composition affects fuel demand in this market in the short run.

In the reduced-form analysis, we study the impact of the flex car fleet on (i) retail prices and margins; (ii) the spread between gasoline and ethanol; and (iii) on the correlation between gasoline and ethanol prices. 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.

Our reduced-form analysis exploits variation in the flex fuel penetration due to local differences in the speed of fleet renewal, which is mostly driven by cross-sectional variation in income and economic activity. (We account for this possible source of omitted variable bias by adding income as an additional control.) In principle, variation in fuel prices (or rather variation in the expectation about future fuel prices) may also have an effect on fleet renewal; several studies have shown that fuel prices affect demand for automobiles (Busse, Knittel and Zettelmeyer, 2013; Goldberg, 1998; Kahn, 1986; Klier and Linn, 2010; Li, Timmins and Haefen, 2009; Pakes, Berry and Levinsohn, 1993), and even specifically consumer choice between diesel and gasoline vehicles in Europe (Verboven, 2002). To account for the potential endogeneity due to reverse causality, we employ an IV strategy that builds on the recent empirical trade literature (Autor, Dorn and Hanson, 2013; Costa, Garred and Pessoa, 2016), using data on the local presence of car dealerships.

Consistent with the predictions of our model, the results show that fuel stations have significantly reduced ethanol prices and margins: for example, a 10 percentage point increase in the market share of flex cars reduces ethanol prices by approximately 8 cents of BRL. At the same time, while the estimated effects of flex cars on gasoline prices are statistically non-significant in some of our most stringent specifications, we observe a significant negative impact on gasoline margins. A 10 percentage point increase in flex car penetration reduces gasoline margins by 2 cents of BRL. The absolute effects are stronger for ethanol, which is consistent with the fact that ethanol has a smaller market share in the automotive fuel market in Brazil. The augment of the flex car fleet has also increased the spread between gasoline and ethanol prices. This is despite the fact that the correlation between them has increased. Our results provide evidence of market power in fuel retail and that innovations that increase consumer choice may benefit even those consumers who choose not to adopt them.

In the second empirical exercise, we estimate price response functions (Pinkse, Slade and Brett, 2002) across stations within a local market, and study how these are affected by observed variation in the sizes of the three fleets (flex cars, gasoline-only cars, and ethanol-only cars). This is of interest since, given our theoretical model, the price response functions identify several aspects of fuel demand in the short run. 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 no direct information about demand, 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 an increasing literature on the industrial organization of ethanol as automotive fuel and its relation to the gasoline market. Anderson (2012), Corts (2010) and Shriver (2015) are examples of recent studies that investigate the ethanol market in the US.[1] Anderson (2012) studies the demand for the product. Shriver (2015) 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 (2010) 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, 2011; 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

[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 (2013), who employ an opinion poll among flex car owners to document the relevance of motives other than price to choose between fuels.

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.

2 Flex Cars and the Automotive Fuel Market in Brazil

2.1 Ethanol-Powered and Flex Cars

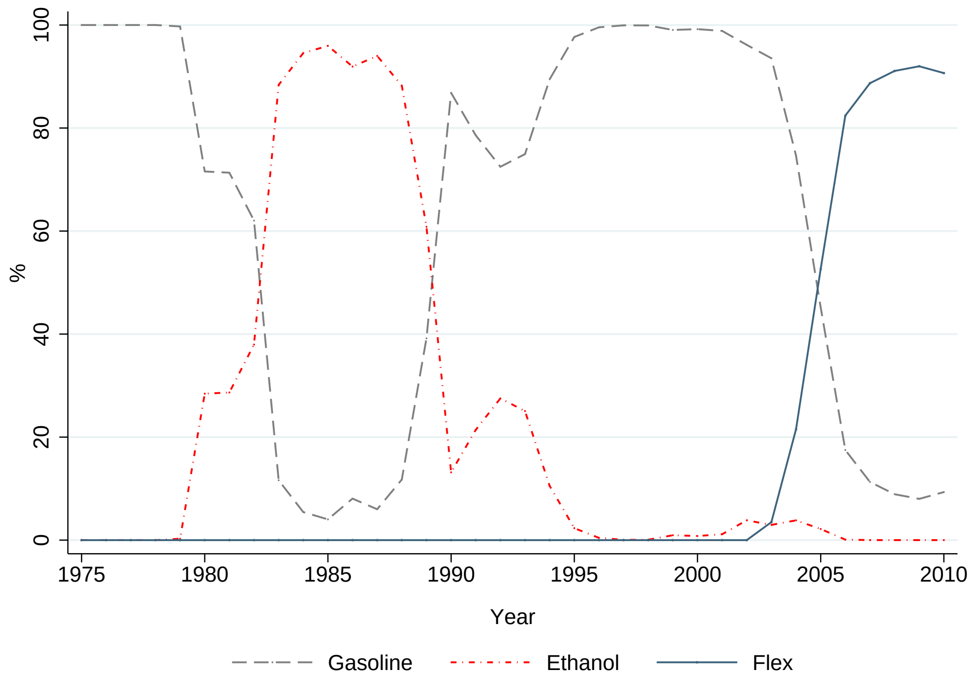
Brazil has a long history of using ethanol as a vehicular fuel. In the 1970s, in response to the first oil crisis, the military government launched the Pró-álcool program to encourage the production of ethanol from sugarcane and stimulate the adoption of ethanol-fueled cars. The program included the use of credit subsidies for ethanol production and set 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 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.

Figure 1: Registration of New Cars by Fuel Type



NOTES: Figure shows shares (in percentage) of new car registrations by fuel type. Diesel and electric cars are not included in the calculations.
Sources: Anfavea.

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 Biocombustv́eis (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 set freely 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 four 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 substitutes. In the main version of the model, we assume gasoline and ethanol are perfect substitutes; in section 3.3, we relax this assumption and discuss the case where the fuels are imperfect 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 car 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-fuelled car owners, ethanol-fuelled car owners, and flex car owners. We call θ 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.) We relax this assumption in Subsection 3.3.

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 McAfee 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

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

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, according to our data, there is substantial variation 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

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

and

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

$\mathbb{1}\{A\}$ 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}, is discontinuous at point $p_{ig} = p_{ia}$. The value of the profit at this point depends on how flex car owners break the tie between fuels, but it always lies between the left-hand and the right-hand limits $\lim_{p_{ig}\nearrow p_{ia}} \pi_i$ and $\lim_{p_{ig}\searrow p_{ia}} \pi_i$, which correspond to the extreme cases that all flex car owners buy ethanol or gasoline when prices are equal, respectively.

Therefore, in order to show that $p_{ig} = p_{ia}$ cannot be optimal, it suffices to show that either the left-hand derivative is negative or the right-hand derivative is positive at that point.

Let x and y be the right and left derivatives, respectively, at that point:

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

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 $c_{ig} \neq c_{ia}$. ■

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

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

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:

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

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.

3.3 Model with Imperfect Substitution

In this subsection, we present an extension of the model that relaxes the assumption of perfect substitutability between fuels for flex car owners. If fuel prices at station i are p_{ia} and p_{ig}, then a fraction $H(p_{ia} - p_{ig})$ of flex cars elect to buy gasoline. H is increasing and ranges for 0 to 1. For analytical convenience, we assume it is smooth and sufficiently well-behaved so the first-order conditions are sufficient to characterize optimal pricing, but otherwise H can be general. (It is reasonable to assume $H(0) = 1/2$, but this will not be used in the proof below).

To preserve symmetry and facilitate comparison with the perfect substitution model, we continue to assume that the quantity of each fuel purchased by each individual is

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

where $j = a, g, f$. As before, $\bar{p}_{-ia}$ and $\bar{p}_{-ig}$ are the average prices of alcohol and gasoline charged by other stations. $\bar{p}_{-if}$ is the average price a flex car owner expects to pay in other stations. In the perfect substitutes case, the latter is the average of the minimum of the prices of the two fuels in each station. In the imperfect substitutes case, this is no longer true, since flex car owners do not necessarily always buy the cheapest fuel.

To preserve generality, we do not assume a specific expression for $\bar{p}_{-if}$. We need only to assume that

$$\bar{p}_{-if} < H\bar{p}_{ig} + (1 - H)\bar{p}_{ia}.$$

The right-hand side is the expected price paid by flex car owners if all of those willing to buy gasoline at station i would also buy gasoline in all other stations and vice versa; that is, there was no substitution across fuels. Economically, the inequality above posits that there is some degree of substitution towards the cheaper fuel.

Under these assumptions, we obtain the following result:

Proposition 3 *For sufficiently small θ, a rise in θ leads to a reduction in the average of the prices chosen optimally the station i, for any increasing function H, and any $\bar{p}_{-if}$, $\bar{p}_{ig}$ and $\bar{p}_{ia}$ that satisfy $\bar{p}_{-if} < H\bar{p}_{ig} + (1 - H)\bar{p}_{ia}$.*

Proof. The profit of firm i is

$$\begin{aligned}\pi_i &= (p_{ia}-c_{ia})\left[\frac{1-\theta}{2}q(p_{ia},\bar{p}_{-ia})+\theta(1-H(p_{ia}-p_{ig}))q(p_{ia},\bar{p}_{-if})\right]\\ &\quad +(p_{ig}-c_{ig})\left[\frac{1-\theta}{2}q(p_{ig},\bar{p}_{-ig})+\theta H(p_{ia}-p_{ig})q(p_{ig},\bar{p}_{-if})\right]-F_i\end{aligned}$$

