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Ethanol demand under the flex-fuel technology regime in Brazil

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ABSTRACT

This paper analyzes the characteristics of ethanol demand in the context of fuel mix diversification in Brazil. Currently, ethanol is the most important gasoline additive and alternative fuel consumed in Brazil and is responsible there for profound changes in the dynamics of fuel consumption. The diffusion of flex-fuel vehicles in Brazil symbolizes a new stage of ethanol expansion and is a central component of the increasing demand for fuel. Accordingly, we evaluate ethanol demand in Brazil following the introduction of flex-fuel vehicles using a cointegration approach and autoregressive distributed lag bounds tests over the period 2003–2010. The evidences confirm that during the last decade, ethanol has strengthened its position as both an independent fuel and a substitute for gasoline. There is also evidence that growth in the Brazilian automobile fleet based on flex-fuel technology is a major driving factor of long-run ethanol demand. Further, the dynamics of gasohol (mandatory blend of gasoline and ethanol) and ethanol prices operate in a symmetric manner over ethanol demand, thereby evidencing the increasing substitutability between these alternative fuels.

1. Introduction

In April 2008, ethanol became the second most consumed liquid fuel (in volume)used for transportation purposes in Brazil after diesel (ANP, 2010a). This attainment well demonstrates current trends in fuel consumption in Brazil and reflects the increasing importance of ethanol in the available fuel mix. The increment in ethanol consumption over the last decade is, to a great degree, attributable to certain market drivers, the most remarkable of which are the growing sales of flexible fuel (flex-fuel) vehicles (FFVs) (Anfavea, 2010) and the relative price advantage of ethanol over gasoline during this period (ANP, 2010a). However, notwithstanding the impactof market forces, the diffusion of ethanol in Brazil is also a positive response to a number of policy-oriented initiatives, including the expansion ofproductive capacity that has successfully converted a colonial cultivation (sugarcane) into the most outstanding example of biofuel application in the world (Goldemberg et al., 2004). It is also an outcome of the establishment of flex-fuel technology as the main platform for the national automobile industry.

Ethanol usage in Brazil has its roots in the 1930s, when the fuel (anhydrous ethanol) first served as an additive to gasoline (BNDES, 2008). The introduction of ethanol as an independent fuel in its hydrous form came in 1975 with policies promoting its use as a strategic response to the oil crises of 1973 and 1979 and to depressed international sugar prices (Rosillo-Calle and Cortez, 1998; Rosillo-Calle and Heatford, 1987; Rothman et al., 1983). Resounding progress in the demand for the new fuel followed in the second half of the 1970s and throughout the 1980s. Ethanol demand subsequently collapsed because of lower oil prices, the appreciation of sugar prices in the international market and the withdrawal of government sponsorship of the ethanol program (BNDES, 2008). However, during the period 1997–2003, a revised set of institutional arrangements and market-leading innovations provided new momentum for the ethanol program in Brazil (EPE, 2008). This included the creation of the National Energy Policy Council and the National Agency for Petroleum, Natural Gas, and Biofuels in 1997 and the establishment of the current regulatory framework for biofuels (BNDES, 2008), culminating in 2003 with the launch of the first flex-fuel car in Brazil (Anfavea, 2010).

It is in the context of the rapid transformation of the Brazilian fuel mix that we propose this study. Our main purpose is to provide updated estimates of ethanol demand in Brazil after 2003. To do this, we assess ethanol demand in Brazil as a function of the price of ethanol, the average income of consumers, fleet growth and cross effects with the price of gasohol. From this point onward, we refer to the blend of gasoline and anhydrous ethanol as gasohol. This is an exclusively gasoline-based fuel commercialized in Brazil for road transportation purposes. We formulate the empirical analysis using a cointegration approach with autoregressive distributed lag (ARDL) bounds test. The main benefit of this approach is that it allows the simultaneous and consistent estimation of short- and long-run elasticities in the context of a limited data series (Bentzen and Engsted, 2001; Ghosh, 2010). We carry out our evaluation using monthly data from January 2003 to July 2010.

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This work is one of a number of other research initiatives concerned with better comprehending the current debate on ethanol development in Brazil. Interest in the recent history of ethanol development is an object of particular interest for researchers because of the perspectives and challenges faced by ethanol in the middle and long term. The evidence provided demonstrates that the fundamental determinants of ethanol demand in Brazil are growth in the automobile fleet followed by the influence of ethanol and gasohol prices. The results also show that ethanol and gasohol prices exhibit an inverted and symmetric effect on ethanol demand, thereby indicating that ethanol as a fuel has strengthened its position as a gasohol substitute.

The remainder of the paper is structured as follows. Section 2 provides an update of the Brazilian ethanol program, along with a review of the factors driving increased ethanol consumption in Brazil. Section 3 surveys the previous research on fuel demand in Brazil and discusses the data and methodological aspects of the study. Section 4 presents the main results and some selected policy implications. Section 5 concludes.

2. Fuel mix, consumer profile and the record of fuel demand in Brazil

2.1. Fuel mix and current trends in fuel consumption in Brazil

Ethanol is currently the most important additive and alternative fuel to gasoline in Brazil. Anhydrous ethanol is blended with gasoline in a mandatory and flexible concentration that ranges from 20% to 25%, varying according to ethanol availability and price practice by the producer (BNDES, 2008). Compared with other additives, anhydrous ethanol represents better value in terms of price and availability, and given its innate composition, it operates as an octane booster for conventional gasoline that improves fuel performance while mitigating carbon dioxide emissions (Joseph, 2005). In turn, hydrous ethanol is the third main source of energy (after diesel and gasohol) used for transportation purposes in Brazil (ANP, 2010a).The reader may find interesting that when converted from physical units (liters) to energy units (tons of oil equivalent, toe), ethanol consumption ranks as the third most consumed Brazilian fuel mix, while if considered in physical terms, it would rank as the second most consumed. The reasons will be detailed further in this study. Fig. 1 illustrates the evolution of fuel consumption in Brazil in toe since 1970, plotting anhydrous ethanol separately from gasoline for precision.

