Coordenação
Maria Leonor da Silva Carvalho
Pedro Damião de Sousa Henriques
Vanda Narciso

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SUPPLY BEHAVIOR OF HYDROUS ETHANOL IN BRAZIL

Cinthia Cabral da Costa (Resercher, Embrapa Instrumentação, Brazil)
Heloisa Lee Burnquist (Associate Professor, University of Sao Paulo, Brazil)
Luciano Rodrigues (Manager, Economics Department of UNICA, Brazil)
Maurício Jorge Pinto de Souza (Ph.D Professor University of Sao Paulo, Brazil)

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Abstract

This study describes the behavior of Brazilian hydrous ethanol supply, with particular emphasis on how producers responded to own prices and to price of substitute products based on sugarcane - such as sugar and anhydrous ethanol - emphasizing factors that have affected the supply of the product through the last decade. For this purpose, an econometric model of hydrous supply and of sugarcane supply was built, based on panel data model for the main producer states in Brazil. The data period selected to estimate the model was 2000/01-2011/12. The results indicated that the supply price elasticity for hydrous ethanol was 1.94 and the price of sugar has no influence on hydrous ethanol price through this period. For the sugarcane supply, the planted area and the number of newly installed plants at each state were important determinants of the current planted area. The sugarcane supply price elasticity lagged by one period was 0.25. As expected, the supply price response was higher in ethanol production than in that of sugarcane.

Keywords: hydrous ethanol; fuel; sugarcane; supply; Brazil

1. Introduction

In view of continuously rising petroleum costs and the historical dependence on fossil fuel resources, considerable efforts are being spent to identifying substitute energy resources. The use of gasohol (mixture of ethanol and gasoline) as an alternative motor fuel has been increasing steadily around the world. In Brazil, domestic production and use of fuel ethanol is expected to reduce the dependence on foreign oil, avoiding negative effects of trade deficits, while stimulating jobs in rural areas, reducing air pollution and global climate change due to carbon dioxide emissions. Ethanol, unlike gasoline, is an oxygenated fuel that contains 35% oxygen, which reduces particulate and NO_x emissions from combustion. Most importantly, when burned, ethanol derived from fermentation produces no net increase in carbon dioxide, the main greenhouse gas, in the atmosphere (Lang et al., 2001**b**). Ethanol is currently the most widely used liquid biofuel. Most fuel ethanol is produced from sugar cane or sugar beet.

While ethanol represents an important renewable liquid fuel for motor vehicles (Lewis, 1996), Brazil is a countries with a highly developed system of production, distribution and consumption of this biofuel. Since the introduction of the ProAlcohol in 1975, in response to the first oil crisis, the Brazilian government has provided incentives to build ethanol distilleries along with the development of the infrastructure for ethanol distribution. Two types of ethanol fuel are obtained from sugarcane biomass, namely hydrous and anhydrous ethanol. The latter is added to gasoline A in a proportion established by federal Brazilian law, which can vary from 18 to 25 percent to produce gasoline C (or gasohol). Hydrous ethanol can be used as a substitute for gasoline C in vehicles moved exclusively by ethanol – introduced in the 1970s with the ProAlcohol program – and, more recently, mixed in different proportion in cars with flex-fuel engines.

In the past 30 years, Brazil became not only a leader in renewable energy but also a virtually energy independent country. The introduction of flex-fuel engines in 2003 was an innovation of outstanding importance that stimulated the demand for hydrous ethanol in the country. In response, the supply of ethanol was expanded from the relatively low level of 5 billion liters in 2000 to 18 billion liters in 2008.

The objective of this study is to identify the related supply price elasticities in the Brazilian sugarcane market, given the impact of hydrous ethanol supply expansion after the introduction of the flex-fuel vehicles in Brazil. These elasticities are important to understand the main determinants in this market affecting hydrous ethanol production, as well as their impact upon sugarcane production. In addition, these results can be important to form expectations and provide information for policymaking. The price elasticity of supply is essential to identify market responses and policy directions. More specifically, the analysis is developed to identify what would be the consequence of price control in the economy for ethanol production, and - what is the magnitude of policy stimulus required to produce sufficient to stabilize prices, given the increasing demand.

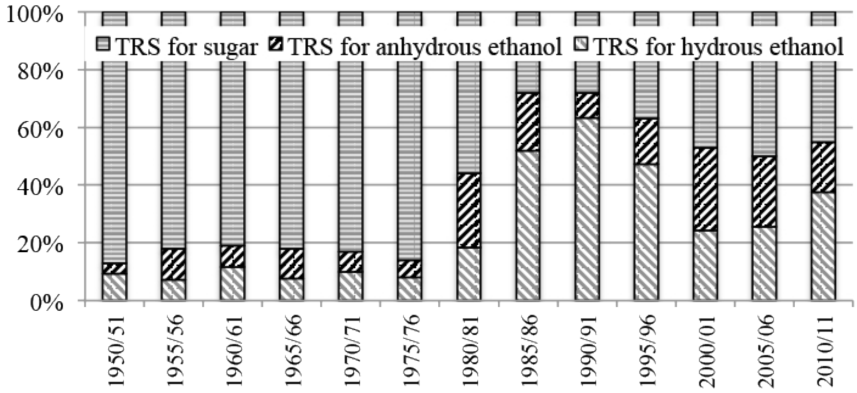
In part 2 we describe the background of the ethanol production in Brazil and make a review of the other studies that focus on the supply of the sugarcane industry. Part 3 describes the main forces that could affect hydrous ethanol production and in 4 we explain the methods and data used in this study, in order to improve on the results described in section 2. Part 5 describes and analyzes the results and finally, conclusions are drawn in part 6.

