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An Economic Model of Brazil's Ethanol-Sugar Markets and Impacts of Fuel Policies

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Abstract

The lack of growth in the Brazilian sugarcane-ethanol complex since the 2008 financial crisis has been blamed on policies: lower mandate, holding gasoline prices below world levels, high fuel taxes, and inadequate fuel tax exemptions for ethanol. This paper develops an empirical model of the Brazilian fuel-ethanol-sugar complex to analyze the impacts of these policies. Unlike biofuel mandates and tax exemptions elsewhere, Brazil's fuel-ethanol-sugar markets and fuel policies are unique such that each policy, in theory, has an ambiguous impact on the market price of ethanol and hence on sugarcane and sugar prices. The results indicate two policies that seemingly help the ethanol industry do otherwise in reality: low gasoline taxes and high anhydrous tax exemptions lower ethanol prices. But higher mandates, hydrous ethanol tax exemptions, and gasoline prices had the expected impact of increasing ethanol and sugar prices. Eliminating Brazilian ethanol tax exemptions and mandates reduces ethanol prices by 21 percent. Observed changes in prices are explained by outward shifts in fuel transportation and sugar export demand curves, and bad weather reducing sugarcane supply.

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Produced by the Research Support Team

An Economic Model of Brazil's Ethanol-Sugar Markets and Impacts of Fuel Policies[*]

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1. Introduction

Brazil is the biggest sugar producer in the world (25 percent of the world total), the biggest sugar exporter (60 percent of the world total) and until overtaken by the United States recently, the world's biggest ethanol producer and exporter. Hence, the world prices of sugar and ethanol are expected to be directly linked and not diverge significantly, given the economics of sugarcane processing in Brazil. Figure 1 provides evidence that this may be the case. Brazil is regarded as the lowest cost producer of ethanol in the world but since mid-2009 to mid-2012, Brazil's market price of ethanol was higher than the U.S. price and Brazil became a major importer of U.S. ethanol.[1] The reasons for high ethanol prices in Brazil in this time period are manifold, including strong domestic demand for transportation fuels, increasing demand for sugar with world record sugar prices, and bad weather affecting the sugarcane harvests in the 2010/11 and 2011/12 harvest seasons. The impact of Brazilian government ethanol policies is also blamed for inadequate domestic supplies of ethanol due to lack of investment since the 2008 financial crisis (Jank, 2012), an issue we will pay close attention to in this paper.

Brazil has developed a unique system of producing competing tradable products – sugar and ethanol – from non-traded sugarcane. Modern "flex-plants" can produce either sugar or ethanol from sugarcane, and within a production year, can switch between the two products up to about 65 percent of a product.[2] Furthermore, flex-plants can extract up to 18.6 liters of ethanol per tonne of sugarcane processed into sugar from molasses, a by-product of sugar production (Gopal and Kammen, 2009).[3] The total output of sugarcane is shown in Figure 2 where ethanol's share has ranged between 45 and 57 percent of the total in the past 7 years.[4] This leads to two different demand curves for ethanol as transportation fuel: an *anhydrous* ethanol-gasoline fuel mixture (which we define as "fuel" in this paper) that all cars can use, and E-100 (100 percent *hydrous* ethanol) which only flex cars can use (23 percent of total cars in Brazil are

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[1] Because of potential technological advances, Brazil may regain its export market share in the future.

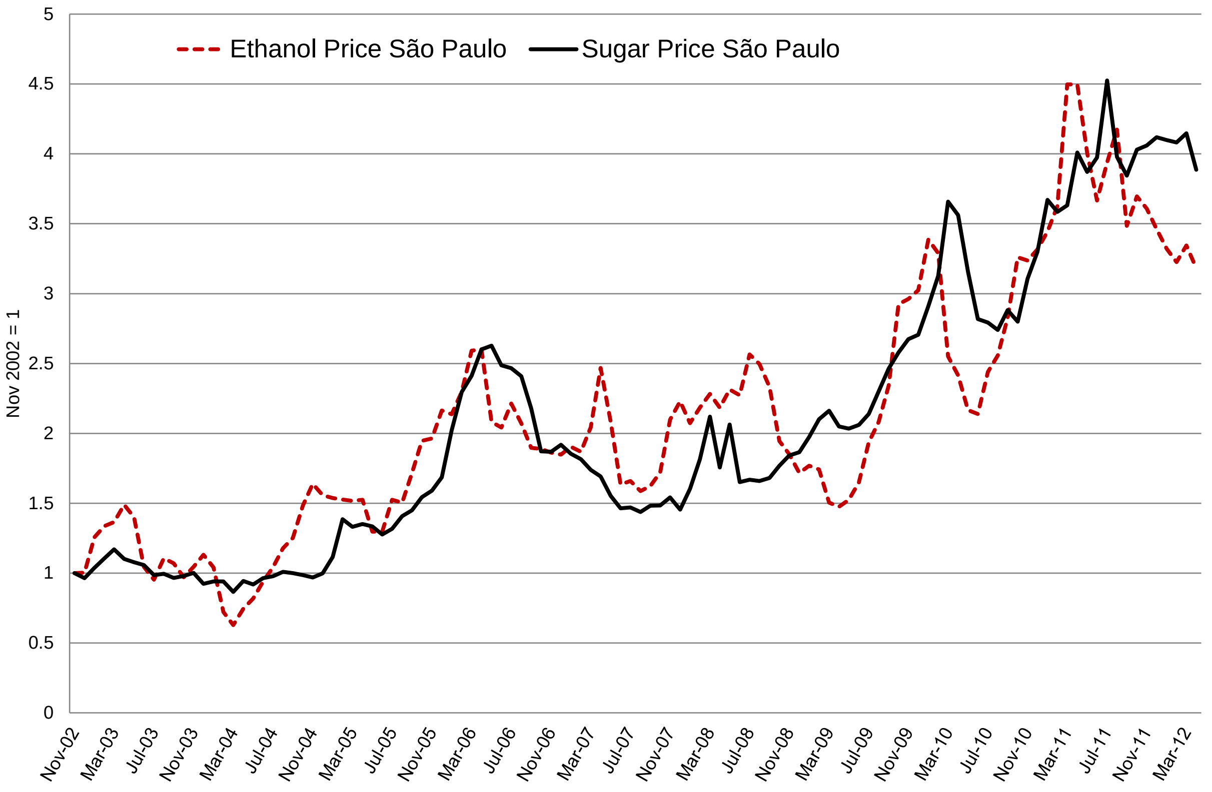
[2] About 300 plants today are flex-plants, mostly in the Southeast and Central West region of Brazil, where a substantial share of total sugarcane processed occurs. The other plants are either dedicated to ethanol only (125 plants in 2010, UNICA) and sugar only (12 plants, UNICA), the latter mostly located in the Northeast where they have quotas to export sugar.

