# THE IMPACT OF A GROWING ETHANOL MARKET ON THE DEMAND ELASTICITY FOR GASOLINE IN BRAZIL[†]

By

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*ABSTRACT*

In response to the oil shocks during the 1970s and the consequent deterioration of the country's balance of payments, the Brazilian government channeled efforts to the exploration of off-shore oil basins and to stimulating the use of biofuels in place of gasoline and diesel. The government national ethanol program aimed at reducing the consumption of fossil fuels by imposing the addition of dehydrated alcohol to the gasoline used in Otto cycle engines and by stimulating the production and use of hydrated alcohol fueled vehicles. Over the years, as the production of ethanol increased, the technological improvements in agricultural techniques and in the industrial production of ethanol promoted significant cost reduction, even when the lower energetic density of this biofuel is taken into account. Since 2003, light vehicles which allow consumers to use hydrated alcohol or gasoline as fuels started being sold in Brazil, increasing dramatically the market for ethanol in the country. Using a dynamic model with panel data including all Brazilian federal states, this paper estimates an econometric model to measure the effect of the introduction of this flex fuel technology on the demand for gasoline in Brazil. The results indicate the expansion of ethanol's participation in the fuels market has led to a substantial increase in the price and cross-price elasticity of the demand for gasoline.

Keywords: Gasoline Demand Elasticity; Ethanol; Flex Fuel Vehicles.

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# 1. INTRODUCTION

Over time, the use of energy resources has been characterized by the overwhelming preference of a single energy input over its substitutes. The transition from wood to coal and, later, to petroleum occurred through the progressive substitution of one input over another due to market pricing rather than the exhaustion of traditional fuels reserves. Logistic easiness, abundant reserves and lower relative costs have consolidated petroleum derived fuels as the primary world energy source since the past century, gradually reducing the use of coal and wood. In the last few years, however, oil prices volatility, growing exploration costs and political instability in the main producing countries have fueled uncertainties with regards to the availability of oil at reasonable prices and spurred the search for substitutes to petroleum.

Growing concerns about global warming have also centered efforts in research and use of renewable fuels. Targeting the transport segment is fundamental in the quest to reduce greenhouse gases, due to its high growth rate and heavy reliance on fossil fuels. For instance, it was estimated that, by 2000, transport emissions would responsible for almost 15% of the total anthropogenic emissions in the world, while, in Brazil, this rate could reach 50% (see Poole et al, 1998; and Baumert et al, 2005). Therefore, the increasing use of renewable fuels in transportation not only provides greater energy security for countries dependent of fossil fuel imports, but it also helps lowering the emission of pollutants that contribute to global warming.

The policies underway in most developed countries with regards to biofuels have focused on the need to reduce environmental pollution and to diversify the energy mix by reducing fossil fuel dependency. In developing countries, in turn, government policies have also aimed at fostering greater employment rates associated with the biofuels production chain and foreign exchange savings with the decreased reliance on oil imports. In Brazil, the government has channeled efforts to the exploration of off-shore oil basins by the state oil company Petrobras and to stimulating the use of biofuels in place of gasoline and diesel.

In response to the oil shocks during the 1970s and the consequent deterioration of the country's balance of payments, the Brazilian government sponsored its first major biofuel national program, the "Pró-Alcool". Introduced in 1975, the program aimed at reducing the consumption of fossil fuels by imposing the addition of dehydrated alcohol to the gasoline used in Otto cycle engines and by stimulating the production and use of hydrated alcohol fueled vehicles. The incentives included setting market prices below costs, tax breaks and funding for research and development. The consequent growth in the demand and production of ethanol stimulated the leaning-by-doing process that led to technological improvements in agricultural techniques and in the industrial production of ethanol, promoting significant cost reduction and granting a competitive edge to the biofuel.

While during the 1980s the market for ethanol expanded greatly, this trend was dramatically reversed in the 1990s, as the fuel prices were liberalized domestically and the international oil prices fell. For instance, the number of hydrated alcohol vehicles sold in the country, which represented as much as 95.8% of the car sales in the country in 1985, fell to 0.8% in 1996 (see Calle and Cortez, 1998). This downward performance persisted until early 2000s, and the consumption of ethanol relative to gasoline reduced almost to the level of the first years of the "Pró-Alcool" program.

In 2003, however, an innovative technology led to a significant shift in light vehicles fuel market in Brazil. Light vehicles, which allow consumers to use hydrated alcohol or gasoline as fuels, started being sold in Brazil, increasing dramatically the market for ethanol in the country. This new technology has allowed consumers to exploit the price differences in ethanol and gasoline, increasing the substitutability between the two fuels. It is expected that in the next two years the sale of these new type of vehicle will reach the totality of the light automobiles sold in the country.