2. Background

2.1. Ethanol production

Sugar, anhydrous and hydrous ethanol are produced in Brazil through sugarcane processing - so that an increase in the production of one of these co-products implies a decrease in the proportion of the others in the total potential production. This trade-off can be represented by using the percentage of total recoverable sugar (TRS) from the sugarcane needed to obtain each of these products. As shown in Figure 1, the sum of TRS used to produce both anhydrous and hydrous ethanol production amounted to less than 20 percent or TRS until the end of the decade of the 1970s. In the first years of the 1980s, however, ethanol production showed a rapid expansion, taking its participation in TRS up to almost 50 percent. With the implementation of the ProAlcohol Program, ethanol production expanded. By 1986, however, the participation of sugar production in the TRS had been reduced to less than 30 percent. When the first ethanol supply crises developed at the end of the 1980s, the Brazilian sugarcane sector was expanding its sugar production again. Ethanol's importance as transformed sugar started to be restored only in the mid 2000s, when the flex-fuel car fleet expanded and consumers were again stimulated to consume fuel ethanol, which presented became relatively cheaper than gasoline. At the 2010/11 harvest, 38 percent of the cane was allocated to hydrous ethanol production; 17 percent to anhydrous and the 45 percent was left for sugar production (Figure 1).

Figure 1 – Sugarcane used for sugar, anhydrous ethanol and hydrous ethanol (E100) in Brazil. Period: from 1950/51 to 2010/11

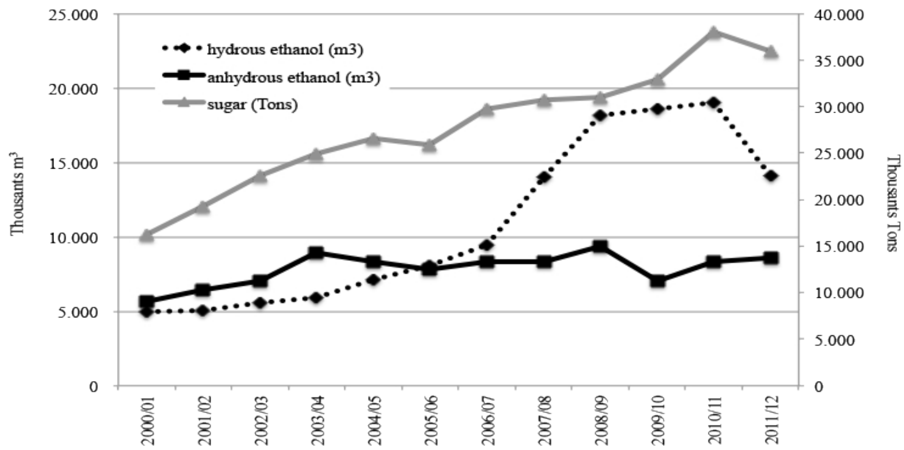


Note: TRS is total recoverable sugar.

Sources: Brazil (2009) and Unica (2012a).

Figure 2 illustrates the impressive growth of hydrous ethanol production (with an annual growth rate of 10 percent), at the expense of anhydrous ethanol which suffered a drop of 4 percent in the same period. Sugar production was also boosted, showing an annual growth rate of 7 percent in the last decade.

Figure 2 – Brazilian production of sugarcane, sugar, anhydrous and hydrous ethanol in the decade of the 2000s



Source: Unica (2012a).

2.1. Empirical evidence on the sugarcane industry supply

Selected articles have been written about the price elasticity of supply for sugarcane in Brazil, focusing on different time periods are listed in Table 1. Barros (2010) estimated two price elasticities for Brazil, considering different time periods, such as before the introduction of the flex-fuel vehicle (1998-2004) and after its adoption by consumers (2005-2009). The purpose of the study was to verify if the new technology affected the sugarcane supply in Brazil. The results indicated that after the introduction of the flex-fuel cars, sugarcane supply became more sensitive to changes in prices in São Paulo (0.93 percent against 0.48 percent before introduction of the flex-fuel vehicle). For the period 1976-2006, Satolo and Bacchi (2009) obtained an estimated price elasticity of sugarcane supply of 0.25, which is more inelastic than that found by Barros (2010). However, Barros (2010) did not consider prices in real terms. Santos (2001) found relatively low price elasticity for the sugarcane supply in the northeastern region of Brazil, indicating that for a 1 percent increase in sugarcane price, the supply rose 0.06 percent.