[3] Molasses is therefore, in theory, a very important source of ethanol because if 55 percent of total sugarcane production were devoted to sugar production, and every plant maximized ethanol production from molasses, then 25 percent of total ethanol production in Brazil could come from molasses alone. But plants dedicated to just sugar production find it uneconomical to extract ethanol from molasses.

[4] Another unique aspect of processing sugarcane into ethanol and sugar is that the bagasse (leftover biomass) can be burned for electricity production to be used by the plant itself with excess electricity sold on the grid.

currently flex but growing fast as over 80 percent of new car sales in the past two years were flex).[5] Strong domestic demand for ethanol in Brazil is due to growing incomes. Since 2010, about 50 percent of total gasoline plus ethanol consumed in Brazil has been ethanol, compared to 10 percent in the United States. Gasoline consumption in Brazil increased by 2 billion liters from 2000/01 to 2009/10 but ethanol consumption increased a whopping 24 billion liters. But since 2009, total ethanol consumption (hydrous and anhydrous) has declined by almost 20 percent (Figure 3) due to rising ethanol prices, along with lower gasoline taxes and gasoline prices pegged below world prices.

Figure 1: Brazilian Ethanol versus Sugar Prices (Index)



The share of anhydrous ethanol in total ethanol consumption has increased from 33 percent in 2009/10 to 45 percent in 2011/12.[6] The reason for this development is not just an increase in the relative price of hydrous and anhydrous ethanol but also a narrowing of the "parity gap" between fuel and E100 prices. In other words, the price of E100 is usually

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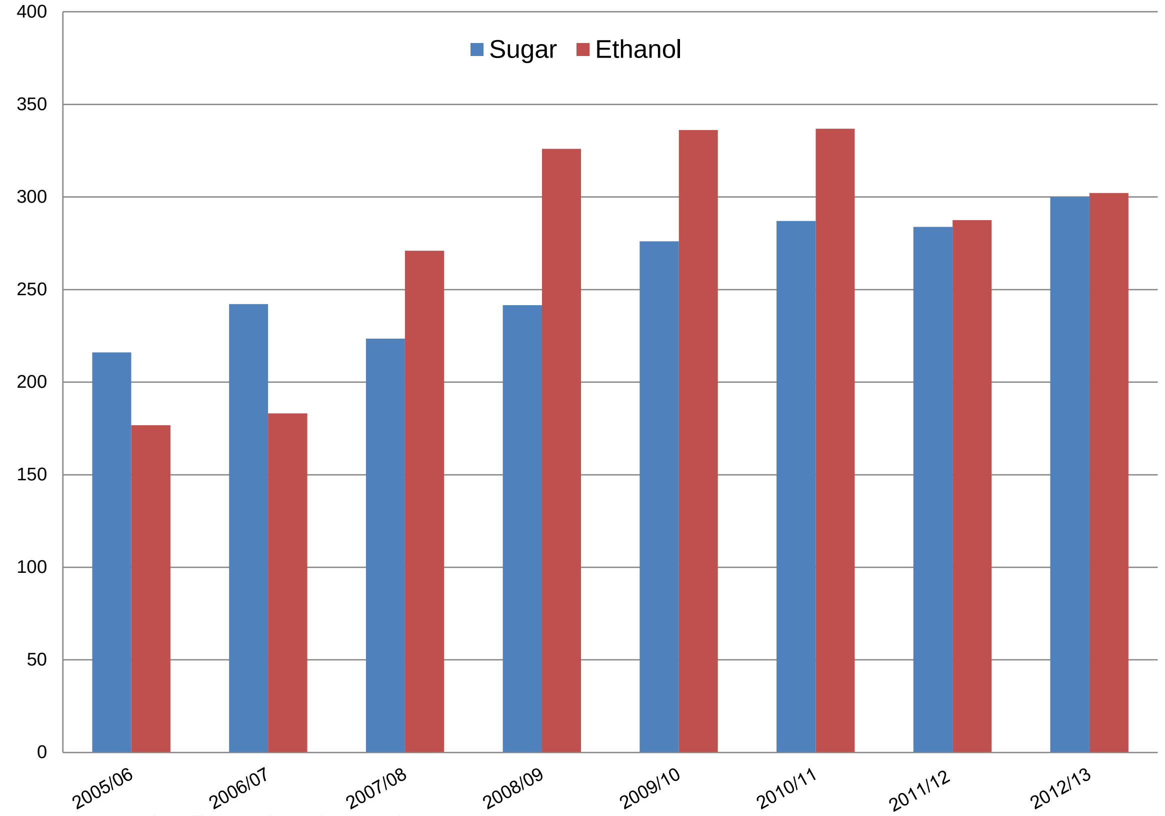
[5] The Brazilian government also gives tax breaks for the purchase of flex-cars.