Assuming the optimal prices are characterized by the first order conditions, we can employ the implicit function theorem to obtain expressions for the derivatives of the optimal prices with respect to θ. These, evaluated at $\theta = 0$, are as follows:

$$\begin{aligned}\left.\frac{\partial}{\partial\theta}p_{ig}\right|_{\theta=0} &= \frac{1}{\beta}\Bigg[H(p_{ia}-p_{ig})q(p_{ig},\bar{p}_{-if})-\frac{1}{2}q(p_{ig},\bar{p}_{-ig})\\ &\quad +(p_{ia}-c_{ia})H'(p_{ia}-p_{ig})q(p_{ia},\bar{p}_{-if})\\ &\quad -(p_{ig}-c_{ig})\left(H'(p_{ia}-p_{ig})q(p_{ig},\bar{p}_{-if})+\beta\left(H(p_{ia}-p_{ig})-\frac{1}{2}\right)\right)\Bigg]\end{aligned}$$

$$\begin{aligned}\left.\frac{\partial}{\partial\theta}p_{ia}\right|_{\theta=0} &= \frac{1}{\beta}\Bigg[(1-H(p_{ia}-p_{ig}))q(p_{ia},\bar{p}_{-if})-\frac{1}{2}q(p_{ia},\bar{p}_{-ia})\\ &\quad -(p_{ig}-c_{ig})(H'(p_{ia}-p_{ig}))q(p_{ig},\bar{p}_{-if})\\ &\quad +(p_{ia}-c_{ia})\left(H'(p_{ia}-p_{ig})q(p_{ia},\bar{p}_{-if})-\beta\left(\frac{1}{2}-H(p_{ia}-p_{ig})\right)\right)\Bigg]\end{aligned}$$

Adding the two expressions, and using the first-order conditions to substitute for the marginal costs, we obtain

$$\left.\frac{\partial}{\partial\theta}\left(\frac{p_{ig}+p_{ia}}{2}\right)\right|_{\theta=0} = \frac{\gamma}{2\beta}[(\bar{p}_{-if}-\bar{p}_{-ig})H(p_{ia}-p_{ig})+(\bar{p}_{-if}-\bar{p}_{-ia})(1-H(p_{ia}-p_{ig}))] < 0.$$

■

In the result above, the condition that θ is small is done for analytical tractability; when θ is large, the formulas used in the proof become much more cumbersome. Focusing on the case of θ near zero allows us to present the key feature of the model in an algebraically simple way: to the extent that flex cars allow some degree of substitution across fuels, introducing this technology leads to lower fuel prices on average, as consumers become more price-sensitive. This conclusion does not depend on perfect substitutability across fuels.

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 38 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 motor vehicles department 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

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

on number of hotels per square km in each municipality (provided 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

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 is shown, 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 related closely 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 north-eastern part of the state, the traditional region of sugarcane production in Rio de Janeiro. Table A.1 in the Appendix shows how the percentage of flex cars changed between 2004 and 2007 in the 38 municipalities in our sample.

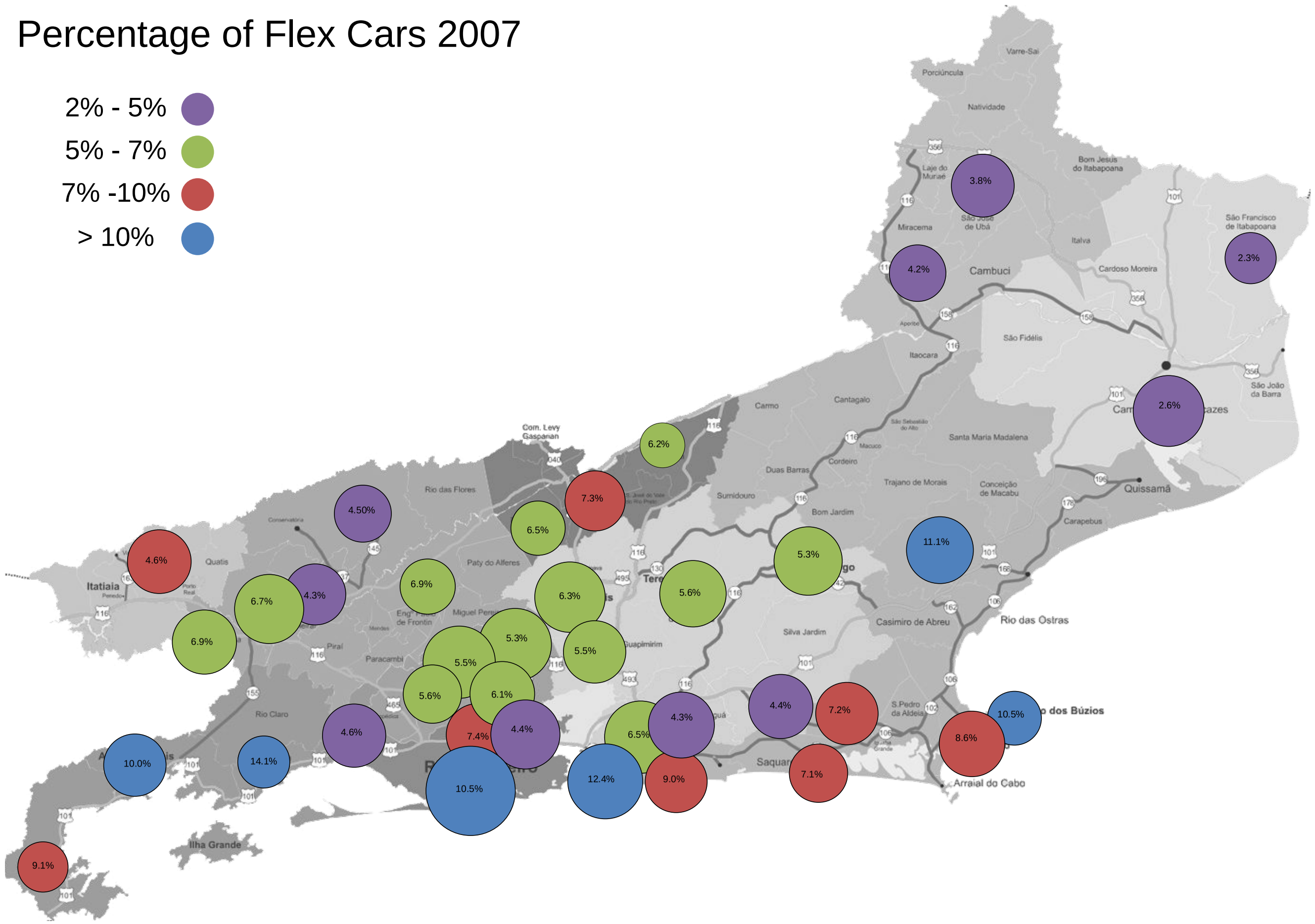
Table 1: Gasoline and Ethanol Average Prices by Year in the State of Rio de Janeiro (in R$)

	Ethanol Price	Gasoline Price	$\frac{Ethanol\ Price}{Gasoline\ Price}$	Share of Sample with Cheaper Ethanol
2002	1.021	1.643	0.62	0.78
2003	1.175	1.774	0.66	0.60
2004	1.014	1.656	0.61	0.76
2005	1.150	1.741	0.66	0.71
2006	1.325	1.837	0.72	0.38
2007	1.161	1.752	0.66	0.66

NOTES: Table presents retail prices for gasoline and ethanol, the ratio between the two prices and the share of stations in our sample that provide ethanol as the cheapest fuel, between 2002 and 2007. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI).
Sources: ANP.

Table 1 presents the evolution of retail prices over time for each type of fuel. All

Figure 2: Geographic Distribution of Sample across Rio de Janeiro State.

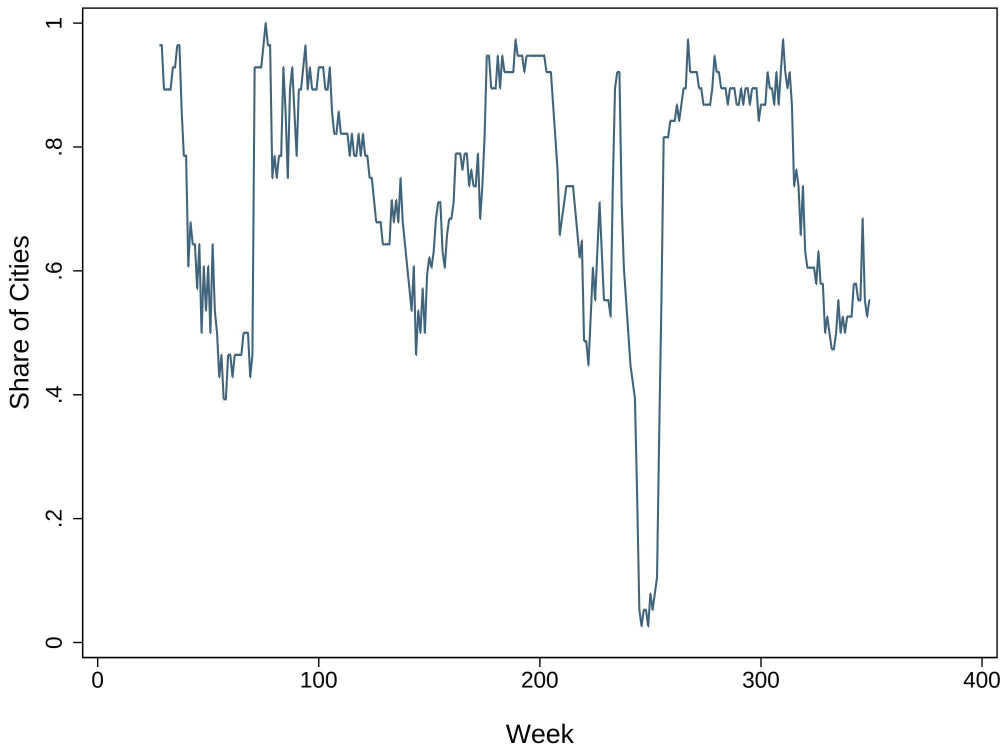


NOTES: Map shows the share of flex cars in the municipalities considered in our sample across the state of Rio de Janeiro in 2007.
Sources: Detran RJ.

prices are expressed in real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). 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. Table A.2 in the Appendix provides other basic statistics on wholesale prices, retail prices. and margins (i.e., the gap between wholesale and retail prices) in our data.

Figure 3 shows the share of markets (defined as a week-city pair) across time in which a single fuel is not the cheapest across all stations. We can see that there is no point in time when a single fuel is the cheapest across all markets. Hence, consumers looking for the cheapest fuel in a given market in our sample may end up choosing either ethanol or gasoline depending on which station they visit. This suggests that both fuels are being used as instruments for price competition between stations during the period we analyze.