Table 1 – Supply price elasticities for sugarcane in Brazil for different periods

Source	Price elasticity	Period analyzed	Region analyzed
Barros (2010)	0.29 0.69	1998-2004 2005-2009	São Paulo
Satolo & Bacchi (2009)	0.25	1976-2006	Brazil
Santos (2001)	0.06	1980-1995	Brazilian Northwest

Table 2 lists a larger number of studies that analyze the behavior of sugar supply. A possible explanation for this greater emphasis on sugar than hydrous ethanol in Brazil is that the market for this commodity is well established, while the ethanol market is still subject to greater variability in its basic parameters. In addition, since Brazil is the main sugar exporter in the global market, it is an important reference for policymakers. Barros (1975) was one of the first studies that obtained estimates of sugar price elasticity for the Brazil. This study found that sugar supply is less responsive to price change in the short run (with an elasticity of 0.25) than in the long run (price elasticity of supply of 3.94), which might be explained by the period of this analysis (1947-1973). Comparing these results with those obtained by Arend (2001), who considered a more recent period (1969-1998), it can be observed that the sugar supply price elasticity was relatively higher in the short run (0.332) and lower for the long-run 0.979 than the values identified by Barros (1975). However, Arend (2001) did not consider ethanol prices in his model. Caruso (2002) estimated the sugar supply for São Paulo State during the period from January, 1994 to October, 2000, using hydrous ethanol price as an explanatory variable. The sugar supply elasticity identified by this author for own prices was a 1.89 percent, while the value of the sugar supply response to a change in ethanol price was negative, as expected, due to the substitutability between sugar and ethanol. Shikida et al. (2007) analyzed data from Parana, another important sugarcane producing state in Brazil for the period between 1980-2004 and found that sugar supply increased by 1.239 percent in response to a rise of 1 percent in sugar prices. In addition, they found that the sugar supply also increased by 1.976 percent when the ethanol price fell by 1 percent.

Table 2 - Estimated price elasticities of supply for sugar in Brazil

Source	Price elasticity	Period analyzed	Region analyzed
Barros (1975)	0.25 (short run) 3.94 (long run)	1974-1973	Brazil
Arend (2001)	0.332 (short run) 0.979 (long run)	1969-1998	Brazil
Caruso (2002)	1.89	Jan.1994- Out.2000	São Paulo State
Shikida et al. (2007)	1.239	1980-2004	Parana State
Bertotti et al. (2009)	1.106	1990-2006	Brazil

Bertotti et al. (2009) analyzed the sugar supply through the period 1990-2006, including ethanol production and the size of ethanol vehicles fleet as explanatory variables in the sugar supply model. The variables used to explain sugar supply and their respective elasticities values were: sugarcane supply (0.79), sugar price in the domestic market (1.106) and international sugar price (-1.091). These authors concluded that ethanol production and the size of the ethanol vehicles fleet were not show statistical significant effects and seemed to distorted the results of the sugar supply model when included in the estimated equation.

Unlike sugar, the production of hydrous and anhydrous ethanol seems just sufficient to supply the domestic demand, so that only a small volume of the anhydrous ethanol produced has been exported in recent years. This might explain why there are fewer studies that analyze their supply elasticities. Marjotta-Maistro & Barros (2003) estimated the price elasticity of supply for anhydrous ethanol in Brazil, arriving at a value of 0.084. The period used for the analysis was January 1995 to December 2000. The authors defend that the price inelasticity could be explained by the fact that producers did not follow market changes to determine their supply, since the Brazilian government had, for a long time, assured them that all ethanol produced would be purchased at a predetermined price.

Analyzing specifically hydrous ethanol supply, in Parana State, Shikida et al. (2007) found that, although the signs for price elasticities were as expected, these were non-significant. The authors blamed this result on instabilities that affected the ethanol market after the 1980s. Oliveira et al. (2008) analyzed the Brazilian ethanol supply for a more recent period (1995-2006) and found significant price elasticity, but at a low value (0.207), which represents an inelastic supply. In their model, those authors used ethanol price alone as an explanatory variable, plus a dummy variable for a period 2002-2006, due to an increase in oil prices in the international market.

Table 3 – Supply price elasticities for ethanol in Brazil and U.S. for different periods

Source	Price elasticity	Period analyzed	Region analyzed
Marjotta-Maistro & Barros (2003)	0.084 (anhydrous)	1995-2000	Brazil
Shikida et al. (2007)	Not significant	1980-2004	Parana State
Oliveira et al. (2008)	0.207	1995-2006	Brazil
Rask (1998)	0.75	1984-1993	U.S.
Luchansky & Monks (2009)	0.2	1997-2006	U.S.

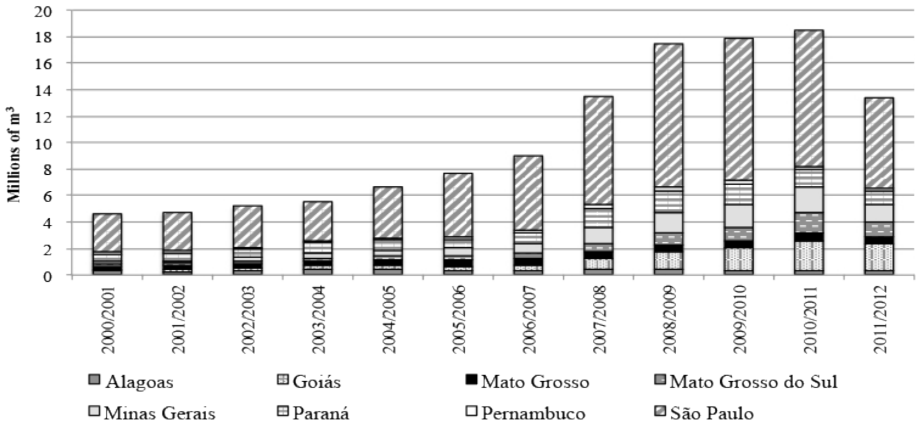
Supply price elasticities were estimated for the US ethanol market by Rask (1998) and Luchansky & Monks (2009). Rask analyzed the period from 1984 to 1993 and found a value of 0.75 for supply price elasticity. Luchansky & Monks (2009) analyzed a more recent period (1997-2006) and found a supply price elasticity of 0.2. These authors considered corn oil price as an explanatory variable in the supply model and found a significant, positive and inelastic elasticity. In this case, price elasticity for corn oil in the ethanol supply was positive because it is a co-product of corn ethanol in the U.S. In Brazil, however, sugar and anhydrous ethanol compete for sugarcane and we expect negative values for their price elasticities in the hydrous ethanol supply model.