[6] The reason for production of anhydrous ethanol is the blend mandate; the tax exemption for anhydrous ethanol is very low compared to hydrous ethanol.

discounted to the price of fuels in terms of the cost per kilometer traveled. The price of E100 at parity (cars get about 30 percent less kilometers per liter of E100 relative to fuel) is denoted by the dotted line in Figure 4. But historically, E100 prices were at a substantial discount compared to the fuel parity, often reaching levels 25 percent lower than the parity fuel price. This encouraged the adoption of flex cars and infrastructure like E100 dispensing stations. But as the share of flex cars has increased, and hydrous ethanol prices have risen, this discount in the past 2-3 years has disappeared.

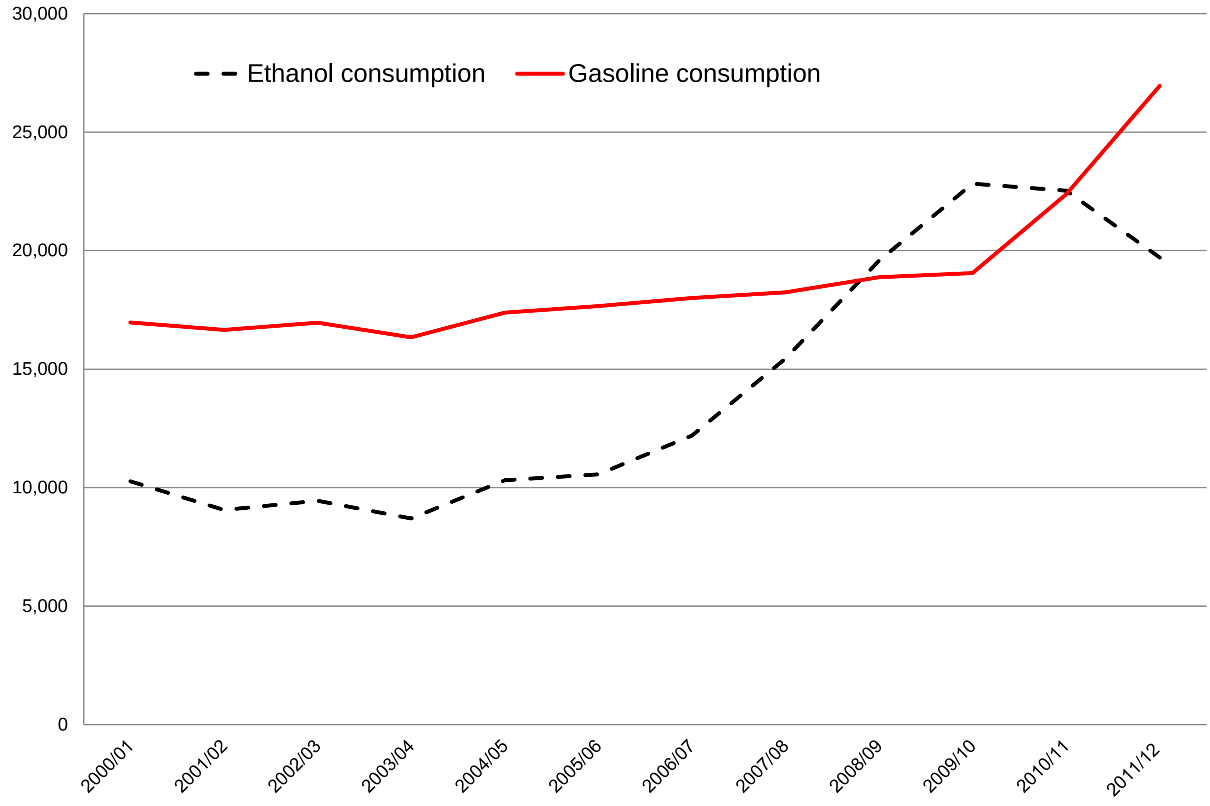
Figure 2: Brazil Sugarcane Processed (million tonnes)



Source: CONAB (Brazilian Food Supply Agency)

The market price of anhydrous ethanol exceeds that of hydrous ethanol because more sugarcane is required to produce a gallon of anhydrous ethanol and there is additional non-sugarcane related production costs associated with anhydrous production. Because sugarcane is used to produce sugar, hydrous ethanol and anhydrous ethanol, then it must be that for a flexible plant – modeled in this paper – the marginal benefits of these three production processes are equal (adjusted for ethanol from molasses, a by-product from sugar production).