Fig. 1 well reflects the progress and regress experienced by ethanol in Brazil and also outlines several of the possible interactions between the available fuels. With hydrous ethanol, we can discern three main stages. The first stage comprises an increase in hydrous ethanol demand in response to the launch of the National Ethanol Program (Proalcool) at the end of the 1970s. The second stage begins with a period of stagnation, followed by a systematic decline in the 1980s and 1990s. In the third stage, we observe in the mid-2000s a sharp increase in hydrous ethanol demand. In contrast, the trend in the demand for anhydrous ethanol is more subtle, reflecting the relatively stable blend mandate across time. We can also see that the demand for gasoline moves inversely to the demand for hydrous ethanol. This trend confirms the posted interaction between these fuels. Apart from these market dynamics, we can see that diesel consumption has steadily grown during the same period and shows little evidence of a dynamic linkage with the remaining fuels.

Historically, the establishment of ethanol as a competitive fuel is determined by the conditions of oil market. Periods of stable oil supply and decreasing oil prices have operated as a barrier for sustainable development of ethanol market in Brazil, and vice-versa (Rapsomanikis and Hallam, 2006). Due to the importance of oil as main energy commodity and considering the natural linkages of this fuel in the world economy it is widely accepted that oil and its market components as supply and price are susceptible of fluctuations in a timeline. In the recent years this condition has given signals of change in Brazil since ethanol has assumed characteristics of normal commodity becoming a competitor for gasohol (Goldemberg and Lucon, 2010). However, in a context of increasing domestic production of oil there are some concerns on the sustainability of ethanol and other biofuels programs (Nogueira and Alencastro, 2009; Pires and Schechtm, 2008).

2.2. Driving factors for increasing ethanol demand

The turning point in the renewal of the ethanol program in Brazil came with the launch of FFVs in 2003. This new technology enables consumers to use any proportion of gasohol–ethanol in the same vehicle, simultaneously and without any operational constraints (Ferreira et al., 2009). In the five years after the introduction of the first FFV, the reshaping of the national automobile industry has made FFVs the main platform for all new cars produced in the country (BNDES, 2008). As at July 2010, 95% of all cars sold in Brazil had a flex-fuel engine (Anfavea, 2010).

Increases in consumer income and the availability of credit in Brazil are fundamental factors determining the increase in car ownership among middle-class consumers in both urban and rural areas (IPEA, 2010). In this context, it is plausible to consider that the increase in private car retail sales in the last decade is a major reason for the observed increase in fuel consumption in Brazil (EPE, 2008). Figures on the number of automobiles and motorbikes registered for private purposes reveal an average annual growth of 6.3% and 15.2%, respectively (Denatran, 2010). Overall, consumers of automobiles have fundamentally relied on small-capacity vehicles, known in Brazil as popular cars, and these represent about 60% of all automobiles sold

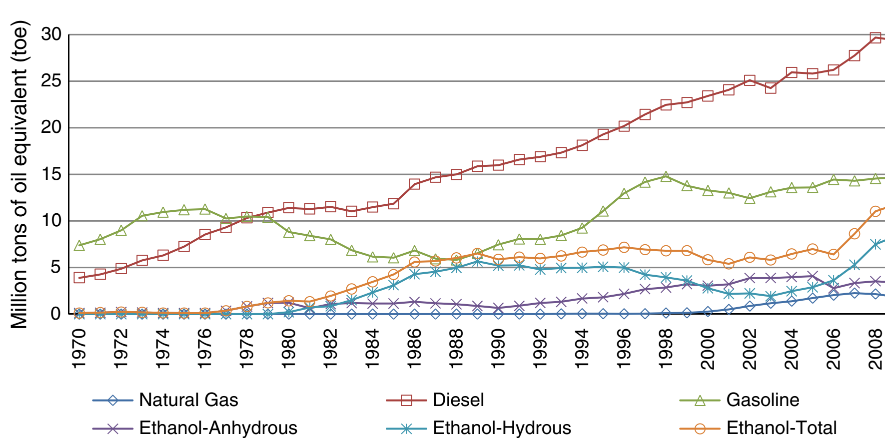

Fig. 1. Transportation fuel consumption in Brazil (1970–2009).
Source: EPE (2010).

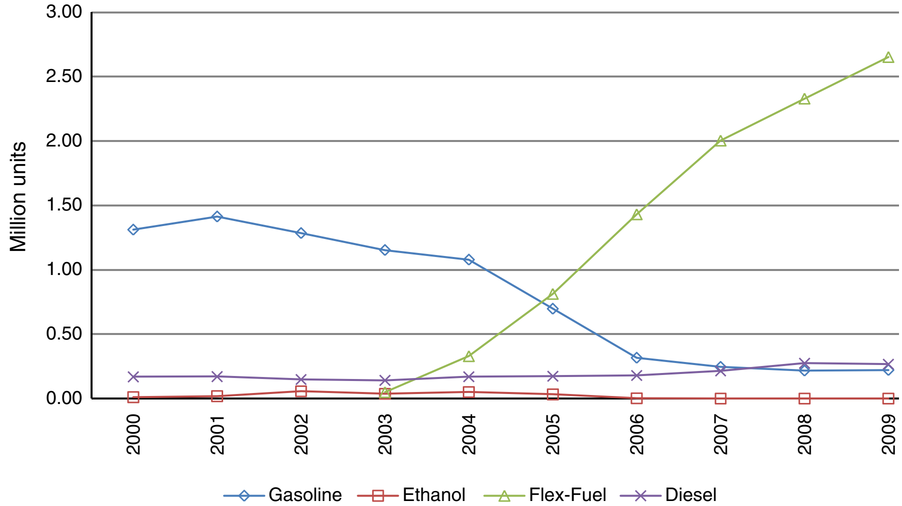

Fig. 2. Registration of new cars by fuel in Brazil (1980–2009).
Source: Anfavea (2010).

each year (Anfavea, 2010). Fig. 2 details the registration of new cars by fuel type from 2000 to 2009.