The next section describes some specificities of the hydrous ethanol and sugarcane supply in the period analyzed and relations between the prices of the sugarcane industry products. These results were used in the supply economic model, presenting better adjustment and results than those described before.

3. Supply of sugarcane and hydrous ethanol in Brazil

The production of sugarcane and hydrous ethanol has been limited to specific regions of the country. Figures 3 and 4 show how hydrous ethanol and sugarcane production evolved, respectively, developed in the main producer states through the last decade. The production of the eight states included in these figures represented more than 90 percent of the Brazilian production from all 27 states in the whole period analyzed. It can be observed that the behavior of hydrous ethanol supply has been different by each of the Brazilian states represented in Figure 3.

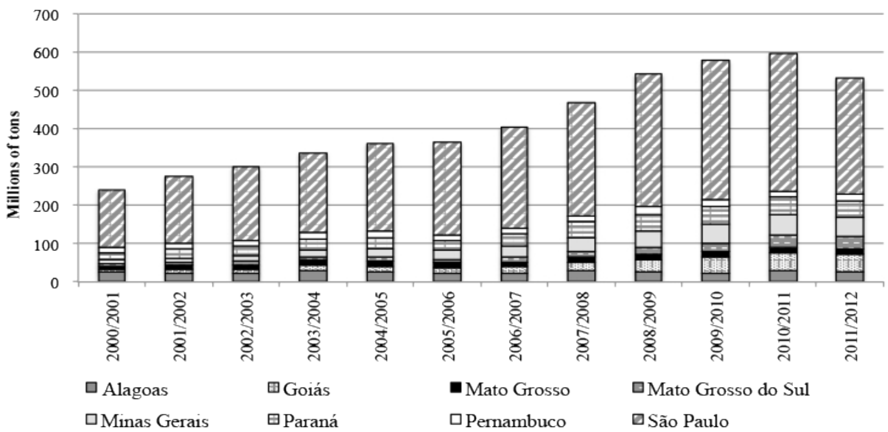
Figure 3 – Profile of hydrous ethanol production in the main Brazilian States from 2000



Sources: Unica (2012a).

Considering the last harvest analyzed (2011/12), there are some interesting variations among the states: on the one hand, Goiás supplied only eight percent of the sugarcane produced in Brazil (third largest share), but 14 percent of hydrous ethanol (second largest share); on the other hand, São Paulo supplied a higher percentage of sugarcane (54 percent) than of hydrous ethanol (49 percent) in Brazil. Thus, the spatial distribution os production seems to be an important variable to be taken into account in this analysis.

Figure 4 – Profile of sugarcane production in the main Brazilian States from 2000



Sources: Unica (2012a).

Sao Paulo state was responsible for 60 percent of the Brazilian production of sugarcane and hydrous ethanol during the whole period chosen for the analysis. Table 4 shows that the production growth rate differed between the states: while in Goias the annual growth rate for hydrous ethanol was 25 percent, in the northeastern states, Alagoas and Pernambuco, it was zero and two percent, respectively.

Table 4 – Annual growth rate and share of Brazilian production in 2011/12 for hydrous ethanol and sugarcane, in the main Brazilian States

	Growth rate per year		Share of Brazilian production in 2011/12	
	Hydrous ethanol	Sugarcane	Hydrous ethanol	Sugarcane
Alagoas	0%	1%	2%	5%
Goiás	25%	18%	14%	8%
Mato Grosso	9%	4%	4%	2%
Mato Grosso do Sul	19%	16%	9%	6%
Minas Gerais	18%	15%	9%	9%
Paraná	6%	7%	7%	7%
Pernambuco	2%	2%	1%	3%
São Paulo	8%	7%	49%	54%

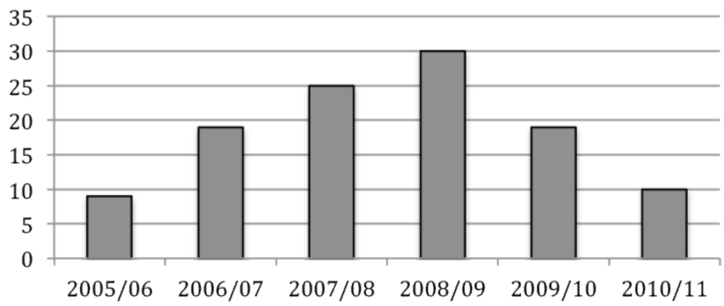
Source: Unica (2012a). Elaborated by authors.