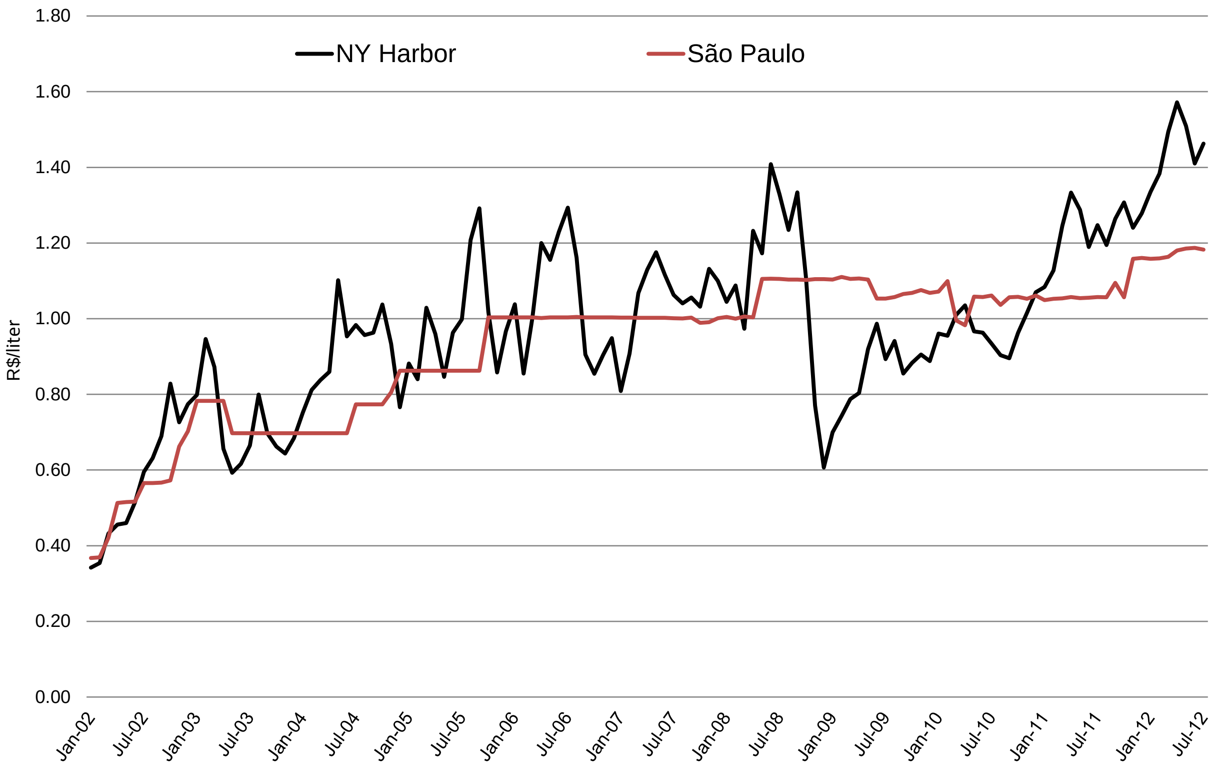
Figure 3: Gasoline versus Ethanol Consumption in Brazil (million litres)



Source: Using CONAB data

Brazilian ethanol policies are also important factors affecting the sugar/ethanol markets and can be classified into four categories. First, Brazil has a mandate for anhydrous ethanol mixed with gasoline, requiring 18 to 25 percent of the total fuel mixture to be anhydrous ethanol, depending on supply-demand conditions (it has recently been raised back to 25 percent but was reduced from 25 percent to 20 percent in October 2011). Second, E100 sales enjoy a tax exemption that is greater than what is needed to compensate for the fewer kilometers obtained relative to a liter of the gasoline-anhydrous fuel mixture. The tax on anhydrous ethanol is even lower, although as we show later, consumers only see the E25 price. Third, the government has often in the past, and again recently, held the price of gasoline below world gasoline prices, which fluctuate with world crude oil prices, to avoid adverse effects on inflation. Fourth, the federal government has recently eliminated the fuel tax. We show that in theory each of these policies has an ambiguous impact on ethanol market prices, but empirically we determine that a higher mandate, gasoline price, and tax exemption[7] for hydrous ethanol results in higher ethanol market (i.e., wholesale) prices, but a lower gasoline tax and a higher tax exemption on anhydrous ethanol results in lower ethanol prices.