In general, owners of FFVs choose between ethanol and gasohol based on a balance of fuel price and combustion performance. Hence, a preference for ethanol over gasohol will occur when the price per liter of the former is about 70% of the price of gasohol (BNDES, 2008). Fig. 3 summarizes the relation between the main fuels used in Brazil in R$ per toe. Converting liters to toe allows us to compare fuel prices by energy unit.

Note: Prices are in real R$ as at July 2010 deflated by the National Consumer Price (IBGE, 2010). Quantities originally in m^3 (ANP, 2010a) are converted to energy units (tons of oil equivalent, toe) usingthe conversion factors provided by the EPE (2010).

Note that during the period under study, the price of ethanol has risen above that for gasoline. Thus, to some extent, and during particular periods, ethanol has lost its comparative price advantage. This scenario of relatively higher ethanol prices is particularly noteworthy during periods of lower sugarcane production (EPE, 2008). The observed competition between fuel prices is a known determinant of fuel consumption in Brazil. For instance, Ferreira et al. (2009) observed that ethanol and gasohol prices are tied in the long run because of the increasing share of FFVs and because market forces guide the ethanol price. Boff (2010) also found that the increase in the flex-fuel fleet has led to the consistent price transmission elasticity of ethanol with respect to gasohol in the long term.Finally, the real growth in population income is another conventional determinant of fuel consumption. In this regard, over the period January 2003 to July 2010, the average monthly growth of 0.15% in income in Brazil corresponded with an increase of 129% in fuel consumption (IBGE, 2010). Fig. 4 depicts the trend in average real income per worker in Brazil during the target period.

In general, we expect income growth to exert a direct and indirect impact on fuel demand. IPEA (2009), for instance, identifies the progressive real income increase as the growth driver for the Brazilian automobile fleet after 2003. As previously discussed, this trend would ultimately increase fuel consumption. Regarding the direct effect, we expect higher income to foster the use of cars by increasing the average traveled distance and substitution of private car usage for public transportation (EIA, 2005; Golob, 1989). We explore the weight and peculiarities of the abovementioned variables within the dynamics of the Brazilian fuel market in the next section.

3. Key references, data sources and modeling

3.1. Key references on fuel demand

Estimating fuel demand is a common exercise in policy analysis and energy economics studies. A search of the literature reveals several different econometric models and numerous explanatory variables that vary according to the objectives and nature of these studies. Based on a survey of relevant existing studies, Dahl and Sterner (1991) categorized the econometric procedures employed into two main

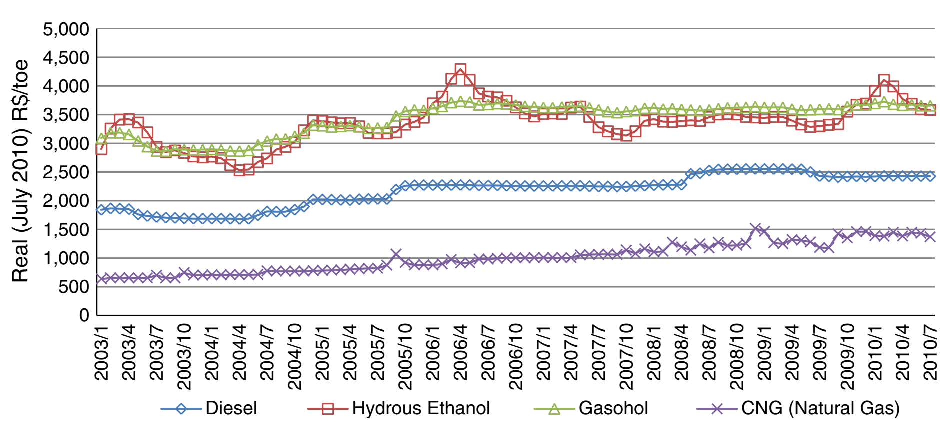

Fig. 3. Real fuel prices in Brazil (January 2003–July 2010).

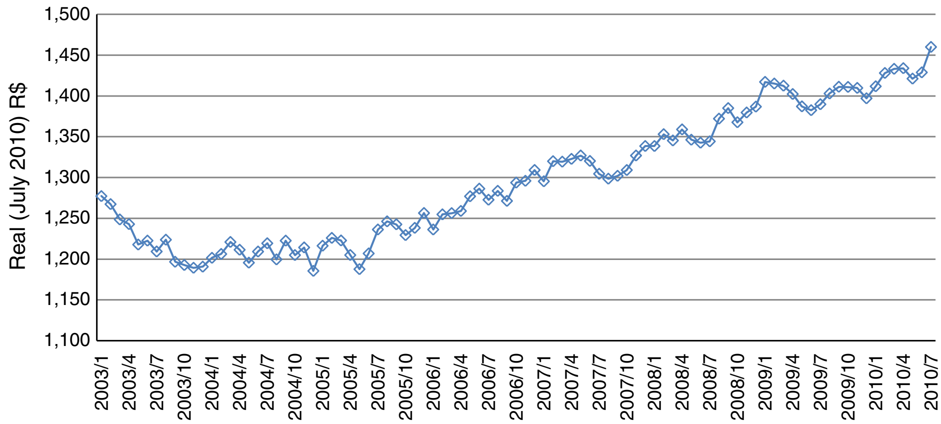

Fig. 4. Average real monthly family incomein Brazil.

types: static and dynamic. Static models analyze a particular fuel according to its own variables,including its real price and consumer income. In addition, static models also normally incorporate as explanatory variables factors such as fleet characteristics and fuel availability. In contrast, and in addition to variables such as price and consumer income, dynamic models also incorporate lagged effects and behavioral and technological changes in the analysis as key determinants of fuel consumption (Dahl and Sterner, 1991).