This paper aims at estimating an econometric model to measure the effect of the introduction of these flex fuel engines on the demand elasticity for gasoline in Brazil. Most estimations of the demand elasticity for gasoline were either undertaken prior to the introduction of flex fuel vehicles in the Brazilian market (see Burnquist and Bacchi, 2002; Alves and Bueno, 2003; and Roppa, 2005) or have implemented time series cointegration analysis using aggregated country data (see Schunemann, 2007; Azevedo, 2007; and Nappo, 2007). Nonetheless, the fuel markets in each federal state have characteristics that should be taken into account in order to derive the overall demand elasticity for the country. Particularly, the costs of ethanol vary greatly from state to state due to differences in state taxation and, most importantly, because production of ethanol is concentrated in only eight states (thus, transportation costs, specially for the northern states, are substantial). This paper innovates in estimating a dynamic model with panel data with all Brazilian federal states using a Generalized Method of Moments – System technique (GMM-SYS).

The present work is organized as follows. The second section briefly describes the market for ethanol in Brazil, stressing the importance of lower taxation burden and technological improvements to its growth. The third section describes the data and the econometric methodology used, while the fourth section analyzes the empirical results and its robustness. The last section concludes the work, pointing out the fiscal and energy policy implications of the findings.

## 2. THE "PRÓ-ALCOOL" PROGRAM

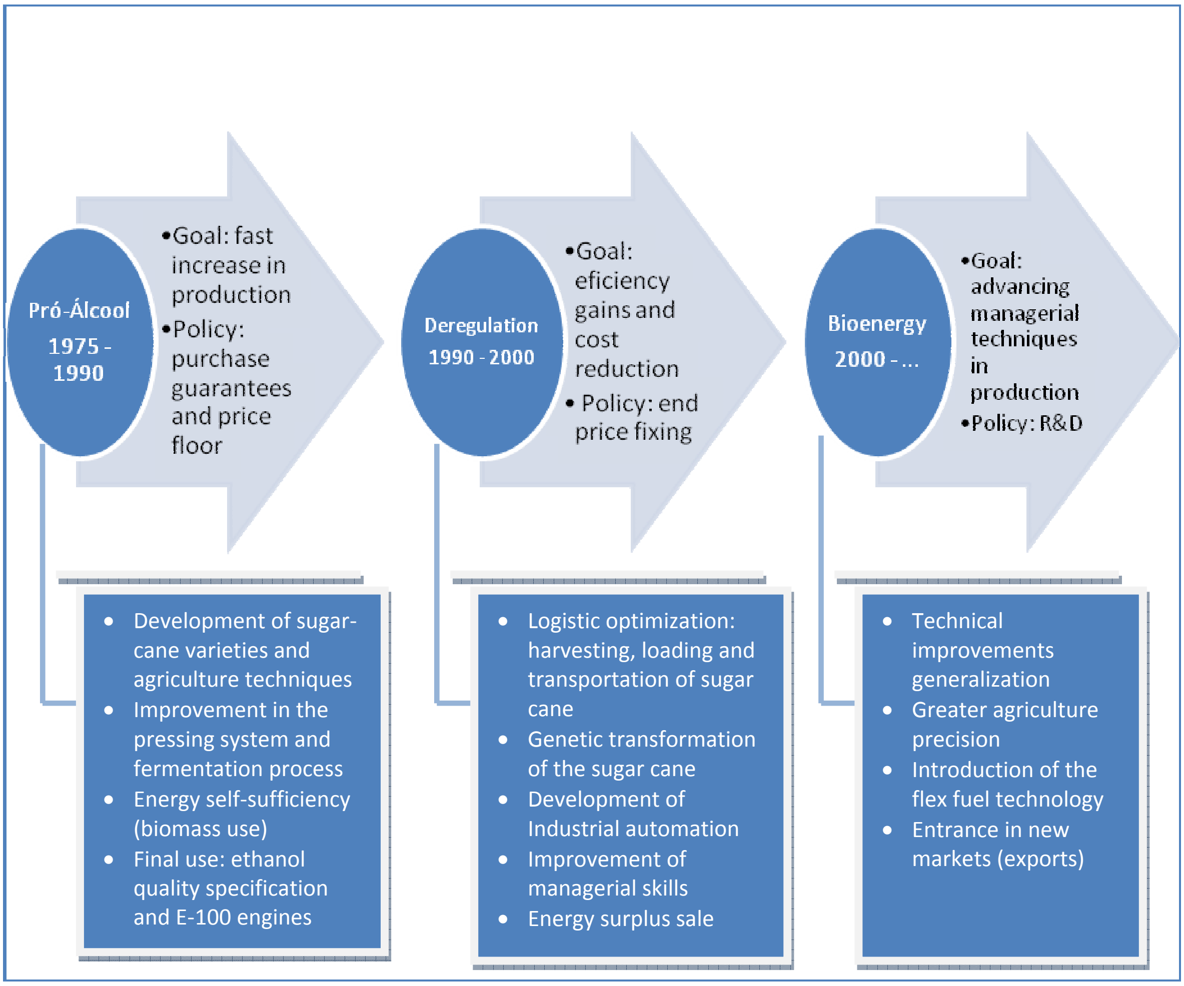
The belief on the strategic role of the petroleum industry in promoting development has led to a strong government intervention in the market for fuels in Brazil. Until the early 1990s, the exploration, refining and commercialization of fossil fuels were monopolized by the government-owned company Petrobras, which, until today and despite the changes in the regulatory framework allowing greater market competition, has a dominant position in setting fuel prices in the domestic market[1].