Figure 4: U.S. and Brazil Gasoline Prices Compared



Source: Brazil ANP, U.S. EIA

The primary objectives of this paper are to (a) develop a general economic model of the trade-off between ethanol and sugar production in Brazil that occurs in a sugarcane processing flex-plant that produces both sugar and ethanol, and where the world prices of each product are determined endogenously; and (b) determine the market effects of Brazil’s ethanol policies. To achieve these objectives, we incorporate unique features of Brazil’s market and policy into the economic model; especially, we model the two fuel demands and the anhydrous ethanol mandate, the changing parity gap between E100 and fuel prices, ethanol produced from molasses, the by-product of sugar production, and bagasse for electricity production. We also use our model to explain the dramatic change in market conditions from 2010/11 to 2011/12 where ethanol and sugar prices soared, fuel consumption increased, sugarcane production fell and the

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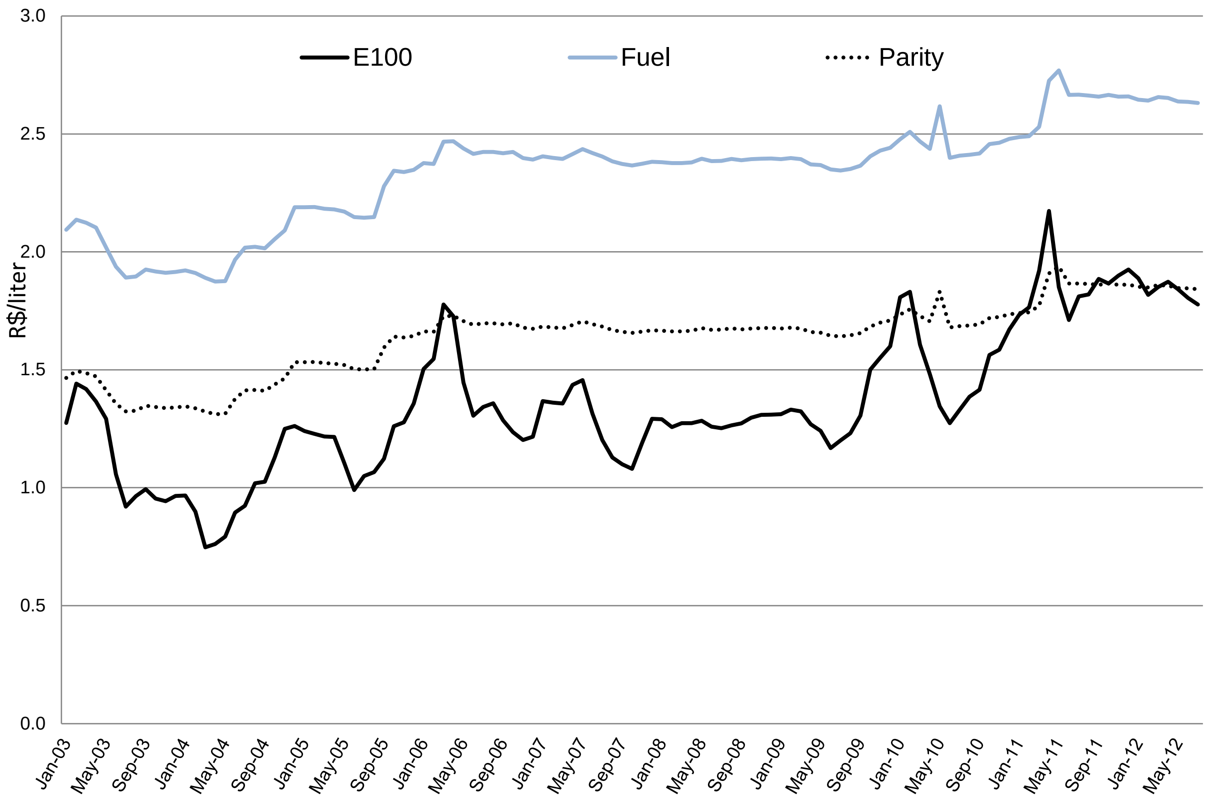
[7] Intuitively, a higher tax exemption for hydrous ethanol incentivizes its consumption which necessitates more production, hence the wholesale price increase.

share of sugarcane processed into ethanol declined (Figure 5). We do not analyze the impacts of U.S. ethanol policy on Brazilian ethanol and sugar markets, but with trade in ethanol, the importance and need for this paper for future research takes on added significance.

The rest of this paper is organized as follows. After a brief description of how our approach relates to the literature, we develop an analytical model in Section 3. Section 4 incorporates the shift in the demand curves for fuel and E100. Section 5 presents the comparative static results. Data and calibration used in our empirical model are described in Section 6. Empirical findings are presented in Section 7; the last section provides key concluding remarks.

Figure 5: Fuel Prices in São Paulo



Source: ANP 2012

2. Relation to the Literature

There is a fledgling literature on the market effects of Brazilian ethanol policies (e.g., Schmitz et al., 2003; Elobeid and Togkoz, 2008; Balcombe and Rapsomanikis, 2008; Serra et al., 2008; Kliauga et al. 2010; Rajcaniova et al., 2011). Elobeid and Togkoz (2008) analyze the effects of U.S. ethanol policies on Brazilian markets, with Brazilian ethanol demand divided into anhydrous and hydrous demand and the share of sugarcane going into sugar and ethanol is endogenous and based on market conditions. Kliauga et al. (2010) hypothesize that through 2008, the U.S. tax credit determined the world ethanol price and that the Brazilian price was often linked to it. However, this study does not consider the complexities of the sugar-ethanol market in Brazil neither distinguishes between anhydrous and hydrous ethanol. Using time series techniques, Rajcaniova et al. (2011) test the theory of Kliauga et al. (2010) but find only partial support for it. They find that Brazil and the United States co-determined the ethanol market price in the period 2002 – 2010.