Regarding the choice of explanatory variables, the existing literature exhibits two main trends. A first group of studies tends to estimate fuel demand based on transport services and fleet characteristics, such as average distance traveled and vehicular performance (Baltagi and Griffin, 1983; Bentzen, 1994; Goodwin et al., 2004). However, there has been some criticism of this approach in the rather unrealistic expectation that highly aggregated variables are able to capture the distinctive characteristics of diversified fleets in a time-series context. A second approach, which is adopted in the present study, assumes a functional relation between fuel demand and a set of aggregate economic variables, including consumer purchasing capacity, fuel prices and fleet size (Ghosh, 2010; Iwayemi et al., 2010; Parikh et al., 2007; Park and Zhao, 2010). However, this approach omits the classical model of economic theory and only indirectly includes aspects of fleet composition. The most general criticisms of this approach usually concern the use of highly aggregated variables and the limitation of details (Berkowitz et al., 1990). We base our choice of this approach on the breadth of the characteristics of the vehicular fleets operating in Brazil and on the limitations of our database in terms of its information on the performance and shares of car types.

Cointegration is the main method used to estimate long- and short-run fuel demand and its dependence on economic variables (Dahl and Sterner, 1991). Originally proposed by Granger (1981), this technique has been subsequently enhanced by auxiliary approaches such as the error correction model (Engle and Granger, 1987; Granger and Weiss, 1983) and the ARDL bounds test (Pesaran et al., 2001; Pesaran and Shin, 1999). Of these, the ARDL is a relatively new approach with increasing acceptance among analysts. We can attribute the reasons for this to the simplicity of the model and the fact that it permits an evaluation free of the constraints found in conventional combinations of cointegration with error-correction models (Bentzen and Engsted, 2001; Ghosh, 2010). A noteworthy advantage of the ARDL approach includes the feasibility of estimating cointegration in a series regardless of the order of integration of the variables (Pesaran and Shin, 1999; Pesaran et al., 2001). The method also allows us to overcome some limitations in sample size, which is an obvious advantage when evaluating new energy sources or the effects of energy demand stress and technology shocks. This is particularly advantageous when considering ethanol in Brazil,where the number of time series observations remains limited.

We considered numerous applications of cointegration as suitable references for this study. For instance, Bentzen (1994) estimated short- and long-run gasoline demand in Denmark as a function of real fuel prices and vehicle stocks. Similarly, Samimi (1995) estimated fuel demand for the Australian road transport sector, while Ramanathan (1999) estimated the demand for gasoline as a function of prices and consumer incomes in India. Problematically, all of these studies fundamentally elaborated upon the context of a fossil fuel monopoly, thereby implying the nonexistence of fuel competition. We also considered studies based on the ARDL approach to cointegration throughout the developing world. The studies reviewed include the analysis of gasoline demand in South Africa over the period 1978–2005 by Akinboade et al. (2008). This work provided price and income elasticity estimates of −0.47 and 0.36, respectively. In a similar analysis, Ghosh (2010) estimated that the long-run income elasticity for high-speed diesel demand in India was 1.27 while that for the short run was 0.46.

Other estimation models have also been employed with relative success. For instance, the partial adjustment models were widely accepted between energy researchers as a method to characterize the process of adjustments of fuel efficiency in response to fuel prices changes. Espey (1996), for example, evaluated the role of fuel prices, income, government taxation and technological change in influencing the consumers' choice of fuel economy in a cross country model. Alternative usage of cointegration methods is also popular. For example, Bonilla and Foxon (2009) developed a two stage cointegration model to study the demand for new car fuel economy in the United Kingdom for the period 1970–2005. Authors observed that higher incomes and long-term price changes in the United Kingdom are the main drivers to achieve improvements in fuel economy and that new car fuel economy changes were scarcely affected by the Voluntary Agreement on CO2 emissions reductions adopted in the 1990s.

In Brazil, the peculiar combination of fuel mixes has attracted the attention of researchers and policymakers alike, resulting in a number of publications on this theme. For instance, a pioneering work by Rogat and Sterner (1998) estimated gasoline demand in several Latin American countries, including Brazil, for the period 1960–1994, attributing the relative decline in the use of gasohol to Brazil's ethanol program. In other work, Burnquist and Bacchi (2002) estimated the demand for gasohol in Brazil for the period 1973–1998, while Alves and Bueno (2003) used a similar approach to analyze the demand for gasohol accompanying the decline of the Brazilian ethanol program from 1984 to 1999. Together, these studies effectively captured the transformation in gasohol demand following the introduction of ethanol and the decline of the Proalcool program.

Some initial evaluations of ethanol demand in Brazil were also undertaken after the introduction of flex-fuel technology. For example, Nappo (2007) estimates the effect of the introduction of FFVs on gasohol demand in Brazil.The results there indicate that the introduction of FFVs caused the price elasticity of gasohol demand to increase from −0.197 to −0.334. In related work, Iootty et al. (2009) used the almost ideal demand system to study the elasticity of demand for the most important fuels in Brazil and found a high degree of substitution between ethanol and gasohol. As an alternative, Azevedo (2007) and Pontes (2009) specified ethanol demand as a dependent variable and developed a series of models to estimate ethanol demand during the transition period following the introduction of flex-fuel technology from 2002 to 2006. Pontes (2009) also found evidence of an increase in the level of substitution between gasohol and ethanol in Brazil, concluding that the increasing share of FFVs in the Brazilian market constrained growth in both gasohol and ethanol prices as consumers were readily able to shift from one fuel to the other. Table 1 summarizes details of selected fuel demand evaluations in Brazil.

As suggested by reviewers of this study, the understanding of ethanol demand dynamics also requires the understanding of gasohol demand pass-through. Previously, Fig. 1 offered a graphical perspective on the substitution effect between ethanol and gasohol markets in Brazil. In turn, Table 1 is indicative of the transforming pattern faced by gasohol demand in Brazil across time. In general, studies of gasohol demand have found the increasing price elasticity of gasohol demand whenever ethanol accounts for a significant share in the fuel mix supply. In particular, a common finding is that the cross effects of ethanol prices on gasohol demand are historically lower than those for gasohol prices on ethanol demand. We can attribute a possible explanation for this distinction to the larger share of exclusive gasohol cars in the domestic market while ethanol demand is predominantly consumed by FFV owners (EPE, 2008).