Dramatic shifts in price have the potential to harm political aspirations of government officers, given the strong dependency of the country's transport sector, particularly freight, on diesel and the weight of gasoline expenditures on consumers' budgets. Thus, the government still takes advantage of Petrobras' market power to buffer domestic fuel prices from exchange rate fluctuations and oil prices volatility.

The development of the Brazilian national ethanol program, known as "Pró-Alcool", introduced biofuels in the Brazilian energy mix in the late 1970s. The program was undertaken, along with greater exploration efforts, in response to the oil shocks, as the government became concerned with the impacts of the growing oil prices on domestic inflation and on the balance of payments. The goal was to reduce the consumption of fossil fuels by imposing the addition of dehydrated alcohol to the gasoline used in Otto cycle engines and by stimulating the production and use of hydrated alcohol fueled vehicles. The evolution of the program is depicted on Figure 1: the arrows show the main goals and policies at each phase of the program, while the boxes lists the most important results achieved.

[1] The regulatory framework was changed substantially since 1995. Measures were undertaken with the goal to eliminate barriers to entry and exit the market, to phase out cross-subsidies among fossil fuels and to let the market prices be determined solely by the interaction of demand and supply (see Cavalcanti (2006) and Macedo (2007)).

**Figure 1 – The Brazilian National Ethanol Program**




Source: Macedo (2007)

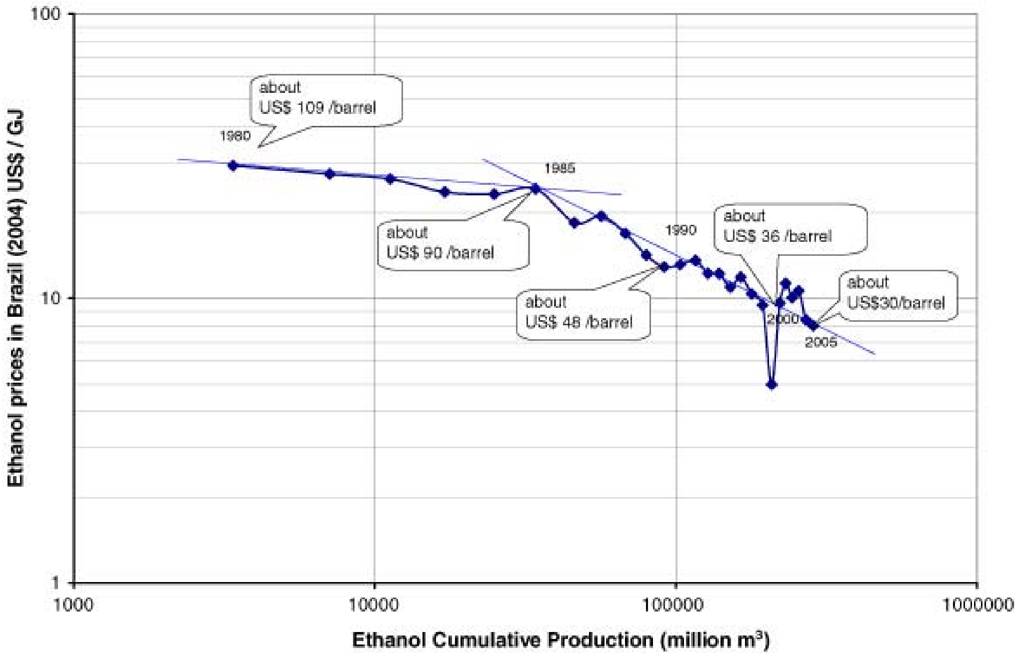
In the first phase, several incentives were designed to foster the production and use of ethanol. Its price was set well below that of gasoline, a direct subsidy was given to ethanol producers and taxes cuts went into place, such as lower taxes charged in the acquisition and property of hydrated alcohol vehicles relative to gasoline fueled cars. Because the government would set fuels' market prices, the lower prices on ethanol actually worked as a cross-subsidy which guaranteed a competitive advantage to the biofuel relative to gasoline[2].

In addition to these fiscal policy initiatives, the government also sponsored research efforts both at the agriculture and at the industry segments, with the aim to improve sugar cane crop yields and the processing industry productivity. Goldemberg (2006) argues that, as the demand and production of ethanol increased and the research efforts results kicked in, production costs fell as part of the learning-by-doing process, even when the lower energetic density of this biofuel is taken into account (see Figure 2). The main improvements were observed in agricultural

[2] Since the fuel market liberalization went into place, the market prices have been normally set taking into account the energetic equivalency of 70%, but, depending on the sugar-cane harvesting period and the consequent impact on the ethanol cost of production, the ethanol price relative to that of gasoline differs from state to state, as will be pointed out below.

practices and management, and use of sugar cane biomass for energy production[3]. Macedo (2007) also lists several gains associated with the technology advancement, such as increased pressing capacity, lower fermentation time, increased fermentation and distillation yields, significant improvement in total yield (from 66 to 86 liters of ethanol/ton of sugar cane), reduced vapor consumption and greater surplus of biomass from the pressing of sugar cane[4].