Figures 3 and 4 show others two specificities: (i) stabilization in hydrous ethanol and sugarcane production from 2009 and (ii) the fall in production of hydrous ethanol and sugarcane in 2011/12. The understanding of these events is important for building good models that capture the producers' response to price changes in this market. First, the economic difficulties generated by the international crisis of 2008 led to lower investments and a slowdown in the installation of new plants in Brazil, especially in the Centre-South states, which are the main generators of the increase in production (FNP, 2011). As described in Figure 5, while in the 2008/09 there were 30 new plants, at the 2011/12 harvest year only 5 new plants started to produce. Besides the 2008 financial crisis, profits made by mills were also lower, slowing investments and production expansion. As shown in Figure 6, the profitability for hydrous ethanol was negative after 2008.

Unica, cited by FNP (2011) indicated that after this period, foreign investments were directed to acquisition of companies facing difficulties instead of the constructing new mills (or starting greenfields). The mills were unable to cover the costs of essential procedures and the rate of renewal of the sugarcane fields was reduced. This, together with climate problems over sugarcane harvests, resulted in sharp losses in agricultural productivity, as described in Figure 7, and explained the lower production.

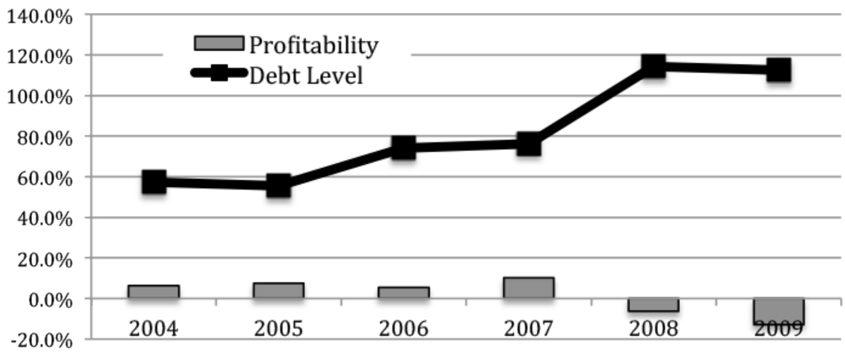
As mentioned above, another factor that interferes with the hydrous ethanol supply is the price of products that compete with it: anhydrous ethanol and sugar. Robust statistics prices of these products are available only for three states in Brazil: São Paulo; Alagoas and Pernambuco. These prices present a very similar behavior among the states for each product. As São Paulo is the main sugarcane products producer, the prices in this State are plotted in Figure 8 for the period analyzed.

Figure 5 – Yearly numbers of greenfield investments in Brazil. Period: 2005-2011



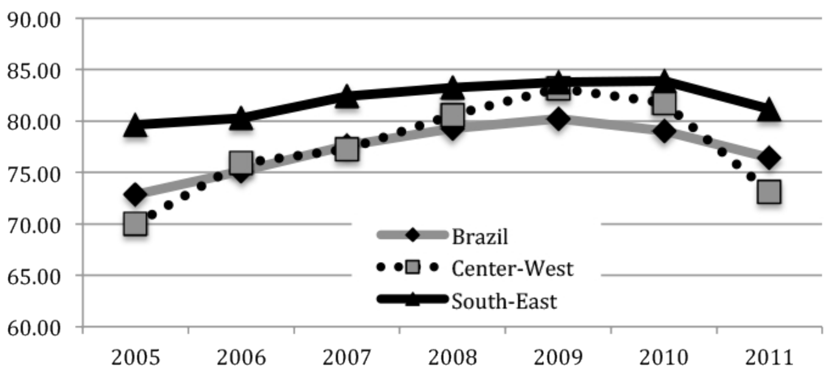
Source: Unica, cited by FNP (2011).

Figure 6 – Profile of profitability (liquid profit/liquid heritage) and debt of the largest group in the sugarcane sector. Period 2004-2009



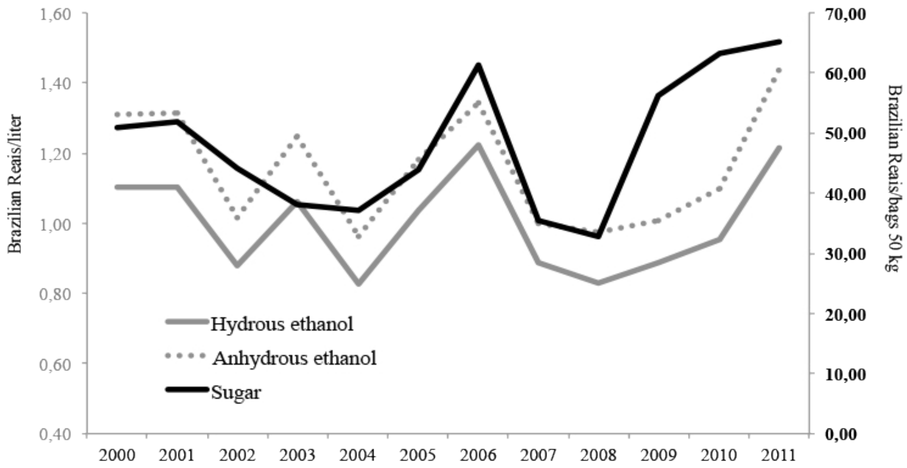
Source: Unica, cited by FNP (2011).