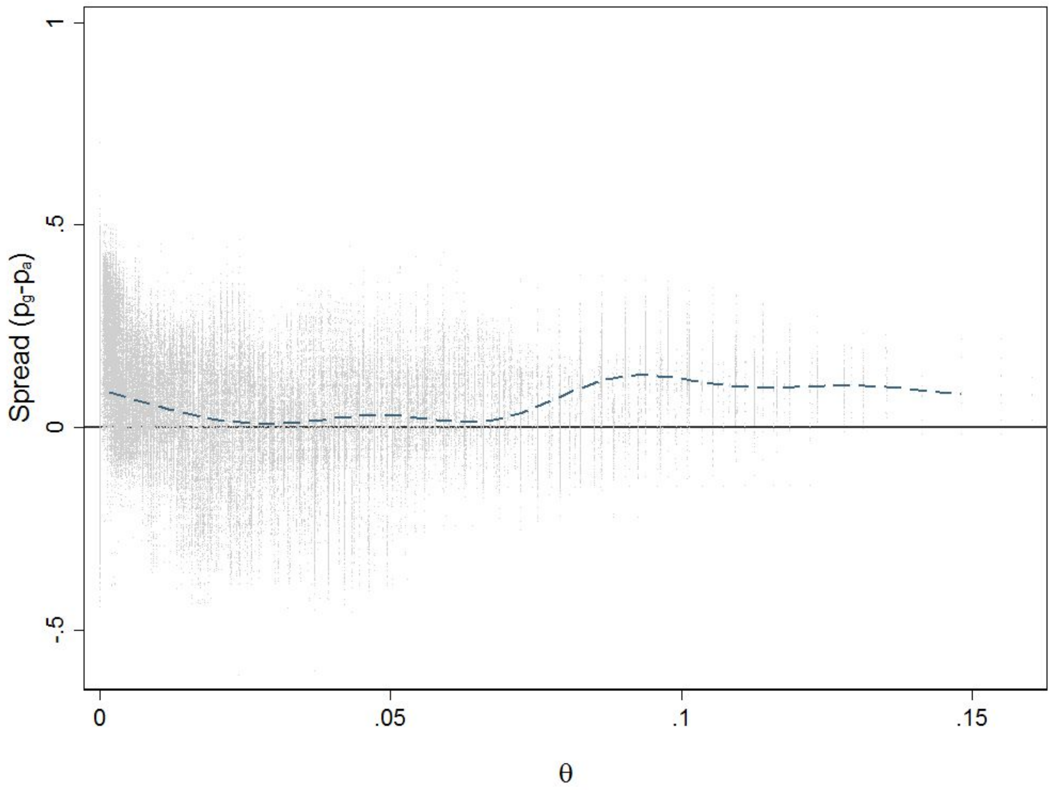
Figure 3: Competition between Gasoline and Ethanol over time



NOTES: Figure plots the share of cities over time in our sample in which both gasoline and ethanol are the cheapest fuel in at least one station, i.e., the share of cities that do not have a single fuel as the cheapest across all stations. Sources: ANP.

Figure 4 presents the scatter plot between the price spread, $p_g - p_a$, and the share of flex cars, θ (with a spline trend estimated with bandwidth 8). Interestingly, we do not find evidence of a negative relationship between the two variables. The figure depicts a clear non-monotonic relationship (the spread being larger for values of θ greater than 6%). Additionally, Figure 5 plots the price spread against time, showing substantial seasonal effects but no strong evidence of price spread reduction over time.

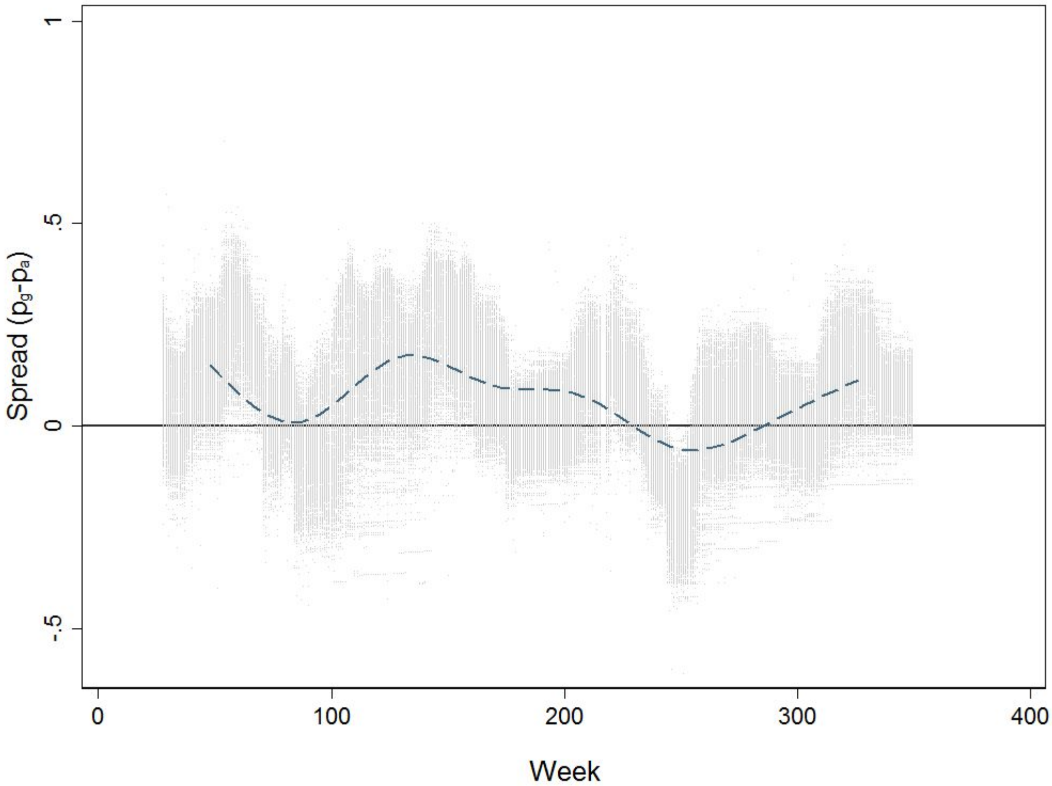
Figure 4: Flex Cars and the Spread between Gasoline and Ethanol Prices



NOTES: Figure plots the price spread between gasoline and ethanol for all the stations in our sample against the share of flex cars in their respective municipalities. It also shows a cubic spline fit of the data. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels.
Sources: ANP and Detran RJ.

Even though 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 2. 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.)

Figure 5: Spread between Gasoline and Ethanol Prices over Time



NOTES: Figure plots the price spread between gasoline and ethanol for all the stations in our sample over time. It also shows a cubic spline fit of the data. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels.
Sources: ANP and Detran RJ.

Table 2: Distributors' Fuel Sales 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)]
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

NOTES: Table shows distributors' consolidated sales volume (cubic meters) in the state of Rio de Janeiro by fuel type between 2002 and 2007, as well as the total car fleet in the state by fuel type. The last two columns compute, respectively, gasoline sales volume per gasoline-powered car and ethanol sales volume per the total of ethanol-powered and flex cars.

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 flex cars (θ) on retail prices and margins for both ethanol and gasoline. Second, we investigate whether θ affected the price spread between gasoline and ethanol. Finally, we investigate the effect of flex car penetration on the correlation between gasoline and ethanol prices.

Our basic estimation equation is:

$$y_{im}^{t} = \delta\theta_{m}^{t} + \zeta' Z_{im}^{t} + \mu_{im}^{t}, \tag{1}$$

where y_{im}^{t} represents ethanol/gasoline prices or margins in station i, municipality m and week t, and θ_{j}^{t} represents the share of flex cars in municipality m at time t. Z_{im}^{t} is a vector containing variables that are potentially important to determine prices at the local level, depending on each regression specification. It includes 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, respectively. It contains station brand fixed effects to capture pricing differences across distinct fuel suppliers[6]. We also control for station fixed effects in order to capture the within correlation between θ and our dependent variable (and not simply how levels of θ are correlated with price/margin levels). Finally, the vector includes monthly fixed effects (for example, January 2003) to account for shocks that may affect fuel prices in the Brazilian territory as a whole.

The error term, μ_{im}^{t}, represents unobserved components that affect prices in a given station. This term might be correlated with unobserved contemporaneous local market shocks that affect price decisions at the station level. Moreover, the decision of purchasing a flex car can be correlated with unobserved local price shocks even after accounting for time and/or market effects.

In order to estimate the "real" effect of flex car penetration on prices and margins, we adopt an instrumental variable (IV) strategy that builds on the literature on trade and labor markets (e.g. Bartik, 1991; Autor, Dorn and Hanson, 2013). Our IV is composed of two terms. The first one is the number of dealers from a particular brand that entered each

[6]Some stations change their brand over time, allowing us to identify the coefficients of these dummies even when we use station fixed effects in our specification.

municipality before 2000 and were still operating by the end of 2015: Fiat, Ford, General Motors, Honda, Mitsubishi, Nissan, Peugeot-Citroen, Renault, Toyota and Volkswagen. (These were the only manufacturers that produced flex cars before early 2008.)[7] This term will suffer from reverse causality if there are anticipation effects of post-2003 shocks that led to differential entry of dealers across municipalities before 2000. The second term is the share of flex car models offered by each vehicle manufacturer in the Brazilian territory.[8] For example, if Ford offered 3 models to Brazilian consumers in January 2000 and only one of them was flex, our measure is equal to 1/3 for Ford at that point in time. This measure should be determined by the Brazilian market as a whole, and should not be influenced by shocks at the municipality level, i.e., local price shocks should not affect this measure (after we control for aggregate time effects).

We then compute the following IV at the municipality-month level:

$$IV_m^t = \sum_k n_{km} \tilde{\theta}_k^t, \tag{2}$$

where n_{km} is the number of dealers of manufacturer k in city m before 2000 that were still active in 2015, and $\tilde{\theta}_k^t$ is the share of flex models offered by brand k in the Brazilian territory in a particular month.