A recent strand of the literature has focused on the analysis of the ethanol-sugar-oil nexus in Brazil (and also on ethanol-corn-oil long run relationships elsewhere). For example, Balcombe and Rapsomanikis (2008) study the long-run price relationships among the three commodities using monthly data for the period 2000 – 2006. They use bivariate error correction model and allow for non-linear adjustment toward the equilibrium. Oil prices were found to determine the long-run equilibria of both sugar and ethanol prices and sugar prices were in turn found to cause ethanol prices but not the other way around. A recent paper by Serra et al. (2011) also uses time-series econometric techniques to investigate the price volatility transmission in the Brazilian ethanol industry in the period 2000-2008; this study, akin to Balcombe and Rapsomanikis (2008), analyzes ethanol, sugar, and oil prices. Serra et al. (2008) find a strong link, both for levels and volatility, between food and energy markets. Their impulse-response analysis shows that an increase in crude oil prices leads the system towards a new equilibrium with higher ethanol prices. Increases in sugar prices are also found to increase ethanol price levels and volatility (see also Serra 2011).

What Balcombe and Rapsomanikis (2008) and Serra et al. (2011) fail to recognize, however, is that it is gasoline, not oil that links ethanol to sugarcane (and sugar). Moreover, the Brazilian government fixes gasoline prices through Petrobras, a publically traded company, where the government is the biggest shareholder (de Miranda, 2010; Zilberman, 2012). Under such a regulation, the domestic gasoline prices are delinked from the world oil prices (Figure 4), which are determined in a free market.

The earlier strand of econometrics literature (see Zilberman et al., 2013 and Serra, 2012 for surveys) shares two common features. First, many studies analyze periods ending in 2007 or

2008; second, they investigate the long run relationships among the prices. Unlike the econometrics studies, our paper provides a structural model that takes a detailed account of the unique features of the Brazilian sugar-ethanol market. The advantage of our methodology is that it is capable of explaining recent significant (short-term) shocks in the market. Our paper also extends the existing literature (e.g., de Gorter and Just, 2009, Lapan and Moschini, 2012) by incorporating two demand curves for ethanol and by modeling the endogenous decision of flex cars owners to shift between consumption of fuel and hydrous ethanol.

While the time-series models discussed above concentrate on the linkage among commodity prices, structural models focus more on the cost-effective mix of feedstocks to meet the stated targets (e.g., Khanna et al., 2013) and on the relative competitiveness of sugarcane and corn ethanol (e.g., Crago et al., 2010). Thus, for example, Crago et al. (2010) find that although the production cost of sugarcane ethanol in Brazil is lower than that of corn ethanol in the United States, once transportation costs for the sugarcane ethanol and the value of corn-related DDGS are included, the relative competitiveness changes. They also find that the relative cost of ethanol in the United States and Brazil is very sensitive to the prevailing exchange rate and prices of feedstocks. This is of particular importance as the Brazilian Real has appreciated about 30 percent in the value relative to the U.S. dollar in the last half decade, (de Gorter et al., 2012).

The existence of a unique system of flexible plants in Brazil able to adjust their production program in favor of either sugar or ethanol, depending on their relative prices, substantially helps improve the profitability of the Brazilian sugarcane processing sector. Other significantly contributing factors are government policies and market developments.

3. The Model

Our model considers a competitive industry that processes sugarcane into three products: sugar, anhydrous ethanol and hydrous ethanol. Sugar and ethanol are competing products because the industry can adjust, although only to a certain extent, the allocation of sugarcane, depending on the relative market price of sugar and ethanol.[8] A by-product of sugarcane processing, regardless of the use of sugarcane, is bagasse, a fibrous matter that is burned in

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[8] In a modern Brazilian “flex” sugarcane processing plant, the share of sugarcane going to sugar can vary between 35 and 65 percent.

special boilers to cogenerate electricity and steam.[9] Sugar production also yields a by-product – molasses, which is further used to produce anhydrous and hydrous ethanol.

For proper comparison purposes, we express all quantities related to the fuel market (i.e., ethanol and gasoline) in gasoline equivalent liters (GEEL).[10] A typical Brazilian flexible sugarcane processing plant extracts δ = 6.20 GEELs[11] of ethanol from one metric tonne of sugarcane processed into sugar. [12] Out of this amount, anhydrous ethanol represents δ_A = 1.80 GEELs and hydrous ethanol represents the rest, δ_H = 4.40 GEELs.