Figure 7 – Profile of sugarcane productivity in Brazil. Period: 2005-2011



Sources: IBGE (2012).

Figure 8 – Variation in sugarcane products prices: sugar, hydrous and anhydrous ethanol in São Paulo State. Period: 2000-2011



Source: CEPEA (2012). Elaborated by authors.

Figure 8 shows that hydrous and anhydrous ethanol prices trends are very similar, while the sugar prices varies differently, such that price correlation between hydrous ethanol and sugar was 63 percent and between hydrous and anhydrous ethanol was 98 percent. The positive and high correlations between these prices mean that one price influences another.

Therefore, the relative independence of the sugar price can be due to plants producing only sugar. This independence between sugar and ethanol price possibly explains the models for the studies described in part 2. Caruso (2002), for instance, concludes that the ethanol price had no influence on sugar supply. However, there is some evidence that the reverse causality might be a plausible assumption. In the anhydrous ethanol supply model estimated by Marjotta-Maistro and Barros (2003), sugar prices explained the anhydrous supply.

The price transmission between sugar and anhydrous ethanol prices, was studied by Alves (2002) for the period of May 1998 to June 2002. This author concluded that these relations were not as strong as expected. Venâncio et al. (2010) analyzed the effects of interdependence between the sectors of sugar and ethanol in the price and supply of the sugarcane sector, from 1979 to 2007. They found that the variation in the ethanol price has more influence on the sugar price than the reverse. As a limitation of that study, the data used correspond largely to the period of regulation in this sector. However, no studies can be found estimating price transmission between anhydrous and hydrous ethanol.

These studies illustrated that an evaluation of estimates considering the changes in hydrous ethanol market in Brazil after the introduction of the flex-fuel vehicle, as those obtained in this study, can be important and useful for policymaking.

4. Methods and data

. This section describes the economic models for hydrous ethanol and sugarcane supplies, the econometric approach for estimates and the data used. In order to obtain good estimates for the model explaining hydrous ethanol and sugarcane producer behavior in the last decade, the data was separated by the main producer states in Brazil. As explained in section 3, the states had different performance profiles. Consequently, a panel data was applied to obtain these estimates.

The model proposed for hydrous ethanol supply (Sh) is represented by equation (1):

$$Sh_{i,t} = \alpha_0 + \alpha_1 Ph_{i,t} + \alpha_2 Pa_{i,t} + \alpha_3 Ps_{i,t} + \mu_{i,t} \qquad (1)$$

where Ph is the hydrous ethanol price; Pa is the anhydrous ethanol price; Ps is the sugar price and; μ is the error term for the model.

The subscript i in equation (1) indicates the data from each of the main producer states and; t symbolizes the series of times used to estimate this model, which comprehends the harvests years between 2000/01-2011/12. The states analyzed in equation (1) were: São Paulo (SP), Minas Gerais (MG), Paraná (PR), Goiás (GO), Mato Grosso (MT), Mato Grosso do Sul (MS), Alagoas (AL) and Pernambuco (PE).

Price data received by producers for the hydrous ethanol (Ph), anhydrous ethanol (Pa) and sugar (Ps) were obtained from CEPEA (2012). As the producer prices for these products were only provided for São Paulo, Alagoas and Pernambuco, the reference considered for the other states was the São Paulo producer price, given its relevance for price formation in Brazil. This model also confirmed the no significance of the influence of the sugar price variable in the ethanol market though the relation between the sugar and ethanol prices was not significant in other estimations (Caruso, 2002 and Shikida et al., 2007).

The model proposed to explain the sugarcane area (Ssc) is represented by the equation (2):

$$Ssc_{i,t} = \gamma_0 + \gamma_1 Ssc_{i,t-1} + \gamma_2 Psc_{i,t-1} + \gamma_3 Mills_{i,t} + \varepsilon_{i,t} \qquad (2)$$

where Psc is the ATR (Total Recoverable Sugar) price, which is a technical combination of the sugar, hydrous and anhydrous ethanol prices; $Mills$ is the number of the new cane-processing plants and; ε is the error terms for the model.

The subscript i represents each of the main producer states and t symbolizes the time series used to estimate this model, equivalent to the harvest years between 2000/01-2011/12. The producer states referred to equation (2) were: São Paulo (SP), Minas Gerais (MG), Parana (PR), Goias (GO), Mato Grosso (MT) and Mato Grosso do Sul (MS). The northeastern states, Alagoas and Pernambuco, were not included, given that there is no area for expansion of sugarcane in these states.

The data used for the sugarcane area (Ssc) were provided by IBGE (2012). The price for the sugarcane producer that was considered the ATR price (Psc) was obtained from Consecana (2012) and the same price was used for all eight states analyzed in each year. The variable $Mills$ was provided by Unica (2012b). The lagged endogenous variable was included in the model to represent the sugarcane harvested in the same area among the period of the analysis. The lagged ATR price was used, given the assumption that the producer takes at least one year to decided wheter to increase or decrease the planted area. Finally, the number of the new mills installed in each state analyzed was considered to represent the additional area needed to sustain an economic production.