**Figure 2 – Ethanol Learning Curve**




Source: Goldemberg (2006)

As a result of the "Pró-Alcool", the consumption of ethanol increased dramatically in the 1980s relative to that of gasoline, as illustrated in Figure 3. The growth in the market for ethanol peaked in 1985, when almost the totality of the light automobiles purchased in the country had hydrated-alcohol fueled engines. As the production of ethanol increased, the dynamic center of the ethanol/sugar industry moved from the northeast region of the country to the south, southeast and mid-west. Currently, only eight of the 27 states produce ethanol in excess of its needs, exporting the surplus to other states and to the international market.

During the late 1980s and 1990s, however, the growth trend experienced during the 1980s was reversed, as international oil prices fell, domestic fuel prices were liberalized and international sugar prices raised (the industry shifted production from ethanol to sugar, reducing the supply of the biofuel in the domestic market). Although the taxation of ethanol remained inferior to that of gasoline, it became no longer an advantage for consumers to acquire hydrated alcohol vehicles. As a result, until early 2000s, the consumption of ethanol relative to gasoline reduced almost to the level of the first years of the program.

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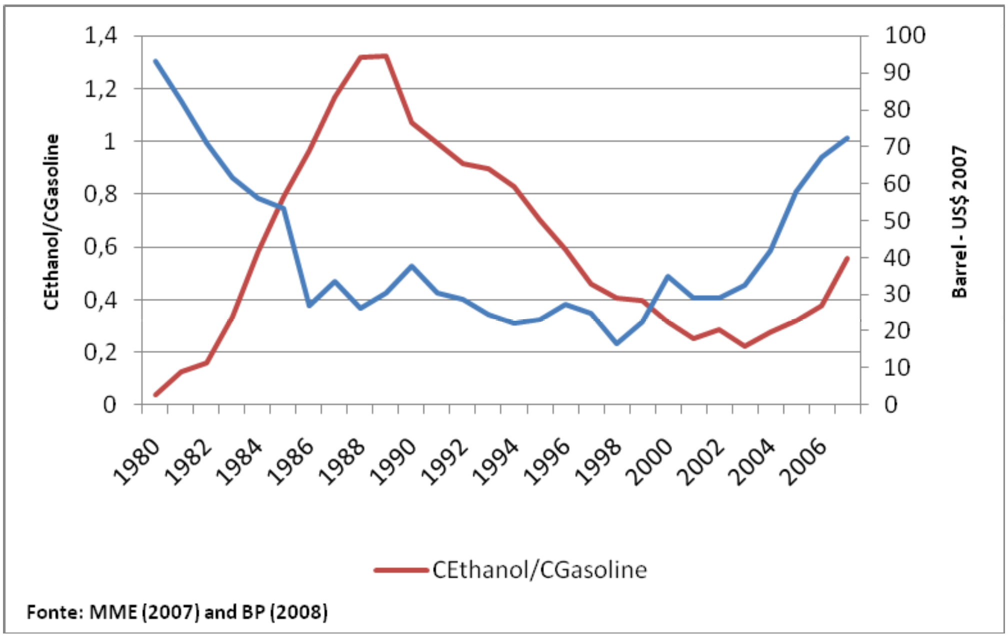
[3] Goldemberg (2006) points out that the use of sugar cane biomass for energy production has allowed sugar cane ethanol to present the best energy balance among biofuels with commercially available technologies.

[4] Brazil produces ethanol solely from sugar cane, and it has a competitive edge over other ethanol producing countries.

**Figure 3 – Relative Consumption of Ethanol in Brazil and Oil Prices: 1980 – 2007**




In 2003, light vehicles that can run on either gasoline or hydrated alcohol started being sold in Brazil. The introduction of these "flex fuel" automobiles in the market, as the new technology became known, increased dramatically the market for ethanol in the country. Both the flex fuel and the ethanol fueled vehicles have a lower performance than the gasoline fueled ones, but the flex fuel technology allows consumers to exploit the price differences in ethanol and gasoline, increasing the substitutability between the two fuels. According to Anfavea (2008), in 2007, 72.7% of the light vehicles sold in the country were flex fuel and 27.3% were gasoline fueled (the percentages were 2.7% and 95.2% in 2003, and 39.4% and 58.4% in 2005, respectively).

The state of São Paulo is the most dynamic industrial area for the production ethanol in Brazil, accounting for 65% of the total production, 42% of the consumption and almost the totality of the country's exports of the biofuel. Along with the states of Paraná, Goiás and Mato Grosso do Sul, these states concentrate close to 80% of the total ethanol produced in the country. The concentration of production in few states, along with differences in taxation, has led to different regional market outcomes.