The idea behind the instrument is that drivers adopted flex cars faster in municipalities that were initially more exposed to brands that adopted flex engines more quickly. In fact, the first stage statistics presented in this section indicate a high correlation between IV_m^t and θ_m^t. And after controlling for local market shocks and aggregate time shocks, the instrument should be uncorrelated with the error term in equation 1.

5.1 Effect of Flex Cars on Retail Prices and Margins

According to proposition 2, the penetration of flex cars tightens the competition in the fuel market, decreasing gasoline and ethanol prices as well margins. Tables 3 and 4 present a reduced-form analysis of the impact of flex cars on prices and margins. Panel A of

[7] We obtain this information from the website of the union of automobile dealers of the state of Rio de Janeiro (SINCODIV): http://www.sincodiv-rj.com.br/. We start with a sample of 145 active local dealers on November of 2015 around the state of Rio de Janeiro. Then we are able to extract information on dealers' date of entry from websites such as http://www.cnpjbrasil.com/. By selecting all the dealers that initiated activity before 01/01/2000, we are left with 59 dealers.

[8] We obtain this information from the website of the national association of automobile vehicles manufacturers: http://www.anfavea.com.br/.

both tables consider retail prices, whereas Panel B consider retail margins. Each column adopts a different set of controls. 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.

Table 3 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. The coefficient is still positive after we account for station fixed effects in column (2). However, this is a result drawn by a common upward trend of prices and flex car penetration. In fact, when we introduce time dummies, in column (3), the coefficient becomes negative. The point estimate implies that a 10 percentage point increase in flex car penetration reduces the gasoline price by $1.68/0.7 = 2.4$ cents (of Brazilian Reais) per liter. Considering flag/brand fixed effects and other controls in column (4) reduces the impact to $1.04/0.7 = 1.49$ cents per liter. We then use our IV strategy, together with monthly and station fixed effects. When we compare the results in column (5) to the ones in column (3) - its OLS counterpart - we can see that the effect of θ is stronger, suggesting that our OLS coefficients are biased towards zero. Our first stages are strong, as suggested by the Kleibergen-Paap statistics (significant at all reasonable levels) shown in the lower part of the panels. Column (6), that includes the same additional controls used in column (4), still shows a negative effect of θ on prices, but the effect is not statistically significant.

Panel B shows a negative relationship between θ and gasoline margins in all specifications. Once again, when we compare columns (3) and (5) we can see that the result becomes stronger after we implement our IV strategy. And the result remains significant even after we include all our regressors in column (6). A 10 percentage point increase in flex car penetration reduces gasoline margins by $1.47/0.7 = 2.1$ cents (of Brazilian Reais) per liter.

Table 4 presents the same analysis for the ethanol market. The effects on ethanol prices are similar but more pronounced. In our preferred specification in column (6), a 10 percentage point increase in flex car penetration reduces the ethanol price by 7.5 cents (of Brazilian Reais) per liter. We estimate a negative but significantly larger effect on ethanol retail margins: a reduction of 11.4 cents per liter.

We also perform some robustness analysis. In our model, competition in fuel markets increase with the share of flex cars as long as the same fuel is not the cheapest one

Table 3: Effect of Flex Car Penetration on Gasoline Price and Margin

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) 2SLS	(6) 2SLS
Panel A			**Gasoline Price (p_g)**			
% Flex Cars (θ)	0.578***	0.561***	-0.168***	-0.104***	-0.195***	-0.012
	(0.119)	(0.086)	(0.030)	(0.035)	(0.049)	(0.065)
GDP per Capita				0.001***		0.001***
				(0.000)		(0.000)
Stations/Cars				-0.019***		-0.020***
				(0.003)		(0.003)
Hotels per km^2				-0.024		-0.028
				(0.025)		(0.026)
KP F-Stat (1^{st} Stage)					838	684
$N_{clusters}$	2532	2532	2532	2406	2532	2406
Observations	280778	280746	280746	272190	280746	272190
Panel B			**Gasoline Margin ($p_g - c_g$)**			
% Flex Cars (θ)	-0.062	-0.006	-0.197***	-0.155***	-0.237***	-0.147**
	(0.046)	(0.023)	(0.027)	(0.033)	(0.048)	(0.067)
GDP per Capita				0.001***		0.001***
				(0.000)		(0.000)
Stations/Cars				-0.010***		-0.011***
				(0.002)		(0.003)
Hotels per km^2				-0.022		-0.022
				(0.028)		(0.028)
KP F-Stat (1^{st} Stage)					796	587
$N_{clusters}$	2528	2528	2528	2402	2528	2402
Observations	195491	195457	195457	189894	195457	189894
Monthly Fixed Effects	No	No	Yes	Yes	Yes	Yes
Station Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effects	No	No	No	Yes	No	Yes

NOTES: Table displays estimated effects of shares of flex cars, θ, on gasoline retail prices (Panel A) and gasoline margins (retail minus wholesale prices - Panel B). Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to March 2008. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels. θ represents the share of flex cars in municipality m in a given month. Columns 1-4 estimated by OLS and columns 5-6 by 2SLS. Columns 2-6 include station fixed effects and columns 3-6 include monthly fixed effects as controls. Columns 4 and 6 also include station-brand fixed effects, yearly municipal GDP per capita, the monthly number of stations divided by the car fleet at the municipality level, and the yearly number of hotels per square kilometer in a municipality as controls. Instrument for share of flex cars, IV_m^t, is equal to $\sum_k n_{km}\tilde{\theta}_k^t$, where n_{km} is the number of dealers of car manufacturer k in city m before 2000 that were still active in 2015, and $\tilde{\theta}_k^t$ is the share of flex models offered by manufacturer k in the Brazilian territory in a particular month. Standard errors clustered by city-month in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Effect of Flex Car penetration on Ethanol Price and Margin

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) 2SLS	(6) 2SLS
Panel A			**Ethanol Price (p_a)**			
% Flex Cars (θ)	1.274***	1.031***	-0.658***	-0.627***	-0.750***	-0.755***
	(0.259)	(0.237)	(0.080)	(0.097)	(0.145)	(0.188)
GDP per Capita				-0.001		-0.001
				(0.001)		(0.001)
Stations/Cars				-0.020***		-0.018***
				(0.006)		(0.006)
Hotels per km^2				-0.039		-0.034
				(0.058)		(0.059)
KP F-Stat (1^{st} Stage)					852	722
$N_{clusters}$	2532	2532	2532	2406	2532	2406
Observations	261003	260960	260960	252630	260960	252630
Panel B			**Ethanol Margin ($p_a - c_a$)**			
% Flex Cars (θ)	-0.514***	-0.456***	-0.265***	-0.258***	-0.908***	-1.143***
	(0.052)	(0.042)	(0.081)	(0.100)	(0.113)	(0.153)
GDP per Capita				0.001**		-0.001
				(0.001)		(0.001)
Stations/Cars				0.015***		0.028***
				(0.006)		(0.006)
Hotels per km^2				-0.082*		-0.057
				(0.046)		(0.045)
KP F-Stat (1^{st} Stage)					756	568
$N_{clusters}$	2524	2524	2524	2398	2524	2398
Observations	151659	151615	151615	146789	151615	146789
Monthly Fixed Effects	No	No	Yes	Yes	Yes	Yes
Station Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effects	No	No	No	Yes	No	Yes

NOTES: Table displays estimated effects of shares of flex cars, θ, on ethanol retail prices (Panel A) and ethanol margins (retail minus wholesale prices - Panel B). Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to March 2008. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels. θ represents the share of flex cars in municipality m in a given month. Columns 1-4 estimated by OLS and columns 5-6 by 2SLS. Columns 2-6 include station fixed effects and columns 3-6 include monthly fixed effects as controls. Columns 4 and 6 also include station-brand fixed effects, yearly municipal GDP per capita, the monthly number of stations divided by the car fleet at the municipality level, and the yearly number of hotels per square kilometer in a municipality as controls. Instrument for share of flex cars, IV_m^t, is equal to $\sum_k n_{km}\tilde{\theta}_k^t$, where n_{km} is the number of dealers of car manufacturer k in city m before 2000 that were still active in 2015, and $\tilde{\theta}_k^t$ is the share of flex models offered by manufacturer k in the Brazilian territory in a particular month. Standard errors clustered by city-month in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

across all stations in a given market. Hence, if this characteristic is not present across the markets we are analyzing it is possible that we are simply finding a spurious negative correlation between θ and our price measures. Figure 3 suggests that this is not the case. Nevertheless, we restrict our analysis to markets in which both gasoline and ethanol appear as the cheapest fuel in at least one station and present the results in Tables A.3 and A.4 in the Appendix. They show that the magnitude and sign of the coefficients remain basically unchanged.

Our IV strategy assumes that manufacturers determine their supply of flex cars at the national level. However, big markets such as the city of Rio de Janeiro may have more influence than others in their decision. To verify the robustness of our results, we exclude the city of Rio from our sample and re-estimate equation 1. Tables A.5 and A.6 still show a negative effect of θ on prices and margins. The effect of flex car penetration on gasoline prices is now statistically significant in Panel A of Table A.5, column (6). On the other hand, when we consider ethanol margins in Panel B of Table A.6, the coefficient of θ loses significance in columns (5) and (6).

5.2 Effect of Flex Cars on the Spread between Gasoline and Ethanol Prices

We now investigate the empirical relationship between flex cars and the spread between gasoline and ethanol prices ($p_g - p_a$). Although figure 4 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 5 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 time fixed effects, the coefficient becomes positive and statistically significant. Hence, our linear regressions suggest a positive and significant impact of flex car penetration on $|p_g - p_a|$ even though our non-parametric analysis does not predict a clear monotonic impact. In sum, we fail to find strong evidence that the spread between gasoline and ethanol is decreasing with a faster penetration of flex cars.