All prices were deflated by the General Price Index (GPI) estimate for Brazil (FGV, 2012).

The coefficients α_1 and γ_2, described respectively in equations (1) and (2), are expected to be positive, such that an increase in their price will lead to an expansion in production. Coefficients α_2 and α_3 are expected to be negative, considering that an increase in sugar or anhydrous ethanol price should reduce the hydrous ethanol production. To coefficients γ_1 and γ_3 are expected to be positive, considering that the previously area planted and new mills should contribute positively to the total area planted with sugarcane.

Econometric models

According to Hsiao (1986), a model based on panel data provides several advantages over cross-sectional and time-series models. This is particularly so when there is heterogeneity among the units covered in the study, such as the States in the present study, since these can be controlled in this modeling procedure.

It is believed that there are several characteristics of the States that affect the variable being explained - the production of hydrous ethanol - which cannot be observed and thereby included in the model as explanatory variables. The capacity of the rural worker to produce cane instead of cattle, can be an example, as well as the interaction between soil, climatic conditions, and the influence of culture and history of the State upon its agricultural activities. Although these are not trivial to measure, the omission of these variables in the model can lead to biased results. The panel-data model is indicated for this type of estimation, since the model takes account of the differences between individual units (such as the States, in this case). Hsiao (1986) also highlighted a further advantage of panel data, *viz* the greater number of observations that can be used within the panel model procedure, such that number of degrees of freedom is increased and collinearity between the explanatory variables is reduced. It is well known that in the presence of collinearity, it is hard to determine the extent to which an individual regressor affects the endogenous variable. By solving this problem, the quality of the estimated parameters can be improved.

Panel data estimation relies on the hypothesis that in the estimation procedure, the heterogeneity of each cross-sectional unit is taken into account. The one-way random effect (RE) and fixed effects (FE) models are the most frequently used on panel data.

The fixed effects model is set to control for the omitted variables that vary between the units (States in this study) but are constant through time. Thus, it is assumed that the intercept varies from one individual to another, but is constant for each one. The parameters of the explanatory variables are constant for all individuals and all time periods (Griffiths, Hill and Judge, 1993). Since these response parameters do not vary between individuals nor through time, all the behavioral differences between individuals will be captured by the constant term. Therefore, the estimated constant term in the fixed effects model can be interpreted as the effect of the variables that are omitted in the model. Another important assumption of the fixed effects model is that the fixed coefficient is a constant and unknown parameter that captures the differences between individuals of the sample.

A basic characteristic of these models is that they rely on the hypothesis that differences between cross-sectional units can be captured by means of an intercept term, specific for each unit. The random effect models make the same assumption as the FE model regarding the fixed effect. This means that the intercept varies between individuals but not through time, while the explanatory variable coefficient is constant for all individuals and all periods of time. The difference between the models is how the intercept is interpreted. In the fixed effects model, the intercept is considered as a constant (fixed value), correlated with the explanatory variables in any period of time, while in the variable effects model the intercept is recognized as a random variable. This means that the random effects model considers that the set of individuals for which there is information are a random sample from a larger number of individuals. The fixed effects model is appropriate when the observations are available for the whole population.

There are tests, such as that introduced by Hausman, to identify whether the model should be estimated as a fixed or variable effects model, when the construction of the model is unclear regarding this question. In this analysis, the FE model can be considered more appropriate, since there is no reason to believe that constant characteristics of the States are randomly related to fuel prices in any period of time.

More recently developments model for panel data is related to the introduction of lagged-response or dynamic models. These are used when it is important to include lagged variables in the model, as seen for sugarcane supply model in equation (2). The conventional lagged-response model is described by Rabe-Hesketh and Skrondal (2012) as the autoregressive lag-1 (AR(1)) model, where the dependent variable ($Y_{i,t}$) is regressed on the previous response ($Y_{i,t-1}$).

When lagged variables are included in the model, estimation by OLS, FE and RE are biased. In order to solve this problem, Rabas et al (2011), Anderson and Hsiao (1981) suggested first differencing of variables. Although this method leads to consistency, it is not necessarily efficient, since it does not use all available moment conditions; and does not take into account the differenced structure on the residual disturbances. Rabe-Hesketh and Skrondal (2012) suggest the use of additional lags can be used as instrumental variables in the Anderson and Hsiao approach to increase efficiency. Arellano and Bond (1991) proposed a more efficient estimation procedure, as an extension of instrumental-variables estimation called generalized method of moments (GMM) for this purpose, and which was used in this study to estimate equation (2).

The next section describes and discusses the results obtained with the models presented in equations (1) and (2) and estimation methods explained above.

5. Results and Discussion

The price elasticity of production of hydrous ethanol fuel to its own price and to that of the major substitutes - anhydrous ethanol and sugar - were estimated from a panel function with the expected effects of the variables based on economic theory, as described in equation (1). The results of the estimations of supply equation are presented in Table 6.

Table 6 – Hydrous ethanol production function estimate for Brazil, 2000-2011

	Coefficient estimated	Elasticity
Fixed coefficient	α_0	13.61*
Hydrous ethanol price	α_1	1.94**
Anhydrous ethanol price	α_2	-2.55*

*Denotes statistical significance at 1% level. ** Denotes statistical significance at 5% level.