Though the differences in prices do not seem significant at first inspection, the impact is relevant when the quantity sold in the market is taken into account. Table 1 shows that the prices in states located in the northern region of the country, such as Acre, Amapá and Pará, the price per liter of ethanol can reach a level 86% greater than in São Paulo, the major producer of ethanol in Brazil. The discrepancies in the market for ethanol relative to the gasoline across states can also be seen when analyzing the price dispersion: the standard deviation of the ethanol prices is twice as great as that of the gasoline prices. The tax burden also varies from state to state, and this variation is greater in the market for ethanol, where the standard deviation of the sales taxes is much higher than in the gasoline market.

**Table 1 – Regional Market for Gasoline and Ethanol: Differences in Pricing, Size and Tax Burden**

| | Ethanol Price (R$/l) | Ethanol Sales ($m^3$) | State Sales Tax (%) | Gasoline Price (R$/l) | Gasoline Sales ($m^3$) | State Sales Tax (%) |
|---|---|---|---|---|---|---|
| Acre | 0.012 | 332 | 25 | 0.016 | 4037 | 25 |
| Alagoas* | 0.010 | 2305 | 27 | 0.016 | 13829 | 27 |
| Amapá | 0.013 | 87 | 25 | 0.016 | 4926 | 25 |
| Amazônia | 0.011 | 1222 | 25 | 0.015 | 25756 | 25 |
| Bahia | 0.010 | 5188 | 19 | 0.015 | 82237 | 27 |
| Ceará | 0.010 | 3715 | 25 | 0.015 | 49036 | 27 |
| D. Federal | 0.011 | 7447 | 25 | 0.015 | 57871 | 25 |
| E. Santo | 0.010 | 3641 | 25 | 0.015 | 37567 | 27 |
| Goiás* | 0.009 | 14669 | 26 | 0.015 | 72452 | 26 |
| Maranhão | 0.011 | 854 | 25 | 0.015 | 23841 | 27 |
| Minas Gerais* | 0.009 | 34271 | 25 | 0.014 | 212857 | 25 |
| Mato Grosso* | 0.010 | 5534 | 25 | 0.017 | 29371 | 25 |
| M. Grosso do Sul* | 0.010 | 5739 | 25 | 0.016 | 26523 | 25 |
| Pará | 0.013 | 860 | 30 | 0.016 | 33967 | 30 |
| Paraíba* | 0.010 | 2700 | 25 | 0.015 | 22608 | 27 |
| Paraná* | 0.008 | 40942 | 18 | 0.014 | 133217 | 28 |
| Pernambuco* | 0.010 | 6664 | 25 | 0.015 | 51813 | 27 |
| Piauí | 0.012 | 1361 | 25 | 0.015 | 14061 | 25 |
| RG do Norte | 0.010 | 2172 | 25 | 0.015 | 21321 | 25 |
| RG do Sul | 0.011 | 14981 | 25 | 0.016 | 157639 | 25 |
| Rio de Janeiro | 0.009 | 15950 | 24 | 0.015 | 143225 | 31 |
| Rondônia | 0.011 | 1092 | 25 | 0.016 | 13775 | 25 |
| Roraima | 0.012 | 83 | 25 | 0.015 | 4055 | 25 |
| Santa Catarina | 0.010 | 14639 | 25 | 0.015 | 109539 | 25 |
| Sergipe | 0.011 | 1218 | 27 | 0.015 | 13769 | 27 |
| São Paulo* | 0.007 | 197310 | 12 | 0.014 | 582350 | 25 |
| Tocantins | 0.010 | 1131 | 25 | 0.016 | 10644 | 25 |
| Mean | 0.010 | - | 24.4 | 0.015 | - | 26.1 |
| Std. Deviation | 0.00125 | - | 3.272 | 0.00065 | - | 0.016 |

Note: (i) The prices of ethanol and gasoline are after taxes sales price (median over the 2001-2008 period); (ii) the sales of ethanol and gasoline are the median over the 2001-2008 period; (iii) the tax burden presented in the table shows only state level taxation. Federal taxes were not included, as they are uniform across the country. In 2008, for example, PIS/COFINS amounting to R$0.120 and R$0.148 were charged per liter of ethanol and gasoline sold, respectively; and (iv) the states identified with a * produce ethanol in excess of their needs and export the surplus.
Source: ANP (2009a, 2009b), FECOMBUSTÍVEIS (2009) and UNICA (2009).

Therefore, it is important to eliminate the specific effects associated with each federal state when estimating the demand elasticity for gasoline in the country, especially after 2003, when degree of substitutability between ethanol and the fossil fuel increased[5]. One example of an isolated state policy change that caused a significant impact at a local level: in the end of 2003, the state of São Paulo reduced the state sales tax on ethanol from 25% to 12%, leading to lower tax evasion and fuel adulteration and, as a consequence, stimulating the sales of the biofuel, which grew 76% in the following year.

# 3. DATA AND METHODOLOGY

The tests were run on quarterly panel data of 27 federal states. Panel data has advantages over cross section or pure time series data because it allows accounting for the time series variation of the data and, at the same time, to control for the biases that arise due to non-observable states' specific effects.

Due to data availability constraints, the time period runs from the third trimester of 2001 to the fourth semester of 2006[6]. Note, however, that this sample is large enough to account for the period prior and after the introduction of flex fuels vehicles. Fuel prices and consumption data were obtained from ANP (2009a, 2009b), while information on income per capita and price indexes was provided by IBGE (2009a, 2009b).