Table 5: Effect of Flex Car Penetration on Spread between Gasoline and Ethanol Prices

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) 2SLS	(6) 2SLS
			Absolute Spread ($\lvert p_g - p_a \rvert$)			
% Flex Cars (θ)	-0.609***	-0.509***	0.216***	0.166**	0.351***	0.368***
	(0.095)	(0.099)	(0.065)	(0.080)	(0.100)	(0.140)
GDP per Capita				-0.001		-0.001
				(0.001)		(0.001)
Stations/Cars				-0.005		-0.008*
				(0.005)		(0.005)
Hotels per km^2				-0.067		-0.075
				(0.048)		(0.047)
KP F-Stat (1^{st} Stage)					839	723
$N_{clusters}$	2532	2532	2532	2406	2055	2406
Observations	260427	260383	260383	252076	219182	252076
Monthly Fixed Effects	No	No	Yes	Yes	Yes	Yes
Station Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effects	No	No	No	Yes	No	Yes

NOTES: Table displays estimated effects of shares of flex cars, θ, on absolute retail price spreads (retail gasoline prices minus retail ethanol prices). Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to March 2008. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels. θ represents the share of flex cars in municipality m in a given month. Columns 1-4 estimated by OLS and columns 5-6 by 2SLS. Columns 2-6 include station fixed effects and columns 3-6 include monthly fixed effects as controls. Columns 4 and 6 also include station-brand fixed effects, yearly municipal GDP per capita, the monthly number of stations divided by the car fleet at the municipality level, and the yearly number of hotels per square kilometer in a municipality as controls. Instrument for share of flex cars, IV_m^t, is equal to $\sum_k n_{km}\tilde{\theta}_k^t$, where n_{km} is the number of dealers of car manufacturer k in city m before 2000 that were still active in 2015, and $\tilde{\theta}_k^t$ is the share of flex models offered by manufacturer k in the Brazilian territory in a particular month. Standard errors clustered by city-month in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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. 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 3 and 4 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 3 and 4 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 A.7 in the Appendix presents the results of this regression. We consider two specifications: the first one is an OLS regression considering all our regressors (residuals of the regressions in column (4), Panel A of Tables 3 and 4); in the second, we implement our IV strategy (residuals of the regressions in column (6), Panel A of Tables 3 and 4). In both specifications, we find that flex car penetration has a positive effect on price covariance. The effect, however, is only significant when we consider our IV strategy.

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. therefore, the demand for fuel from a vehicle of type j from station i in market m is

$$q_{ij}^t = \alpha_{mj} - \beta_j p_{ij}^t + \gamma_j \bar{p}_{ij}^t, \tag{3}$$

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

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

$$\begin{aligned} p_{ig}^t = \frac{1}{2}c_{ig}^t &+ \mathbb{I}\{p_{ig}^t > p_{ia}^t\}\left[\frac{\alpha_{mg}}{2\beta_g} + \frac{\gamma_g}{2\beta_g}\bar{p}_{ig}^t\right] \\ &+ \mathbb{I}\{p_{ig}^t < p_{ia}^t\}\left[\frac{\theta_g^t \alpha_{mg} + \theta_f^t \alpha_{mf} + \theta_g^t \gamma_g \bar{p}_{ig}^t + \theta_f^t \gamma_f \bar{p}_{if}^t}{2(\theta_g^t \beta_g + \theta_f^t \beta_f)}\right] + \epsilon_{ig}^t, \end{aligned} \tag{4}$$

$$\begin{aligned} p_{ia}^t = \frac{1}{2}c_{ia}^t &+ \mathbb{I}\{p_{ia}^t > p_{ig}^t\}\left[\frac{\alpha_{ma}}{2\beta_a} + \frac{\gamma_a}{2\beta_a}\bar{p}_{ia}^t\right] \\ &+ \mathbb{I}\{p_{ia}^t < p_{ig}^t\}\left[\frac{\theta_a^t \alpha_{ma} + \theta_f^t \alpha_{mf} + \theta_a^t \gamma_a \bar{p}_{ia}^t + \theta_f^t \gamma_f \bar{p}_{if}^t}{2(\theta_a^t \beta_a + \theta_f^t \beta_f)}\right] + \epsilon_{ia}^t. \end{aligned} \tag{5}$$

ϵ_{ij}^t may be interpreted as an unobserved (to the econometrician) i.i.d. cost shock that is fuel-station-time specific. [9]

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:

[9] 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.

$$p_{ig}^t = \frac{1}{2}c_{ig}^t + \mathbb{1}\{p_{ig}^t > p_{ia}^t\}\left[\frac{\alpha_{mg}}{2} + \frac{\gamma_g}{2}\bar{p}_{ig}^t\right] + \mathbb{1}\{p_{ig}^t < p_{ia}^t\}\left[\frac{\theta_g^t\alpha_{mg} + \theta_f^t\alpha_{mf} + \theta_g^t\gamma_g\bar{p}_{ig}^t + \theta_f^t\gamma_f\bar{p}_{if}^t}{2(\theta_g^t + \theta_f^t)}\right] + \epsilon_{ig}^t, \tag{6}$$

$$p_{ia}^t = \frac{1}{2}c_{ia}^t + \mathbb{1}\{p_{ia}^t > p_{ig}^t\}\left[\frac{\alpha_{ma}}{2} + \frac{\gamma_a}{2}\bar{p}_{ia}^t\right] + \mathbb{1}\{p_{ia}^t < p_{ig}^t\}\left[\frac{\theta_a^t\alpha_{ma} + \theta_f^t\alpha_{mf} + \theta_a^t\gamma_a\bar{p}_{ia}^t + \theta_f^t\gamma_f\bar{p}_{if}^t}{2(\theta_a^t + \theta_f^t)}\right] + \epsilon_{ia}^t. \tag{7}$$

We report estimates both for the case where β coefficients are assumed to be identical and for the more general non-linear 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 1,250 square kilometers; 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.[10]

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 $\mathbb{1}\{p_{ij} < p_{ik}\}$ are endogenous.

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 $\mathbb{1}\{c_{ij}^t < c_{ik}^t\}$ for $\mathbb{1}\{p_{ij}^t < p_{ik}^t\}$, etc. We also instrument for the share of flex cars using the variable IV_m^t described in the previous section.

In addition, we estimate the model with market fixed effects to account for unobserved

[10] 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 large 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.

variation across markets. We use municipality-specific fixed effects to avoid the computational burden of estimating the non-linear model with a large number of 4-digit CEP fixed effects.

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.

Table 6 presents the results of estimating the linear model separately and jointly, respectively. Panel A show the results of the linear model, while Panel B presents the results of the non-linear estimation. In columns (1), (2), and (3) 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 0.35 and 0.54 among all specifications. (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* and, 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. In our linear model in panel A, we estimate that γ_F is 37% smaller than β_F, γ_A is 12% smaller than β_A, and γ_G statistically equal to β_G (these numbers are similar to the ones in the non-linear model); our estimated demands are inelastic. This finding suggests that gasoline and ethanol car owners are less responsive to fluctuations in prices across fuel stations within the market.

Table A.8 presents the results we obtain if we use the narrow market definition. It shows that the coefficients in our preferred specification (column 4) have similar magnitudes to the ones presented in Table 6. Our findings with respect to pass-through are also similar in this case.

Table 6: Structural Estimation

	(1)	(2)	(3)	(4)
Panel A	**Linear Model** - $\beta_A = \beta_G = \beta_F = 1$			
c_G	0.455***		0.475***	0.5
	(0.016)		(0.012)	
c_A		0.532***	0.508***	0.5
		(0.010)	(0.008)	
α_G	0.198***		0.151***	0.162***
	(0.026)		(0.017)	(0.021)
γ_G	1.050***		1.058***	1.008***
	(0.041)		(0.029)	(0.016)
α_A			0.378***	0.374***
			(0.014)	(0.015)
γ_A			0.857***	0.878***
			(0.019)	(0.012)
α_F	-3.594**	0.548*	0.320	0.564**
	(1.799)	(0.305)	(0.254)	(0.261)
γ_F	4.322***	0.593**	0.829***	0.625***
	(1.448)	(0.272)	(0.226)	(0.238)
Panel B	**Non-Linear Model** - $\beta_F = 1$			
c_G	0.351***		0.543***	0.5
	(0.029)		(0.014)	
c_A		0.496***	0.473***	0.5
		(0.008)	(0.012)	
α_G	0.354***		0.170***	0.229***
	(0.041)		(0.012)	(0.040)
γ_G	1.112***		1.049***	1.073***
	(0.021)		(0.012)	(0.019)
α_A		0.487***	0.277***	0.375***
		(0.014)	(0.019)	(0.049)
γ_A		1.022***	1.046***	0.988***
		(0.013)	(0.015)	(0.035)
α_F	-3.171***	0.595***	0.431***	0.608***
	(0.024)	(0.011)	(0.018)	(0.021)
γ_F	4.726***	0.601***	0.911***	0.644***
	(0.030)	(0.012)	(0.021)	(0.017)
β_A		1.174***	1.025***	1.085***
		(0.016)	(0.034)	(0.022)
β_G	1.008***		1.104***	1.095***
	(0.003)		(0.019)	(0.027)
Single Equation: Ethanol	No	Yes	No	No
Single Equation: Gasoline	Yes	No	No	No
Restricted Model	No	No	No	Yes

NOTES: Table displays estimated parameters from the structural model. Columns 1 and 2 in Panel A (Panel B) display separate estimations of equations 6 and 7 (equations 4 and 5), respectively, by 2SLS (by GMM). Columns 3 and 4 in Panel A (Panel B) display joint estimations of equations 6 and 7 (equations 4 and 5) by 2SLS (by GMM), and in column 4 the coefficients of wholesale prices are restricted to be equal to 0.5. Estimations consider a station i located in municipality m in week t as the unit of analysis, from January 2002 to March 2008 [Observations = 117,941]. The relevant market for each fuel station is the 4-digit postal code (CEP). All prices are expressed in BRL real terms, deflated by the monthly IPCA, and the price of gasoline is multiplied by a factor of 0.7. Instruments used in the estimations consider only c_{ig}, c_{ia}, θ_a^t (share of ethanol cars in a municipality), θ_g^t (share of gasoline cars in a municipality), IV_m^t (defined in Equation 2) and municipality fixed effects, as well as different interactions of these terms. For example, we use $\mathbb{1}\{c_{ia}^t < c_{ig}^t\} IV_m^t$ as an instrument for $\mathbb{1}\{p_{ia}^t < p_{ig}^t\}\theta_f^t$. Bootstrapped standard errors clustered by city-month in parentheses [$N_{clusters}$ = 2,443]. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

6.1 Exploring the Demand Estimates

In this section, we report two counter-factual simulations that exploit our demand estimates. 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 calculate the total demand for each fuel delivered by our model from equation 3 above using the results from column (4), Panel B, of Table 6.[11] Next, we multiply the model demand quantities by two constants (one for ethanol and one for gasoline) such that the model demand for gasoline and ethanol match total fuel sales in the state of Rio de Janeiro in 2007 (per station, per week[12]), assuming that the sample of stations in our data set is representative of the overall market. The scale factors we obtain according to this method are 80.2 and 43.5 for gasoline and ethanol quantities, respectively.