The burning of bagasse makes Brazilian flex plants self-sufficient in electricity they need to process sugarcane into individual products. The excess supply of electricity is sold on the grid at the market price. Denote ρ_{SC} as the amount of kilowatt hours (kWhs) of electricity produced from bagasse extracted from one metric tonne of sugarcane; ρ_i as the amount of kWhs of electricity required to produce one unit of product *i*; ϕ_i as the yield (in tonnes or GEELs) of product *i* per tonne of sugarcane; and P_M and P_I as the market and internal (to the processing plant) price of electricity, where $i = \{S,\ H,\ A\}$ and *S*, *H*, and *A* denote sugar, hydrous ethanol, and anhydrous ethanol, respectively. The profit from electricity generation per tonne of sugarcane processed for product *i* is thus given by

$$\Psi_i = P_M\left(\rho_{SC} - \phi_i\rho_i\right) - P_I\phi_i\rho_i \tag{1}$$

The first term on the right-hand side of equation (1) denotes the revenue from selling the excess supply of electricity at the market prices. The second term represents the internal cost of producing electricity from bagasse. We assume that the electricity prices are exogenous to the processing plant, which makes Ψ_i a parameter in the consequent analyses. Notice also that although the observed market price of electricity is higher than the internal price (i.e., $P_M > P_I$),

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[9] The burning of the sugarcane straw for electricity cogeneration is currently not economical because of low energy density of straw and substantial transportation and collection costs.

[10] One gasoline equivalent liter of a fuel denotes the volume that contains the same energy as one liter of gasoline. In converting fuel quantities to GEELs, we assume that one physical liter of anhydrous and hydrous ethanol yield only 67 percent of vehicle kilometers traveled relative to gasoline. In Brazil, one liter of hydrous ethanol yields 70 percent of kilometers traveled on one liter of the 25 percent fuel blend (25 percent of anhydrous ethanol and 75 percent of gasoline).

[11] This corresponds to 9.25 liters.

[12] Molasses from one tonne of sugarcane could potentially yield as much as 18.6 liters of ethanol (Gopal and Kammen, 2009). This yield is expected for new modern production plants.

the profit from electricity generation might be negative, depending on the relative size of the excess supply and internal consumption of electricity.

We assume that production of sugar and ethanol exhibits constant returns to scale. A competitive industry will allocate the sugarcane into sugar, hydrous and anhydrous ethanol so that each production process earns zero marginal profits in equilibrium[13]

$$P_{SC} = \phi_S P_S + \delta_H P_H + \delta_A P_A + \Psi_S - \phi_S \xi_S \tag{2}$$

$$P_{SC} = \phi_H P_H + \Psi_H - \phi_H \xi_H \tag{3}$$

$$P_{SC} = \phi_A P_A + \Psi_A - \phi_A \xi_A \tag{4}$$

Equation (2) comes from a zero profit condition for sugar production and takes into account the additional quantity of ethanol that can be produced from molasses. In equation (2), P_{SC} and P_S denote market prices of sugarcane and sugar (measured in \$/tonne), respectively, and P_H and P_A denote market prices of hydrous and anhydrous ethanol (measured in \$/GEEL), respectively. The parameter ξ_S denotes (constant) processing cost (other than the cost of feedstock and electricity) per tonne of sugar.

Equation (3) relates prices of sugarcane and hydrous ethanol while equation (4) links prices of sugarcane and anhydrous ethanol. The processing costs per GEEL of hydrous and anhydrous ethanol are denoted by ξ_H and ξ_A, respectively.

On the supply side, market prices of hydrous and anhydrous ethanol are linked through the cost of feedstock (sugarcane) and processing cost of hydrous and anhydrous ethanol as follows

$$P_A - P_H = \xi_A - \xi_H - \left(\frac{\Psi_A}{\phi_A} - \frac{\Psi_H}{\phi_H} \right) + \left(\frac{1}{\phi_A} - \frac{1}{\phi_H} \right) P_{SC} = \beta_0 + \beta_1 P_{SC} \tag{5}$$

Equation (5), obtained by the summation and rearrangement of equations (3) and (4), shows that the gap between anhydrous and hydrous ethanol market prices widens as the price of sugarcane increases. It is because the production parameters satisfy $\phi_A < \phi_H$, implying that production of one gallon of anhydrous ethanol is less efficient. This puts anhydrous ethanol at a

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[13] Our model represents a long run equilibrium in the relevant markets.

relative disadvantage because consumers have to pay a higher (fuel) price to compensate producers of anhydrous ethanol for the higher production cost and lower efficiency.

Competition among fuel blenders results in zero profits (up to a constant marketing margin m_F) which implies a link between the fuel price paid by consumers, P_F, price of anhydrous ethanol and exogenous gasoline market price, P_G

$$P_F = \alpha\left(P_A + t_A\right) + \left(1-\alpha\right)\left(P_G + t_G\right) + m_F \tag{6}$$

where α denotes an energy-equivalent blend mandate, and t_A and t_G denote taxes on anhydrous ethanol and gasoline (measured in \$/GEEL), respectively.[14] We assume the gasoline price is exogenous to fuel blenders because the Brazilian government regulates gasoline prices through Petrobras and ethanol production is assumed not to affect world oil prices.

Similarly, the consumer price of hydrous ethanol (E100) is determined by

$$P_{E100} = P_H + t_H + m_{E100} \tag{7}$$

where, t_H denotes the E100 fuel tax and m_{E100} denotes a constant marketing margin.