3.2. Data sources

The present analysis employs national monthly data from January 2003 to July 2010 collected from official publications and databases. The ethanol and gasohol prices and monthly consumption data are from the statistical division of the National Oil, Natural Gas and Biofuels Regulatory Authority, ANP (ANP, 2010a). The price data used correspond to the weighted national average values collected monthly by the ANP auditing division from a randomly selected sample of fuel stations throughout Brazil. The fuel consumption data, which correspond to the total amount of fuel commercially sold in the country, are available from the ANP statistical division (ANP, National Oil, Natural Gas and Biofuels Regulatory Authority, 2010a). Annual data on the conversion factors used to transform physical units into energy content units are from the National Energy Balance (EPE, 2010). The figures on monthly family income are by the Brazilian Institute of Geography and Statistics, IBGE (IBGE, 2010). We deflate all prices and incomes by the consumer price index estimated by the IBGE (IBGE, 2010). The Brazilian automobile fleet data are from the National Transit Department (Denatran, 2010) and corresponds to sum of fleet stock and new car registers minus the monthly car scrap records.

The preliminary evaluation of data series shows the incidence of seasonality on ethanol prices and consumption quantity corresponding to the sugarcane intercrop period. Information from ethanol producers suggests that the sugarcane intercrop season in Brazil starts in November and lasts until the following March(FIESP, 2001; Torquato, 2006). During this intercrop interval, the fuel supply reflects the reduced level of ethanol production. This contraction in supply increases final prices for consumers, resulting in lower consumption. In general, fuel consumption is also sensitive to other seasonal effects. To control for the effects of seasonality,we specify a set of dummy variables for each month in our model. By employing these dummies, it is possible to discern the magnitude of seasonal effects on the dynamics of fuel mix consumption in Brazil.

Despite the robustness of the data, several disturbance factors can also affect consumer choice. For example, the persistent incidence of fuel adulteration can potentially distort the purchasing behavior of consumers, particularly outside large urban centers where the incidence of fuel adulteration is more common (ANP, 2009b). Two common adulteration practices reported by the auditing division of the ANP are the excessive inclusion of blends of anhydrous ethanol in gasoline and the direct mixing of water or methanol into hydrous ethanol (ANP, 2009b). Both practices criminally increase the profits of “last-mile” suppliers or final fuel retailers while reducing the reliability of the fuel, thereby adversely affecting vehicle operation. Given the potential risk, consumers are then willing to pay higher prices for fuel in order to maintain the performance of their vehicles.

3.3. Estimable demand models

We carry out the estimation for ethanol demand in two stages. In the first stage, we test for long-run relationships between ethanol demand

Table 1
Studies of long-run gasohol and ethanol demand elasticities.

Reference[a]	Dependent variable[b]	Period	Explanatory variables and elasticity[c,d]			
			Gprice	Eprice	Income	Fleet
Rogat and Sterner, 1998	Gasohol	1960–1994	−0.98		0.90	
Burnquist and Bacchi, 2002	Gasohol	1973–1998	−0.23		0.96	
Alves and Bueno, 2003	Gasohol	1984–1999	−0.464	0.48	0.122	
Roppa, 2005	Gasohol	1979–2000	−0.20	−0.14	0.69	
Azevedo, 2007[e]	Ethanol	01.2002–06.2006	−0.364	−0.459	0.137	
Azevedo, 2007[f]	Ethanol	01.2002–06.2006	1.017	−0.857	0.13	
Azevedo, 2007[g]	Ethanol	01.2002–06.2006	1.251	−1.250	0.002	
Schünemann, 2007[h]	Gasohol	1980–2005	−0.292		1.34	
Schünemann, 2007[i]	Gasohol	01.1991–02.2007		−0.337	1.749	−0.041
Schünemann, 2007[j]	Gasohol	07.2001–02.2007	−0.411		0.537	−0.012
Nappo, 2007	Gasohol	08.1994–07.2006	−0.334		0.69	
Pontes, 2009	Ethanol	7.2001–10.2008	1.374	−0.934	1.255	
Silva et al., 2009	Gasohol	04.2001–12.2006	−0.945	0.049	0.154	

[a] References ordered by year of publication.
[b] Specifies which fuel demand model was evaluated.
[c] Eprice, Gprice and Y are real ethanol price, real gasohol price and real income, respectively.
[d] Coefficients refer to long-run elasticities.
[e] Results for Brazil.
[f] Results for the southeast region of Brazil.
[g] Results for the northeast region of Brazil.
[h] Estimation of annual gasohol demand without ethanol price.
[i] Estimation of monthly gasohol demand without gasohol price.
[j] Estimation of monthly gasohol demand without ethanol price and with a dummy for the introduction of flex-fuel vehicles in the market.

(C_{eth}) as the dependent variable and the lagged and contemporaneous values of income (Y), ethanol prices (P_{eth}), gasohol prices (P_{gas}), the number of car sales (F) and its own lagged value (C_{eth}) as independent variables. While economic factors establish the coefficients for the variables commonly associated with fuel demand, the lagged dependent variable aims to capture the adjustment of fuel consumption in response to changes in the explanatory variables (Bentzen and Engsted, 2001).

We tested for a long-run relation between the variables using the bounds tests based on the Wald test (F-statistic). The null hypothesis of no cointegration (H_0: $\delta_1=\delta_2=\delta_3=\delta_4=\delta_5=\delta_6=0$) is tested against the alternative hypothesis (H_0: $\delta_1\neq\delta_2\neq\delta_3\neq\delta_4\neq\delta_5\neq\delta_6\neq0$), see following Eq. (1) for reference. If the computed F-statistic exceeds the upper critical bound, then the null hypothesis is rejected. On the other hand, if the estimated F-statistic falls below the lower bound, the null hypothesis of no cointegration cannot be rejected. Critical values for the bounds tests are in Pesaran et al. (2001).