We then are able to perform two distinct exercises. 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.

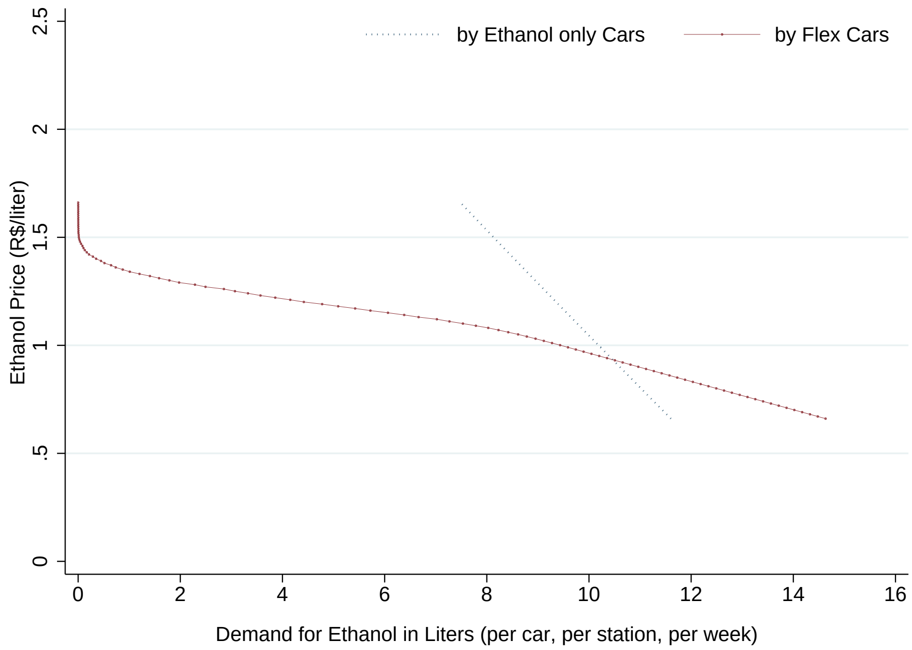
Figures 6 and 7 present the results of our first experiment. These figures show how the average demand (per car, per station, per week) changes in response to a change in the average ethanol price, holding price dispersion fixed. Figure 6 is a standard demand curve, plotting the price and demand for ethanol, while figure 7 presents the effect of the price of ethanol on the demand for gasoline.

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 from ethanol to gasoline. For intermediate prices, some of the flex car owners use ethanol and some use gasoline,

[11] We use the point estimates for all the parameters, except for γ_F. Using the point estimate for this parameter produces gasoline demand quantities from flex car owners that are considerably lower than the demand from gasoline car drivers. Hence, in this section we use the point estimate plus one standard deviation for this parameter.

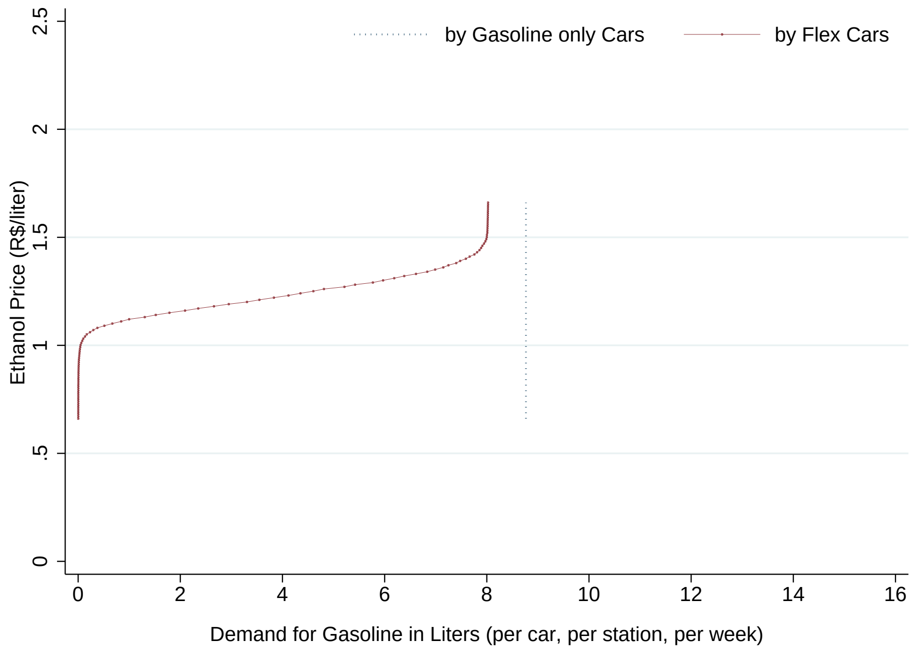
[12] This information comes from ANP.

Figure 6: Effect of Average Ethanol Price Change in Demand for Ethanol



NOTES: Figure presents the average ethanol demand (per car, per station, per week) changes in response to a change in the average ethanol price, holding price dispersion fixed, considering ethanol and flex cars. We obtain the series by using the parameters estimated in Panel B, column (4), of Table 6. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels.
Sources: Authors' calculations from ANP and Detran RJ data.

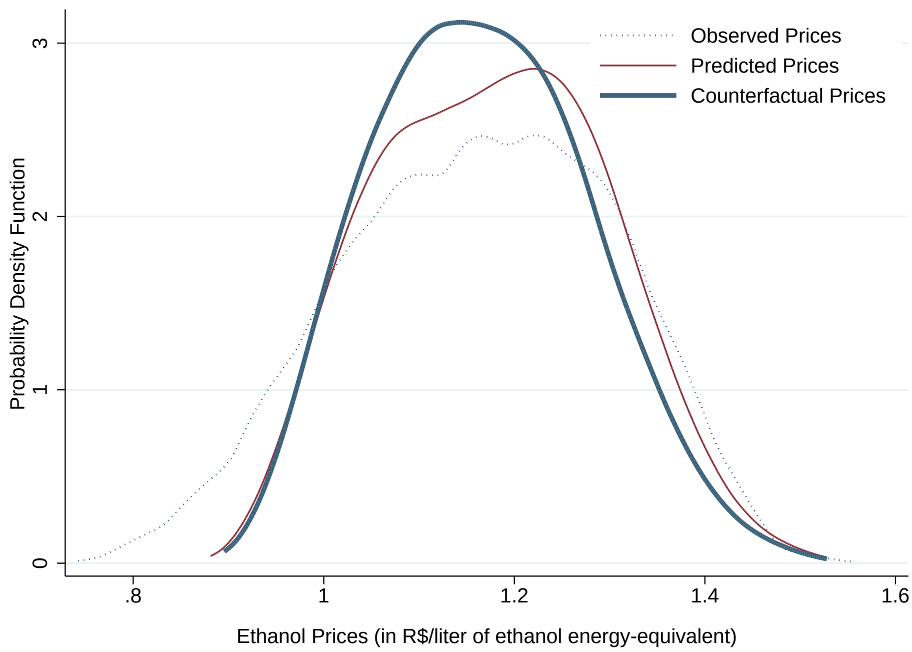
Figure 7: Effect of Average Ethanol Price Change in Demand for Gasoline



NOTES: Figure presents the average gasoline demand (per car, per station, per week) changes in response to a change in the average ethanol price, holding price dispersion fixed, considering gasoline and flex cars. We obtain the series by using the parameters estimated in Panel B, column (4), of Table 6. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels.
Sources: Authors' calculations from ANP and Detran RJ data.

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, which is compatible with the fact that the ethanol car fleet is old and presumably used less intensively.

Figure 8: Counterfactual Ethanol Price

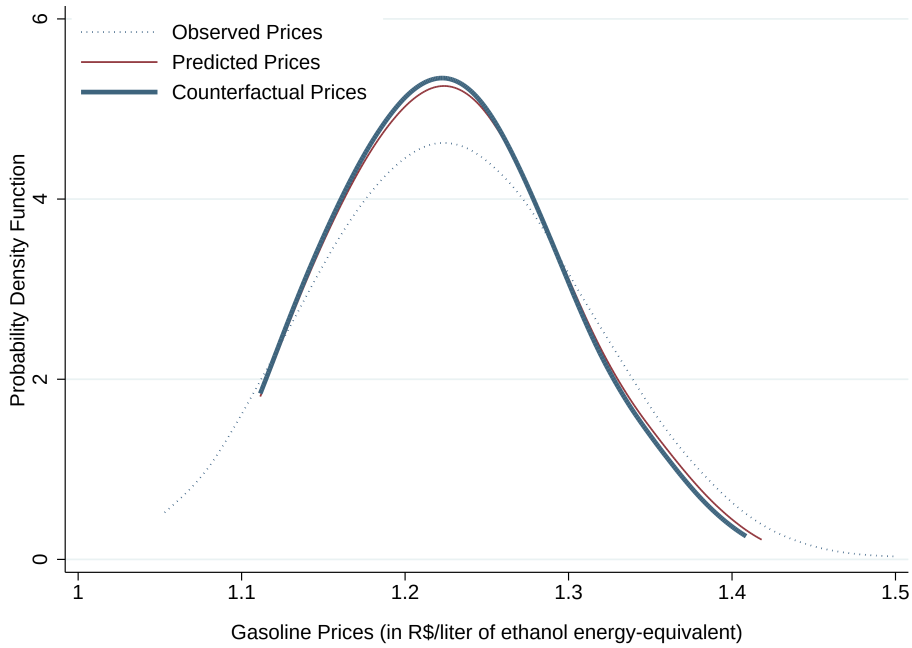


NOTES: Figure shows the observed distribution of ethanol prices in our sample, the predicted (by our model) distribution of ethanol prices and the distribution of gasoline prices arising from a counterfactual exercise in which the share of flex cars goes to 100% in all municipalities. We obtain the predicted and counterfactual exercises by numerically solving the system of best reply equations estimated in Panel B, column (4), of Table 6. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels.
Sources: Authors' calculations from ANP and Detran RJ data.