The econometric analysis aimed at testing the hypothesis that the introduction of the flex fuel technology has increased the elasticity of the demand for gasoline in Brazil, because it allows for a greater substitutability between hydrated alcohol and gasoline. The tests were run on both the full time period and on a shorter sample ranging from 2003, the year of introduction of the flex fuel technology, and 2007. Lack of state level panel data prior to 2001 does not allow estimating the demand elasticity prior to the introduction of the new technology, but the results obtained here were compared to those presented by the works cited before, which used time series annual data.

Since the independent variables are endogenous, the fixed effects model normally used in panel data analysis leads to biased estimators. For this reason, the choice of econometric methodology was GMM, which is more efficient. The following equation was estimated:

$$\mathbf{QGAS_{i,t} = \alpha + \beta_1 PGAS_{i,t} + \beta_2 PETH_{i,t} + \beta_3 Y_{i,t} + \beta_2 QGAS_{i,t-1} + \mu_i + \lambda_t + \varepsilon_{i,t}}$$

where QGAS = log of sales of gasoline, PGAS = log of the real price of gasoline, PETH = log of the real price of ethanol, Y = log of the real gross domestic product per capita, $\mu$ represents the matrix of state dummy variables, and $\lambda$ is the matrix of time dummy variables[7].

Arellano e Bond (1991) suggest to first-difference (GMM-DIF) the above equation in order to eliminate the specific effects associated with each federal state and to deal with endogeneity, using the lagged levels of the explanatory variables as instruments. According to Blundell and Bond (1998) and Beck (2001), this procedure eliminates the cross-section variation of the data, which represents a conceptual disadvantage and econometric shortcoming. These authors go on to suggest the use GMM on a system of equations (GMM-SYS). In this system, lagged levels are used as instruments for the first-differenced equations, while lagged first-differences are used as instruments for the equations in levels. Blundell and Bond (1998) argue that the system

[5] The substitution of gasoline for ethanol is felt more intensely in exporting states during the harvesting period and in states where the burden of taxation is reduced.
[6] Pricing data at the state level is only available starting in the third trimester of 2001, while income data, also at the state level, can be gathered up to the last quarter of 2006.
[7] The real prices were calculated dividing the current prices by the consumer price index IPCA (see IBGE, 2009b).

estimator reduces the potential biases and imprecision associated with the difference estimator and performs better in Monte Carlo simulations in finite samples.

Therefore, the GMM-SYS is estimated stacking the regressions in differences and in levels, with the following moment conditions applied to the first and second part of the system, respectively[8]:

$$E[(\varepsilon_{i,t} - \varepsilon_{i,t-1})QGAS_{i,t-j}] = 0,\ \ j = 2, ..., t-1 \text{ e } t = 3, ..., T;$$

$$E[(QGAS_{i,t-j} - QGAS_{t-j-1})\varepsilon_{i,t})] = 0, j = 2,...,t-1 \text{ e } t =3, ...,T.$$

For the GMM estimator to be consistent, it is necessary that ε does not exhibit serial correlation and the instruments must be valid. Two standard tests will be used to confirm the validity of these hypotheses, as suggested by Arellano and Bond (1991). The serial correlation test verifies if the differenced error terms are second-order serially correlated, since the model suggest by construction that the errors are first-order serially correlated. If the hypothesis of second-order serial correlation is rejected, the original error term is not serially correlated and the moment conditions are correctly specified.

The Sargan test, in turn, confirms whether the instruments used in the econometric tests are representative. The null hypothesis is that the instruments are not correlated with the residuals and its rejection implies that the orthogonality conditions are not met (the model has not been correctly specified). The Sargan statistic follows a $\chi^{(q-k)}$ distribution, where q is the number of estimated coefficients and k is the instruments rank.

## 4. RESULTS

The descriptive statistics and correlations among the variables are presented in Table 2. Overall, there is significant variation in QGAS and in Y across the states, reflecting the differing economy sizes and development levels. Note also that the standard deviation of PETH is greater than PGAS, confirming the outcome pointed out on Table 1: there are significant asymmetries in the market for ethanol among Brazil´s federal states. With respect to the correlation among the variables, the signs are as expected: QGAS is negatively correlated with PGAS and positively correlated with PETH and Y. Note also that the correlation between PGAS and PETH is quite elevated and increases slightly in the shorter sample, indicating the high degree of substitution between the two fuels.

The results of the GMM-SYS estimation are shown on Table 3. The coefficients of the independent variables represent the elasticities, and some of the results are quite different from those presented in previous studies, which highlights the importance of detangling the states' specific effects. For instance, in the full sample, the price elasticity of the demand for gasoline in Brazil ($\varepsilon_{PGAS}$) is –0.945, a result that is statistically significant at the 1% level. This elasticity level is significantly greater than the results found in other studies (see Table 4). Besides the specific effects, this difference may be also due to the fact that there are few observations prior to the introduction of the flex fuel technology and, therefore, the results are mostly reflecting the impact of that technology shock. This reasoning can be confirmed by inspecting the results obtained with the shorter sample: the demand for gasoline becomes quite elastic, –1.505 (this result is statistically significant at the 1% level).