The second stage of our methodology consists of estimating the coefficients of the long-run relationship. In this study,we employ the ARDL bounds testing approach of cointegration. This approach follows a dynamic specification that includes lags of the dependent variables and lagged and contemporaneous values of the independent variables as explanatory factors. We carry out the estimations using the following unrestricted error correction model (UECM) equations:

$$\begin{aligned}\Delta\, lnCeth = {} & \beta_0 + \sum_{i=1}^{n}\beta_1\ \Delta\, lnY_{t-i} + \sum_{i=1}^{n}\beta_2\ \Delta\, lnPeth_{t-i} \\ & + \sum_{i=1}^{n}\beta_3\ \Delta\, lnPgas_{t-i} + \sum_{i=1}^{n}\beta_4\ \Delta\, lnF_{t-i} + \sum_{i=1}^{n}\beta_5\ \Delta\, lnCeth_{t-i} \\ & + \delta_1\ lnY_{t-1} + \delta_2\ lnPeth_{t-1} + \delta_3\ lnPgas_{t-1} + \delta_4\ lnF_{t-1} \\ & + \delta_5\ lnCeth_{t-1} + \alpha_1 \mathrm{Jan} + \alpha_2 \mathrm{Feb} + \alpha_3 \mathrm{Mar} + \alpha_4 \mathrm{Apr} \\ & + \alpha_5 \mathrm{May} + \alpha_6 \mathrm{Jun} + \alpha_7 \mathrm{Jul} + \alpha_8 \mathrm{Aug} + \alpha_9 \mathrm{Sep} + \alpha_4 \mathrm{Oct} \\ & + \alpha_5 \mathrm{Nov} + \varepsilon_t \end{aligned} \tag{1}$$

where Δ is the first difference operator of the logarithms of selected variables. We obtained the optimal lag length using the Akaike Information Criterion (selecting a maximum of three orders) with a one-year lag as the optimal lag for the UECM variables. We estimate the long- and short-run elasticities using the coefficients in Eq. (1). We obtain the long-run elasticities by multiplying the coefficients for the lagged explanatory variables by negative one and afterwards dividing the result by the estimated coefficient of the lagged dependent variable (Bardsen, 1989). The short-run elasticities correspond to the coefficients of the first-differenced variables.

The choice for the methodological approach adopted in this study differs from most applications carried so far on the theme of ethanol demand. Evaluation proposed in this study offers an alternative to the conventional combination of cointegration approach and error correction models allowing a new source for consistence exams. The inclusion of fleet variable and the usage of energy units instead of physical units to measure for fuel consumption are also expected to expand the discussion on the issue of fuel demand in Brazil.

The choice for converting fuel quantity to energy content is an attempt to capture the differences in fuel efficiency. Reviewers of this paper have called attention to several factors affecting fuel consumption performance besides the energy content of each fuel. References from the literature have reported,for example,that conditions external to vehicular operation, such as weather and road circumstances, technical aspects related to fuel combustion and the preference of consumers, are also potential factors impacting the choice between ethanol and gasohol in Brazil (Costa and Sodré, 2010, 2011; Pacini and Silveira, 2011). However, due to data limitation other variables besides fuel efficiency were not included in the model.

Finally, we submitted the final model to several tests in order to obtain the most parsimonious system. Section 4 details the outcomes of these tests and the results of the estimation of the elasticities of demand.

4. Empirical evidence on ethanol demand and its implications

4.1. Empirical results

By taking into consideration the key features of the ethanol market in Brazil, we can gage the expected effects of the variables on ethanol demand using economic theory. Hence, among other things, we expect an increase in the price of ethanol to reduce the demand for ethanol. We also expect that an increase in consumer income will increase ethanol demand, as will an increase in gasoline prices. We also expect an increase in car fleet to affect positively the demand for ethanol. We base these expectations on our understanding that the hydrous ethanol sold in Brazil is a normal good, with gasohol as a competitor. Table 2 provides summary statistics and descriptions of the variables employed.

The results of the bounding test for cointegration are in Table 3. The bounds test confirms the presence of cointegration in the model proposed in this study. In other words, the F-test result for the proposed system is higher than the critical value at the 1% level.

Table 4 summarizes the estimations carried out in this study. The values presented are from a parsimonious system that includes only statistically significant variables. We employ Ramsey's Regression Equation Specification Error Test (RESET) to test for specification error in the model. The results for this test reject the presence of specification error. We test for serial correlation in the residuals with the Breusch–Godfrey LM test. The test statistic rejects the hypothesis of no serial correlation up to lag order 1 at the 95% confidence level. Finally, the Jarque–Bera test indicates that the residual series are normally distributed. Coefficient results of tests are in the notes attached to Table 4.

Within the final model specification, the absence of income among the explanatory variables is remarkable. In other words, average family income is not a statistically significant influence on the change in ethanol consumption. This is unexpected, as previous studies of fuel consumption have, in general, assigned weight to income as an important explanatory factor for fuel consumption; see, for example, Table 1. A detailed review of the literature on Brazilian case reveals, however, that income has historically had only marginal importance in explaining ethanol consumption in the country. Azevedo (2007), for example, reports a similar finding when using survey-based family income (as in this study) and instead opts to use industrial production as a proxy for income. Pontes (2009) adopted a similar strategy to Azevedo (2007) and obtained a relatively higher income elasticity; see Table 1 for details. Our conclusion is that the survey-based income data conventionally used internationally in this type of study do not satisfy the model conditions prevailing in Brazil.

Table 2
Summary statistics and descriptions of the demand function variables (January 2003–July 2010).