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 share of flex cars goes to 100% in all municipalities. We then find the new equilibrium prices by numerically solving the system of best reply equations estimated above.

Figures 8 and 9 show our counterfactual, predicted and observed prices for ethanol

Figure 9: Counterfactual Gasoline Price



NOTES: Figure shows the observed distribution of gasoline prices in our sample, the predicted (by our model) distribution of gasoline prices and the distribution of gasoline prices arising from a counterfactual exercise in which the share of flex cars goes to 100% in all municipalities. We obtain the predicted and counterfactual exercises by numerically solving the system of best reply equations estimated in Panel B, column (4), of Table 6. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels.
Sources: Authors' calculations from ANP and Detran RJ data.

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. (Table A.9 in the Appendix shows that average ethanol prices fall by more than 1 cent of Real while average gasoline prices remain basically unchanged.) 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 show 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. A 10 percentage point increase in the share of flex cars decrease ethanol and gasoline energy equivalent prices per liter by approximately 8 cents and 3 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 retail price gap as well as the retail price correlation between the two fuels has increased with the adoption 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 show 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 results show that new technologies that increase consumer choice may benefit even those consumers who choose not to adopt them. This is an important potential welfare-improving channel to be taken into consideration by policy makers who aim to incentivize the use of new technologies, especially when considering dissemination of alternative automobile fuels, such as hydrogen and electricity.

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Appendix A - Other Figures and Tables

Table A.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%

NOTES: Table shows stocks and percentages of flex cars by municipality in the state of Rio de Janeiro, in 2004 and in 2007. It also shows the total number of stations by city in 2010, the average number of stations by municipality in a week in our sample and the ratio between the two measures, i.e., the average percentage of stations sampled weekly by municipality.
Sources: Detran RJ and ANP.

Table A.2: Fuel Wholesale and Retail Prices and Margins (in R$)

	Observations	Mean	St. Deviation	Min	Max
Ethanol Price	265988	1.144	0.189	0.529	2.035
Ethanol Wholesale Price	154158	0.952	0.202	0.223	2.126
Ethanol Margin	154158	0.193	0.105	-0.775	0.817
Gasoline Price	286077	1.734	0.125	1.287	2.287
Gasoline Wholesale Price	198829	1.537	0.095	0.855	2.277
Gasoline Margin	198829	0.198	0.078	-0.557	1.073

NOTES: Table shows usual descriptive statistics for fuel wholesale and retail prices and margins in our sample. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI).
Sources: ANP.

Table A.3: Effect of Flex Car Penetration on Gasoline Price and Margin: Competition

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) 2SLS	(6) 2SLS
Panel A			**Gasoline Price (p_g)**			
% Flex Cars (θ)	0.587***	0.555***	-0.147***	-0.051	-0.223***	-0.014
	(0.127)	(0.094)	(0.031)	(0.036)	(0.048)	(0.065)
GDP per Capita				0.002***		0.002***
				(0.000)		(0.000)
Stations/Cars				-0.020***		-0.020***
				(0.003)		(0.003)
Hotels per km^2				-0.031		-0.033
				(0.026)		(0.026)
KP F-Stat (1^{st} Stage)					809	614
$N_{clusters}$	2055	2055	2055	1974	2055	1974
Observations	238892	238858	238858	232940	238858	232940
Panel B			**Gasoline Margin ($p_g - c_g$)**			
% Flex Cars (θ)	-0.058	-0.021	-0.183***	-0.120***	-0.230***	-0.125*
	(0.045)	(0.026)	(0.028)	(0.035)	(0.047)	(0.068)
GDP per Capita				0.001***		0.001***
				(0.000)		(0.000)
Stations/Cars				-0.011***		-0.011***
				(0.003)		(0.003)
Hotels per km^2				-0.031		-0.031
				(0.031)		(0.031)
KP F-Stat (1^{st} Stage)					740	511
$N_{clusters}$	2052	2052	2052	1971	2052	1971
Observations	167372	167334	167334	163324	167334	163324
Monthly Fixed Effects	No	No	Yes	Yes	Yes	Yes
Station Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effects	No	No	No	Yes	No	Yes

NOTES: Table displays estimated effects of shares of flex cars, θ, on gasoline retail prices (Panel A) and gasoline margins (retail minus wholesale prices - Panel B) excluding from the sample city-week pairs where either gasoline or ethanol is the cheapest fuel in all stations. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to March 2008. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels. θ represents the share of flex cars in municipality m in a given month. Columns 1-4 estimated by OLS and columns 5-6 by 2SLS. Columns 2-6 include station fixed effects and columns 3-6 include monthly fixed effects as controls. Columns 4 and 6 also include station-brand fixed effects, yearly municipal GDP per capita, the monthly number of stations divided by the car fleet at the municipality level, and the yearly number of hotels per square kilometer in a municipality as controls. Instrument for share of flex cars, IV_m^t, is equal to $\sum_k n_{km}\tilde{\theta}_k^t$, where n_{km} is the number of dealers of car manufacturer k in city m before 2000 that were still active in 2015, and $\tilde{\theta}_k^t$ is the share of flex models offered by manufacturer k in the Brazilian territory in a particular month. Standard errors clustered by city-month in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.4: Effect of Flex Car Penetration on Ethanol Price and Margin: Competition

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) 2SLS	(6) 2SLS
Panel A			**Ethanol Price (p_a)**			
% Flex Cars (θ)	1.190***	0.927***	-0.601***	-0.547***	-0.676***	-0.645***
	(0.276)	(0.258)	(0.085)	(0.105)	(0.147)	(0.200)
GDP per Capita				-0.000		-0.000
				(0.001)		(0.001)
Stations/Cars				-0.013**		-0.012*
				(0.006)		(0.006)
Hotels per km^2				-0.042		-0.038
				(0.063)		(0.064)
KP F-Stat (1^{st} Stage)					836	650
$N_{clusters}$	2055	2055	2055	1974	2055	1974
Observations	219786	219741	219741	214048	219741	214048
Panel B			**Ethanol Margin ($p_a - c_a$)**			
% Flex Cars (θ)	-0.511***	-0.497***	-0.277***	-0.260***	-0.830***	-1.101***
	(0.056)	(0.046)	(0.080)	(0.100)	(0.113)	(0.164)
GDP per Capita				0.002**		-0.001
				(0.001)		(0.001)
Stations/Cars				0.022***		0.033***
				(0.006)		(0.006)
Hotels per km^2				-0.118**		-0.096*
				(0.052)		(0.051)
KP F-Stat (1^{st} Stage)					677	471
$N_{clusters}$	2048	2048	2048	1967	2048	1967
Observations	128327	128276	128276	124819	128276	124819
Monthly Fixed Effects	No	No	Yes	Yes	Yes	Yes
Station Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effects	No	No	No	Yes	No	Yes

NOTES: Table displays estimated effects of shares of flex cars, θ, on ethanol retail prices (Panel A) and ethanol margins (retail minus wholesale prices - Panel B) excluding from the sample city-week pairs where either gasoline or ethanol is the cheapest fuel in all stations. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to March 2008. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels. θ represents the share of flex cars in municipality m in a given month. Columns 1-4 estimated by OLS and columns 5-6 by 2SLS. Columns 2-6 include station fixed effects and columns 3-6 include monthly fixed effects as controls. Columns 4 and 6 also include station-brand fixed effects, yearly municipal GDP per capita, the monthly number of stations divided by the car fleet at the municipality level, and the yearly number of hotels per square kilometer in a municipality as controls. Instrument for share of flex cars, IV_m^t, is equal to $\sum_k n_{km}\tilde{\theta}_k^t$, where n_{km} is the number of dealers of car manufacturer k in city m before 2000 that were still active in 2015, and $\tilde{\theta}_k^t$ is the share of flex models offered by manufacturer k in the Brazilian territory in a particular month. Standard errors clustered by city-month in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.5: Effect of Flex Car Penetration on Gasoline Price and Margin: State Capital

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) 2SLS	(6) 2SLS
Panel A			**Gasoline Price (p_g)**			
% Flex Cars (θ)	0.896***	0.639***	-0.162***	-0.123***	-0.437***	-0.365***
	(0.087)	(0.059)	(0.039)	(0.042)	(0.119)	(0.130)
GDP per Capita				0.002***		0.001***
				(0.000)		(0.000)
Stations/Cars				-0.021***		-0.021***
				(0.003)		(0.003)
Hotels per km^2				-0.004		-0.005
				(0.024)		(0.024)
KP F-Stat (1^{st} Stage)					138	116
$N_{clusters}$	2458	2458	2458	2335	2458	2335
Observations	191139	191123	191123	184455	191123	184455
Panel B			**Gasoline Margin ($p_g - c_g$)**			
% Flex Cars (θ)	0.151***	0.014	-0.202***	-0.166***	-0.409***	-0.364***
	(0.046)	(0.021)	(0.037)	(0.042)	(0.114)	(0.126)
GDP per Capita				0.001***		0.001*
				(0.000)		(0.000)
Stations/Cars				-0.012***		-0.011***
				(0.003)		(0.003)
Hotels per km^2				0.012		0.012
				(0.029)		(0.029)
KP F-Stat (1^{st} Stage)					136	113
$N_{clusters}$	2454	2454	2454	2331	2454	2331
Observations	132274	132263	132263	128148	132263	128148
Monthly Fixed Effects	No	No	Yes	Yes	Yes	Yes
Station Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effects	No	No	No	Yes	No	Yes