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[8] Similar moment conditions are applied to the explanatory variables, which are considered potentially endogenous. Since the lagged levels are used as instruments for the regression in differences, only the most recent differences are used as instruments for the regression in levels, as the use of additional lagged differences would lead to redundant moment conditions (see Arellano and Bover, 1995).

**Table 2 – Descriptive Statistics and Correlations**

| Descriptive Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Full Sample | | | | Shorter Sample | | | |
| | PGA | QGAS | PET | Y | PGAS | QGAS | PETH | Y |
| Mean | 0.016 | 70594.3 | 0.011 | 1519.9 | 0.015 | 71580.8 | 0.011 | 1578.78 |
| Median | 0.016 | 28676.1 | 0.011 | 1221.4 | 0.015 | 29585.9 | 0.011 | 1280.70 |
| Maximu | 0.019 | 650810. | 0.016 | 6203.3 | 0.018 | 612496.4 | 0.016 | 6203.32 |
| Minimum | 0.013 | 2954.7 | 0.006 | 427.69 | 0.013 | 3448.698 | 0.006 | 539.46 |
| Std. Dev. | 0.001 | 112288. | 0.002 | 934.10 | 0.001 | 111142.9 | 0.002 | 991.039 |
| Skewness | 0.248 | 3.454 | 0.032 | 2.247 | 0.314 | 3.373 | -0.059 | 2.355 |
| Kurtosis | 2.652 | 15.738 | 2.966 | 9.831 | 2.710 | 15.162 | 2.983 | 9.910 |
| # Obs. | 594 | 594 | 594 | 594 | 405 | 405 | 405 | 405 |
| **Correlations** | | | | | | | | |
| | Full Sample | | | | Shorter Sample | | | |
| | PGA | QGAS | PET | Y | PGAS | QGAS | PETH | Y |
| PGAS | 1.000 | | | | 1.000 | | | |
| QGAS | -0.281 | 1.000 | | | -0.330 | 1.000 | | |
| PETH | 0.611 | -0.463 | 1.000 | | 0.618 | -0.495 | 1.000 | |
| Y | -0.098 | 0.411 | -0.225 | 1.000 | -0.080 | 0.389 | -0.253 | 1.000 |

**Table 3 – Tests Results: GMM-SYS**

| | Full Sample | Shorter Sample |
|---|---|---|
| C | -0.051*** | -0.103** |
| | (-4.558) | (-2.238) |
| ΔPGAS | -0.945*** | -1.505*** |
| | (-3.959) | (-3.725) |
| ΔPETH | 0.049 | 0.611*** |
| | (0.484) | (2.521) |
| ΔY | 0.154* | 0.370** |
| | (1.982) | (2.042) |
| ΔQGAS(-1) | 0.135*** | 1.001*** |
| | (4.348) | (322.834) |
| No. Obs. (n) | 592 | 403 |
| Sargan Test (p-value) | 0.565 | 0.147 |
| Serial Correlation Test (p-value) | 0.265 | 0.132 |

Note: (i) Numbers in parenthesis represent the t-statistics, and *, ** and *** indicate levels of significance of 10%, 5% and 1%, respectively; (ii) the Kernel option used was Bartlett, the Newey and West's fixed bandwidth selection was used and the sample moments were prewhitened; (iii) Time dummies were included.

Another interesting finding refers to the cross-price elasticity ($\varepsilon_{PETH}$): while in the full sample the degree of substitutability between ethanol and gasoline is not noteworthy, the cross-price elasticity reaches a quite high level in the shorter sample. In the full sample, $\varepsilon_{PETH}$ equals to 0.049 (this outcome is not a statistically significant outcome), while in the shorter sample $\varepsilon_{PETH}$ equals to 0.611 (this result is statistically significant at the 1% level). When compared to previous studies, the cross-price elasticity of the demand for gasoline in the shorter sample is somewhat greater. The use of quarterly data in this paper rather than annual data, the shorter time span and, most importantly, the impact of technological shock may be also causing this divergence.

As far as the income elasticity of the demand for gasoline in Brazil ($\varepsilon_Y$) is concerned, its level is not high: 0.154 and 0.370 in the full and shorter samples, respectively (these results are statistically significant at the 10% and 5% levels). Compared to previous studies, the income elasticity of the demand for gasoline is somewhat in the same range of the results reported.