All the parameters described in Table 6 presented the expected signs and were statistically significant. The F test, applied to the fixed effects model indicated that the model can be considered adequate to control for the non-observed characteristics of the units or country regions. However, sugar price was not included in final model although it was a component of equation (1), since sugar price was non significant. A possible explanation is that all mills that produced hydrous ethanol could produce anhydrous, while only some of these mills could also produce sugar.

The Hausman test indicated that the fixed effects model was a robust method to take the heterogeneity in sugarcane supply of the States into account.

The results for the estimation of the hydrous ethanol supply indicated that both the direct price elasticity of supply (1.94), and the cross price elasticity of supply with respect to anhydrous ethanol (-2.55), were relatively more elastic than those identified in previous studies (Marjotta-Maistro & Barros , 2003; Shikida et al., 2007; Oliveira et al., 2008; Rask, 1998; Luchansky & Monks, 2009). These results were expected, in view of the expansion of the flex-fuel car fleet in recent years, such that consumers can choose between fuels considering their relative price.

The estimated coefficient for the response of sugarcane area to producers prices – lagged by one period - was significant and inelastic (0.26), similar to what has been observed in others studies, such as Satolo & Bacchi (2009) and Santos (2001). The estimates for the coefficients in equation (2) are shown in Table 7.

Table 7 – Sugarcane area supply estimate for Brazil, 2000-2011

		Elasticity
Sugarcane area (t-1)	γ_1	0.93*
Sugarcane price (t-1)	γ_2	0.26**
Number of new plants	γ_3	0.05*

*Denotes statistical significance at 1% level. ** Denotes statistical significance at 5% level.

Differently from other sugarcane supply estimations, this study took panel data for the main sugarcane producing states (MG, SP, PR, MT, MS and GO) and included all the decade of the 2000s. Besides, the model considered the previously produced area and the number of new mills installed in those states.

These estimations are important because they provide information about what could happen in the sugarcane industry when there are exogenous changes. They also help the comprehension of the supply response to changes that are relevant information for policymakers.

The results of the estimates suggest, for instance, that an increase by 10 percent on the hydrous ethanol producer price would raise the hydrous ethanol supply in 19 percent. Indirectly, this would increase the sugarcane producer's price by 2 percent, taking into account the sugarcane price parametric formula (Consecana). Consequently, the area planted with sugarcane in the following year would growth 0.52 percent, because of the 10 percent increase in the hydrous ethanol price. This effect takes the relationship between the prices of the other two sugarcane products - sugar and anhydrous ethanol – as given and constant. Therefore, these estimated elasticities are important to support forecasts about the Brazilian ethanol market. Considering that in 2010 and 2011 the U.S. and Brazil were responsible for 76 and 74 percent of the all ethanol produced in world (LMC, 2011), such previsions are important to understand the world market in ethanol, which is an outstandingly important new energy source.

6. Conclusion

This study shows that the introduction of flex fuel cars, as a major technological breakthrough in the Brazilian market, resulted in substantial changes in the fuel market, increasing the supply response of hydrous ethanol to price changes. This is relevant, since it complements the evaluation of the effects of relative price changes considering the demand for fuel, focused by several studies for the period before and after the expansion of the participation of flex fuel cars in the Brazilian fleet.

The results suggest that the introduction of the new technology promoted an important market advance towards greater efficiency, as the competition through prices would lower prices to consumers, at a given demand level, up to a point where these still sustain economic feasibility of production. The price elasticity has increased when all the years of the decade of the 2000s are included in the estimation – compared to previous studies, which did not consider for more recent period. In addition, as the effects of difference in state characteristics are considered, this seems to contribute to a better model.

The results also confirm that in Brazil, the production of cane is less responsive to prices than one of its products - the hydrous ethanol used as a biofuel in flex-fuel cars. This was expected since the cane, as an agricultural product with a relatively long cycle requires a longer period to implement changes in the volume produced. This is relevant, considering that the introduction of policies to stimulate the expansion of cane, as a raw material for ethanol production, would require a different timing compared to investments in expansion of the industrial processing. In addition, for planning investments in cane production and area expansion, producers and investors must foresee a growing and sustained expansion of demand for biofuels and sugar. Considering sugar as a *commodity* that is subject to price uncertainty and fluctuations, if the Brazilian government supports biofuel production as a long-run initiative, it should consider the importance of establishing targets to be reached along time and mechanisms to reduce uncertainty in cane production.

In general, the results confirm that when government policies toward fuel prices are used, there can be expressive changes in the product supply at a relatively short period of time. However, in order to have a sustained increase, there must be enough sugarcane to assure that hydrous, anhydrous and sugar could all respond to market incentives.

The analysis considering the differences among the main producer states in Brazil is also important to capture the producer behavior. When the analysis considers only the period after deregulation, it can be seen that hydrous ethanol producers present a stronger response to our prices, unlike what was indicated by other studies.

By estimating a complete hydrous ethanol supply model that considers the supply of cane, regional differences in Brazil for the period after the sector's deregulation and isolated events as new mills were installed mainly between 2005 and 2008, this study fills a gap presented by previous studies which were also applied to the period after the introduction of flex-fuel vehicles, However, to analyze impacts in policies, it seems that a comprehension of the producer behavior is as important as understanding consumer behavior.

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