NOTES: Table displays estimated effects of shares of flex cars, θ, on gasoline retail prices (Panel A) and gasoline margins (retail minus wholesale prices - Panel B) excluding from the sample the city of Rio de Janeiro (the capital of the state of RJ). Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to March 2008. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels. θ represents the share of flex cars in municipality m in a given month. Columns 1-4 estimated by OLS and columns 5-6 by 2SLS. Columns 2-6 include station fixed effects and columns 3-6 include monthly fixed effects as controls. Columns 4 and 6 also include station-brand fixed effects, yearly municipal GDP per capita, the monthly number of stations divided by the car fleet at the municipality level, and the yearly number of hotels per square kilometer in a municipality as controls. Instrument for share of flex cars, IV_m^t, is equal to $\sum_k n_{km}\tilde{\theta}_k^t$, where n_{km} is the number of dealers of car manufacturer k in city m before 2000 that were still active in 2015, and $\tilde{\theta}_k^t$ is the share of flex models offered by manufacturer k in the Brazilian territory in a particular month. Standard errors clustered by city-month in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.6: Effect of Flex Car Penetration on Ethanol Price and Margin: State Capital

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) 2SLS	(6) 2SLS
Panel A				**Ethanol Price (p_a)**		
% Flex Cars (θ)	1.823***	1.274***	-0.479***	-0.393***	-0.717***	-0.650***
	(0.176)	(0.147)	(0.093)	(0.105)	(0.224)	(0.249)
GDP per Capita				-0.000		-0.001
				(0.001)		(0.001)
Stations/Cars				-0.024***		-0.023***
				(0.007)		(0.007)
Hotels per km^2				0.067		0.066
				(0.061)		(0.061)
KP F-Stat (1^{st} Stage)					156	132
$N_{clusters}$	2458	2458	2458	2335	2458	2335
Observations	180113	180090	180090	173589	180090	173589
Panel B				**Ethanol Margin ($p_a - c_a$)**		
% Flex Cars (θ)	-0.208***	-0.266***	0.355***	0.430***	-0.139	-0.101
	(0.068)	(0.050)	(0.097)	(0.113)	(0.211)	(0.240)
GDP per Capita				0.001**		0.001
				(0.001)		(0.001)
Stations/Cars				0.021***		0.023***
				(0.006)		(0.006)
Hotels per km^2				0.017		0.014
				(0.044)		(0.043)
KP F-Stat (1^{st} Stage)					131	106
$N_{clusters}$	2450	2450	2450	2327	2450	2327
Observations	102610	102591	102591	99086	102591	99086
Monthly Fixed Effects	No	No	Yes	Yes	Yes	Yes
Station Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effects	No	No	No	Yes	No	Yes

NOTES: Table displays estimated effects of shares of flex cars, θ, on ethanol retail prices (Panel A) and ethanol margins (retail minus wholesale prices - Panel B) excluding from the sample the city of Rio de Janeiro (the capital of the state of RJ). Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to March 2008. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels. θ represents the share of flex cars in municipality m in a given month. Columns 1-4 estimated by OLS and columns 5-6 by 2SLS. Columns 2-6 include station fixed effects and columns 3-6 include monthly fixed effects as controls. Columns 4 and 6 also include station-brand fixed effects, yearly municipal GDP per capita, the monthly number of stations divided by the car fleet at the municipality level, and the yearly number of hotels per square kilometer in a municipality as controls. Instrument for share of flex cars, IV_m^t, is equal to $\sum_k n_{km}\tilde{\theta}_k^t$, where n_{km} is the number of dealers of car manufacturer k in city m before 2000 that were still active in 2015, and $\tilde{\theta}_k^t$ is the share of flex models offered by manufacturer k in the Brazilian territory in a particular month. Standard errors clustered by city-month in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.7: The Effect of Flex Car Penetration on Fuel Price Correlation

	(1) OLS	(2) 2SLS
	Product of Residuals from Tables 3 and 4	
% Flex Cars (θ)	0.002	0.018***
	(0.002)	(0.004)
GDP per Capita	-0.000*	0.000
	(0.000)	(0.000)
Stations/Cars	-0.000***	-0.001***
	(0.000)	(0.000)
Hotels per km^2	-0.003*	-0.004**
	(0.002)	(0.002)
KP F-Stat (1^{st} Stage)		723
$N_{clusters}$	2406	2406
Observations	252076	252076
Monthly Fixed Effects	Yes	Yes
Station Fixed Effects	Yes	Yes
Brand Fixed Effects	Yes	Yes

NOTES: Table displays estimated effects of shares of flex cars on products of residuals from regressions in Tables 3 and 4. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to March 2008. Column 1 is estimated by OLS considering the product of the residuals of the regressions in column (4), Panel A of Tables 3 and 4 as the dependent variable. Column 2 is estimated by 2SLS considering the product of the residuals of the regressions in column (6), Panel A of Tables 3 and 4 as the dependent variable. θ represents the share of flex cars in municipality m in a given month. All columns include station fixed effects, monthly fixed effects, station-brand fixed effects, yearly municipal GDP per capita, the monthly number of stations divided by the car fleet at the municipality level, and the yearly number of hotels per square kilometer in a municipality as controls. Instrument for share of flex cars, IV_m^t, is equal to $\sum_k n_{km}\tilde{\theta}_k^t$, where n_{km} is the number of dealers of car manufacturer k in city m before 2000 that were still active in 2015, and $\tilde{\theta}_k^t$ is the share of flex models offered by manufacturer k in the Brazilian territory in a particular month. Standard errors clustered by city-month in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.8: Structural Estimation - 5-digit CEP Market Definition

	(1)	(2)	(3)	(4)
Panel A		**Linear Model** - $\beta_A = \beta_G = \beta_F = 1$		
c_G	0.484***		0.504***	0.500
	(0.015)		(0.014)	.
c_A		0.549***	0.524***	0.500
		(0.008)	(0.010)	.
α_G	0.237***		0.188***	0.187***
	(0.028)		(0.018)	(0.017)
γ_G	0.975***		0.985***	0.992***
	(0.041)		(0.032)	(0.012)
α_A		0.477***	0.415***	0.395***
		(0.019)	(0.015)	(0.013)
γ_A		0.726***	0.807***	0.864***
		(0.024)	(0.025)	(0.011)
α_F	-3.783**	0.798**	0.452*	0.655***
	(1.806)	(0.365)	(0.272)	(0.234)
γ_F	4.450***	0.353	0.691***	0.549***
	(1.427)	(0.323)	(0.238)	(0.211)
Panel B		**Non-Linear Model** - $\beta_F = 1$		
c_G	0.386***		0.552***	
	(0.030)		(0.013)	
c_A		0.513***	0.496***	
		(0.008)	(0.013)	
α_G	0.389***		0.195***	0.265***
	(0.045)		(0.012)	(0.041)
γ_G	1.035***		0.987***	1.042***
	(0.022)		(0.011)	(0.022)
α_A		0.521***	0.350***	0.312***
		(0.015)	(0.025)	(0.046)
γ_A		0.973***	1.003***	1.028***
		(0.015)	(0.016)	(0.037)
α_F	-3.356***	0.843***	0.542***	0.726***
	(0.026)	(0.013)	(0.019)	(0.021)
γ_F	4.859***	0.356***	0.744***	0.589***
	(0.032)	(0.014)	(0.022)	(0.017)
β_A		1.180***	1.069***	1.069***
		(0.017)	(0.040)	(0.021)
β_G	1.011***		1.075***	1.085***
	(0.004)		(0.022)	(0.028)
Single Equation: Ethanol	No	Yes	No	No
Single Equation: Gasoline	Yes	No	No	No
Restricted Model	No	No	No	Yes

NOTES: Table displays estimated parameters from the structural model. Columns 1 and 2 in Panel A (Panel B) display separate estimations of equations 6 and 7 (equations 4 and 5), respectively, by 2SLS (by GMM). Columns 3 and 4 in Panel A (Panel B) display joint estimations of equations 6 and 7 (equations 4 and 5) by 2SLS (by GMM), and in column 4 the coefficients of wholesale prices are restricted to be equal to 0.5. Estimations consider a station i located in municipality m in week t as the unit of analysis, from January 2002 to March 2008 [Observations = 93,360]. The relevant market for each fuel station is the 5-digit postal code (CEP). All prices are expressed in BRL real terms, deflated by the monthly IPCA, and the price of gasoline is multiplied by a factor of 0.7. Instruments used in the estimations consider only c_{ig}, c_{ia}, θ_a^t (share of ethanol cars in a municipality), θ_g^t (share of gasoline cars in a municipality), IV_m^t (defined in Equation 2) and municipality fixed effects, as well as different interactions of these terms. For example, we use $\mathbb{1}\{c_{ia}^t < c_{ig}^t\}IV_m^t$ as an instrument for $\mathbb{1}\{p_{ia}^t < p_{ig}^t\}\theta_f^t$. Bootstrapped standard errors clustered by city-month in parentheses [$N_{clusters}$ = 2,407]. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.9: Counterfactual Prices

	Mean	St. Deviation	Min	Max
Ethanol Price	1.163	0.135	0.742	1.555
Ethanol Predicted Price	1.178	0.112	0.881	1.528
Ethanol Counterfactual Price	1.166	0.104	0.896	1.528
Gasoline Price	1.227	0.066	1.053	1.433
Gasoline Predicted Price	1.227	0.054	1.111	1.418
Gasoline Counterfactual Price	1.224	0.051	1.111	1.402

NOTES: Table shows the mean, the standard deviation, the minimum and the maximum for gasoline and ethanol prices, considering the distribution observed in our sample, the predicted (by our model) distribution and the distribution of prices arising from a counterfactual exercise in which the share of flex cars goes to 100% in all municipalities. We obtain the predicted and counterfactual exercises by numerically solving the system of best reply equations estimated in Panel B, column (4), of Table 6. All prices are expressed in BRL real terms, deflated by the monthly Índice de Preços ao Consumidor Amplo - IPCA (the Brazilian version of the Consumer Price Index - CPI). The price of gasoline is multiplied by a factor of 0.7 so that prices per unit of energy are directly comparable across fuels.
Sources: Authors' calculations from ANP and Detran RJ data.