**Table 4 – Results Reported in Previous Studies**

| | Short-run | | | Long-run | | |
|---|---|---|---|---|---|---|
| | $\varepsilon_{PGAS}$ | $\varepsilon_{PETH}$ | $\varepsilon_Y$ | $\varepsilon_{PGAS}$ | $\varepsilon_{PETH}$ | $\varepsilon_Y$ |
| **Burnquist and Bacchi (2002)** | -0.319 | - | 0.600 | -0.227 | - | 0.959 |
| **Alves and Bueno (2003)** | -0.465 | 0.480 | 0.122 | -0.092 | 0.230 | 0.122 |
| **Roppa (2005)** | -0.073 | -0.197 | 0.472 | -0.634 | 0.402 | 0.164 |
| **Azevedo (2007)** | - | 0.364 | 0.137 | - | 0.301 | 0.433 |
| **Nappo (2007)** | - | - | - | -0.197 | - | 0.685 |

Regarding the robustness of the econometric results, the Sargan test reported on Table 3 confirms that the instruments are not correlated with the residuals and, therefore, that the orthogonality conditions are met (the p-value found is greater than 0.05; thus, the hypothesis that the instruments are valid is accepted at the critical value of 5%). The serial correlation test, in turn, reveals that the original error term is not serially correlated at the second-order and the moment conditions are correctly specified.

The tests were also rerun using the fixed effects model and GMM-DIF. The results, which are depicted on Table 5, shows that choice of methodology do matter. While the signs of the price and income elasticity of the demand for gasoline are, in most cases, consistent with the GMM-SYS results, the cross-price elasticity has unexpected negative sign in the shorter sample. Note, however, that these models have the shortcomings pointed out above: the errors on the fixed-effects model are serially correlated, as indicated by the Durbin-Watson statistic; the same occurs in the estimation of GMM-DIF for the full sample. Only the estimation of GMM-DIF for the shorter sample seems robust (the errors do not exhibit serial correlation and the instruments are considered valid), and the results are quite similar to those obtained using GMM-SYS. Still, as pointed out above, this procedure eliminates the cross-section variation of the data, which represents a conceptual disadvantage and econometric shortcoming.

**Table 5 – Alternative Econometric Methodologies**

| | Fixed Effects* | | GMM-DIF | |
|---|---|---|---|---|
| | Full Sample | Shorter Sample | Full Sample | Shorter Sample |
| C | 6.685*** | 6.425*** | -0.019 | -0.045*** |
| | (13.648) | (8.297) | (-1.549) | (-3.169) |
| PGAS | -0.577*** | -0.316*** | -0.775*** | -1.288*** |
| | (-6.016) | (-3.282) | (-3.104) | (-3.786) |
| PALC | 0.095* | -0.167*** | 0.300*** | -0.037 |
| | (1.686) | (-2.980) | (2.676) | (-0.281) |
| Y | 0.185*** | 0.226*** | -0.060 | 0.244* |
| | (5.092) | (2.530) | (-0.824) | (1.685) |
| QGAS(-1) | 0.015 | 0.004 | 0.331*** | -0.231*** |
| | (1.053) | (0.346) | (7.093) | (-3.762) |
| No. Obs. (n) | 593 | 404 | 573 | 391 |
| Teste de Sargan* | - | - | 0.895 | 0.994 |
| Teste de Correlação Serial | - | - | 0.003 | 0.299 |
| $R^2$ Ajustado | 0.997 | 0.998 | - | - |
| Durbin-Watson Statistic | 1.066 | 1.397 | - | - |

Note: (i) Numbers in parenthesis represent the t-statistics, and *, ** and *** indicate levels of significance of 10%, 5% and 1%, respectively; (ii) In the fixed effects model, time series and state dummies were included and the standard errors are robust to the presence of heterocedasticity (White method); (iii) In the GMM-DIF model, the dependent and independent variables were first differenced and time dummies were included (the instruments used are the lagged levels of the independent variables and the time dummies).

## 5. CONCLUSION

The use of ethanol produced from sugar cane has become a viable substitute for the gasoline used on light vehicles in Brazil. Lower tax burden, innovative incentives and investment in research and development have guaranteed the growing insertion of ethanol in the Brazilian transportation fuel market. By stimulating the use of biofuels, the country has achieved greater energy security, environmental benefits and income generation in rural areas.

Sugar cane has significant comparative advantages relative to other raw materials used in the production of ethanol, due to its consolidated production chain and the technological efforts undergone in the areas of hydrolysis and biomass gasification. In addition, the use of sugar cane biomass for energy production has allowed sugar cane ethanol to present the best energy balance among biofuels with commercially available technologies.

Early in 2000s, the introduction of the flex fuel technology and the consequent expansion of ethanol's participation in the Otto cycle engine fuels market have led to significant changes in the market for gasoline in Brazil. The new technology has dramatically increased the degree of substitution between gasoline and ethanol. Yet, the concentration of production in few of the federal states, along with differences in taxation, has led to different regional market outcomes.

The tests results presented here have not only shown that the cross-price elasticity of the demand for gasoline with respect to ethanol is sizable, but that the demand for gasoline has become quite elastic. These outcomes are econometrically robust and provide better estimates of the several measures of elasticity of the demand for gasoline than previous studies because the tests have controlled for the biases that arise due to the referred non-observable states' specific effects.

There are opportunities to replicate the Brazilian ethanol program in other countries, particularly in the tropical regions of Central America, Africa and Asia. These regions, which currently have low human development indicators, would greatly benefit from the income and employment generated by such initiative. Fostering the use of ethanol and reducing the import barriers imposed by developed countries are therefore essential to achieve greater social and economical progress and significant reduction in greenhouse gases emissions.

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