Variable	Description	Units	Mean	Std. dev.	Min; max	Data source
C_{eth}	Ethanol consumption	10^3toe	368.01	206.26	114.45; 769.59	ANP (2010a)
Y	Real income	R$	1298.20	79.44	1185.51; 1459.88	IBGE (2010)
P_{eth}	Real ethanol price (R$ July 2010)	R$/toe	2695.26	270.60	2310.70; 3472.17	ANP (2010a)
P_{gas}	Real gasoline price (R$ July 2010)	R$/toe	2751.28	168.63	2451.38; 3137.14	ANP (2010a)
F	Fleet stock	10^6 units	28.22	3.93	22.58; 35.95	Denatran (2010)

Notes: Summary statistics corresponds to observations for 91 months.

Table 3
Bounds test for cointegration analysis.

UECM	F-stat	Critical values bounds, $k=5$					
		90%		95%		99%	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
$F_{Ceth}(C_{eth}\|Y,P_{gas},P_{eth},Fleet)$	9.241737	2.26	3.35	2.62	3.79	3.41	4.68

The estimated signs are consistent with previous studies on ethanol demand (Azevedo, 2007; Pontes, 2009). Therefore, we can see that ethanol is progressively strengthening its position as an independent fuel given the relative symmetry between ethanol and gasohol prices. For instance, the elasticities for the price of ethanol and the cross effect of gasohol prices are −1.800 and 1.987, respectively. These values demonstrate a closer substitution effect and confirm the trends of increasing elasticity and symmetry observed in a previous work. Fig. 5 summarizes the studies of ethanol demand.

In the short run,we can clearly see the expected inverted elasticity for ethanol and gasohol price. The estimated elasticity for the price of ethanol in the short run is −1.413, while the cross effect of the price of gasohol is 0.948. These elasticities differ for values in the long run, when the estimates reveal that ethanol demand is relatively more sensitive to price variation than the cross price effect of gasohol.We can attribute this to the changing pattern of fuel prices along the months, with the effect of seasonality on the ethanol price being particularly relevant.

It is noticeable from the available extant studies that income plays a relatively lesser role as an explanatory factor for ethanol demand. Elasticity close to zero reflects the limited influence of this particular variable. The exception is in work by Pontes (2009), where the values for income elasticity were close to the values for the cross-effect gasohol price. Based on those finds it is not possible to draw a conclusive understanding on the effects of income change on ethanol demand.

Finally, the effect of fleet growth on ethanol demand is particularly expressive in the context of this study. According to the empirical evidence, the fleet is the main source of ethanol demand growth after 2003. In the long run,we can see that each 1% growth in the fleet results in a 4.4% increase in ethanol demand. Only a few studies have included fleet parameters as explanatory variable what reduces a full understanding of the importance of this variable in Brazil. An exception is the work by Schünemann (2007),who identified the introduction of FFVs as an inhibitor of gasohol consumption in Brazil.

Table 4
UECM for ethanol demand in Brazil (January 2003–July 2010).

Regressor	Coefficient	t-statistic	Prob.
ΔP_{gas}	0.948490	1.726839	***
ΔP_{eth}	−1.413412	−4.977547	*
$P_{gas}(1)$	0.753745	2.249086	**
$P_{eth}(1)$	−0.683055	−3.326660	*
Fleet(1)	1.682588	3.929919	*
$C_{eth}(1)$	−0.379308	−3.722985	*
JAN	−0.206894	−4.126650	*
FEB	−0.214923	−6.222286	*
MAR	−0.098554	−2.862758	*
APR	−0.168734	−4.562421	*
MAY	−0.132261	−3.341339	*
JUN	−0.192688	−5.773385	*
JUL	−0.123242	−2.991457	*
AUG	−0.178335	−4.530150	*
SEP	−0.141572	−3.893371	*
OCT	−0.122695	−3.195007	*
NOV	−0.193654	−5.113553	*

Notes: (a) $n=91$; (b) values in parentheses arethe number of lags; (c) adjusted R-squared = 0.637645; (d) Durbin–Watson stat. = 2.052; (e) Ramsey RESET F = statistic (p-value) = 0.157(0.693); (f) Breusch–Godfrey Serial Correlation LM Test (p-value) 3.926 (0.048); and (g) Jarque–Bera Test (p-value) 0.035 (0.982).

* Denotes statistical significance at the 1% level.

** Denotes statistical significance at the 5% level.

*** Denotes statistical significance at the 10% level.

4.2. Selected policy implications

The increasing importance of ethanol in Brazil has important implications for domestic energy policy. This study approaches the strengthening capacity of ethanol to substitute for gasohol in the long run, a process that will ultimately increase competition in the domestic fuel market. Conditions associated with the increasing share of FFVs create a new scenario with an impact on all components of the energy market in Brazil. A related outcome for the energy market is that the increase in the production of ethanol results in the greater availability of sugarcane bagasse for electricity cogeneration, an energy source that already accounts for 13% of national energy consumed in Brazil in 2009 (EPE, 2010).

To policymakers, the figures on ethanol demand show the increasing pressure on agriculture modernization with spillover effects on issues such as international ethanol trade and environmental protection strategies, among others. In this context, the preeminent challenge is ensuring the continued supply of ethanol to satisfy domestic and expected international demands.The present study demonstrates not only that the substitution between ethanol and gasohol constitutes a source of demand stress, but also that the increasing motorization of the population and the fast diffusion of flex-fuel cars constitutes a robust factor for increasing ethanol demand, with each 1% increment in the fleet implying an approximately 4.5% increase in ethanol demand.

Reviewers of this study have commented that in the consolidation of ethanol as a normal commodity and a substitute for gasohol, the taxation scheme can exert a strong impact on the trends of fuel consumption. To this extent,we could consider tax schemes as an instrument to correct for any market imperfections or an instrument to reach certain environmental standards, including, for example, initiatives aimed at the phasing out of gasoline. It is noteworthy that the blend mandate itself is a form of external price intervention as the ethanol component of gasohol exerts a negative effect on the final price of gasohol.

The supply industry also performs a crucial role in the current ethanol market. Ethanol producers have been systematically challenged by an average monthly growth rate in ethanol demand of 2.06% during the period under study (the corresponding figure for gasohol is 0.62%). The fact that a persistent supply shortage for the last quarter of 2009 and the first two months of 2010 have pushed ethanol prices to their highest levels since 2002 and forced a reduction in mandatory blending to its minimum authorized level of 20% shows the extent to which the domestic supply of ethanol is a major concern (MAPA, 2010). Giesecke et al. (2008) have advocated that ethanol supply is a major challenge for increasing demand for ethanol in Brazil. In addition, ethanol has successfully been integrated in other industrial processes and in final consumption. Recent advances include the introduction of flex-fuel motorbikes and the use of ethanol as raw material for biodegradable plastics for domestic and industrial usage and as an alternative to the expensive and higher-pollutant methanol used in the biodiesel industry. Pressures to convert ethanol into an international commodity and the high demand for sugar (the production of which is gradually shifting to countries in which the competition for arable land is more severe) are additional concerns related to the supply capacity of the sugarcane industry in general and ethanol policies in particular. These developments suggest that ethanol demand is set to increase in the short run, and this will have important economic, social and environmental effects.

5. Conclusion

The domestic consumption of hydrous ethanol in Brazil has achieved extraordinary growth since the launching of the current

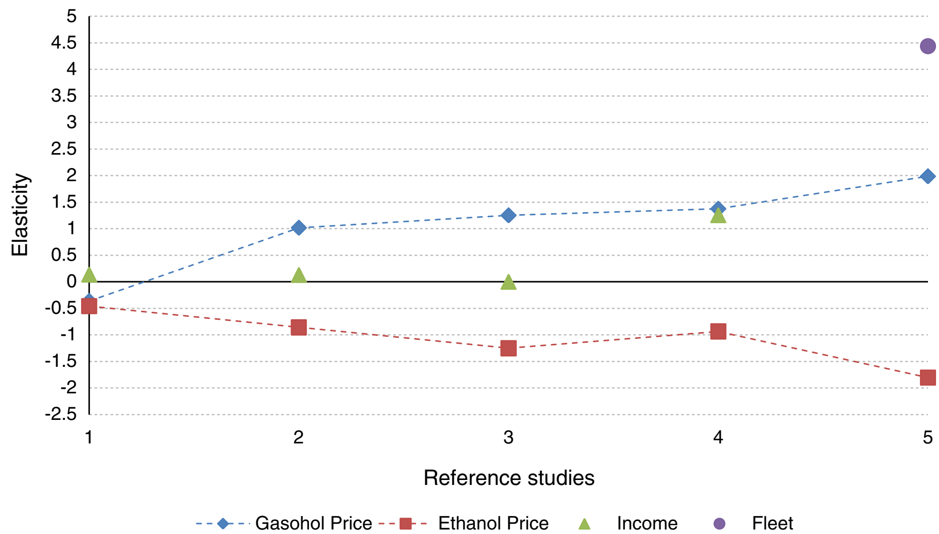

Fig. 5. Long-term ethanol demand elasticity from several studies. Notes: 1: Azevedo (2007), results for ethanol estimation in national level; 2: Azevedo (2007), results for ethanol estimation in regional level–southeast region, Brazil; 3: Azevedo (2007), results for ethanol estimation in regional level—northeast region of Brazil; 4: Pontes (2009); and 5: present study.

ethanol program. Hydrous ethanol demand has risen from 236.82 million liters in March 2003 to 1,317.62 million liters in July 2010. The present study demonstrated that ethanol has progressively increased its importance in itself and as a substitution fuel for gasohol, with fleet growth being the main reason for the observed increase in demand.

We can see that in any scenario with an increasing demand for liquid fuel for transportation use, as in Brazil, the consumption of ethanol as a fuel (anhydrous and hydrous) will also increase. This will arise through the consumption of hydrous ethanol as an alternative fuel to gasoline and through the indirect consumption of anhydrous ethanol mandatorily blended in gasoline. In other words, we expect ethanol demand to respond positively to both rises and falls in the price of gasoline. Estimating ethanol demand as a dependent variable is an exercise conventionally applied to fossil fuels. The application of bounds test for cointegration analysis for ethanol has revealed that such a procedure can satisfactorily capture consumer behavior when deciding between purchasing ethanol and gasohol. Further analysis incorporating additional analytical components, including those related to vehicular characteristics and regional performance, can potentially extend the analysis. Similarly, forecasting exercises based on elasticity estimations about ethanol demand during price shocks could offer policymakers guidance for policy alternatives.

The estimated values for hydrous ethanol consumption with respect to the ethanol price, consumer income and the gasoline price elasticity have also demonstrated a transformative pattern in consumer behavior. A remarkable aspect of the study is the similar elasticity values in both the long and short run, thereby evidencing a shortening in the consumer purchasing decision in the context of overcoming technical limitations attributed to the expanding share of FFVs. The estimated values for the elasticity of ethanol demand have also demonstrated that the increasing income of consumers also tends to increase the demand for ethanol. In addition, the price of ethanol is a critical component of ethanol demand. The capacity of ethanol consumers in changing from one fuel to another in the short run imposes additional challenges on policymakers and fuel suppliers and raises a number of questions relating to the stability of supply and the relevance of current policies, including the mandatory blend, in the long run.

Numerous policy implications could result from further discussion of the findings. The verified robustness of hydrous ethanol demand as an independent fuel could stimulate, for example, further discussion of the maintenance of current blend mandates for gasohol. Another topic with extensive policy implications and a major impact on economic indicators, e.g. inflation, is the supply capacity, requiring careful discussion of the necessity of establishing a secure reserve for ethanol to attend to demand during seasons of lower production. In the same vein, we could consider a review of exports and the expansion of ethanol to other uses in the short term in order to avoid supply crises such as that observed in Brazil between October 2009 and February 2010.

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