The market equilibrium requires that supply of sugarcane, S_{SC}, equal the sum of individual uses of sugarcane: sugar and anhydrous and hydrous ethanol

$$S_{SC}\left(P_{SC}\right) = C_{SC}^S + \frac{D_H + I_H}{\phi_H} - \frac{\delta_H C_{SC}^S}{\phi_H} + \frac{\alpha D_F + I_A}{\phi_A} - \frac{\delta_A C_{SC}^S}{\phi_A} \tag{8}$$

The first term on the right-hand site of equation (8), C_{SC}^S, is the quantity of sugarcane allocated to production of sugar. The second term represents the total quantity of sugarcane corresponding to production of hydrous ethanol. Hydrous ethanol used in the domestic transportation sector is denoted by D_H and the quantity of ethanol used in the domestic non-transportation sector is denoted by I_H ;[15] the latter is assumed to be exogenous. The third (negative) term accounts for the hydrous ethanol produced from molasses. This quantity needs to

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[14] The Brazilian blend mandate requires that α [x100] percent of total fuel volume be anhydrous ethanol, i.e., $\alpha = A/\left(A+G\right)$, where A denotes the quantity of ethanol and G quantity of gasoline. By converting A into GEELs, we express the mandate in energy-equivalent terms.

[15] This term also includes trade in hydrous (and the term I_A in anhydrous) ethanol. In this paper, we do not analyze the implications of U.S.'s or other countries' policies on the trade position of Brazil. Neither do we analyze the possibility of the U.S. EPA considering Brazilian sugarcane ethanol as an advanced biofuel and the implications of this consideration for Brazilian farmers/processors. These and other issues are left for further research.

be subtracted in order to avoid double counting: the total allocation of sugarcane for hydrous ethanol has already been accounted for in the second term.

The fourth term in equation (8) denotes allocation of sugarcane used for production of anhydrous ethanol. Akin to hydrous ethanol, anhydrous ethanol is used in the domestic transportation sector, quantity αD_F, but can also be exported or used in other industries. The quantity for the latter two uses is denoted as I_A and is assumed to be determined exogenously. The last (negative) term again adjusts for the anhydrous ethanol extracted from molasses.

We close the model by equilibrating the sum of domestic and foreign demand for sugar, D_S^D and D_S^W, respectively, with sugar production

$$D_S^D\left(P_S\right) + D_S^W\left(P_S\right) = \phi_S C_{SC}^S \tag{9}$$

An intrinsic feature of the model outlined above is its stability in terms of its “elasticity” where changes in policy parameters have small market effects: even if we change all the policy parameters (blend mandate, taxes and gasoline price) and technology parameters (yields of sugar, hydrous and anhydrous ethanol from one tonne of sugarcane) that changed from the 2010/11 to the 2011/12 levels, the impact on the market is modest and in no way reproduces the market changes from 2010/11 to 2011/12 (we will show this empirically later). This means there must have been major exogenous shocks to the Brazilian sugar-ethanol market complex other than the biofuel policy changes. These shocks came in the form of bad weather (shifting the sugarcane supply curve in by about 18.3 percent), income growth that increased the number of cars and kilometers driven (thereby shifting out demand for fuel), and a major shift in export demand for sugar, as evidenced by record world sugar prices. All these shocks would be manifest in shifting the demand/supply curves for fuel, ethanol, sugar and sugarcane. To explain the significant increase in the market prices of the modeled commodities, it is therefore important to quantify the shifts in market demand/supply curves.

The sugarcane supply curve in 2010/11 is depicted in the upper panel of Figure 6a, denoted by S_{SC} with a corresponding price-quantity pair P_{SC} and Q_{SC}, respectively. The price of sugarcane in the 2011/12 marketing year increased to P'_{SC}, while the quantity supplied reduced to Q'_{SC}. As shown in Figure 6a, this implies an inward shift in the sugarcane supply curve, represented by S'_{SC}. The size of the parallel shift is given by distance $Q'_{SC}a$ and is calculated as

$S_{SC}\left(P'_{SC}\right)-Q'_{SC}$, where the first term represents what the supply of sugarcane would have been if the price had increased to P'_{SC} along the original supply curve.[16]

The lower panel of Figure 6a depicts a shift in the aggregate demand for sugar. Both domestic and export demands experienced an outward shift, and we model them separately in the numerical part of our paper. Unlike the upper panel, a decrease in consumption of sugar combined with an increase in its market price is not sufficient to conclude that the demand shifts in. To see this, consider the intersection of the demand curve D_S with the vertical dashed line corresponding to C'_S. If the price P'_S were below this point (but above P_S), the new demand curve would be to the left of the original one. However, the observed data show that the demand for sugar (both domestic and exports) shifted out. The size of the shift is given by $C'_S-D_S\left(P'_S\right)$. Shifts in demands for fuel and hydrous ethanol are determined in a similar way (Figure 6b).

To see how the assumed elasticities of the demand and supply curves depicted in Figure 6a and 6b affect the size of the shift, we estimate the shifts under three scenarios – low, medium, and high – as shown in Table 1.[17]

Table 1. Elasticities Used in Simulations to Detemine Exogenous Shifts in Supply and Demand Curves

	Low	Medium	High
Sugar supply	0.00	0.50	0.70
Fuel demand	-0.09	-0.23	-0.40
Hydrous ethanol demand	-0.30	-0.68	-0.80
Domestic demand for sugar	-0.50	-0.75	-1.00
Export demand for sugar	-1.00	-2.00	-4.00

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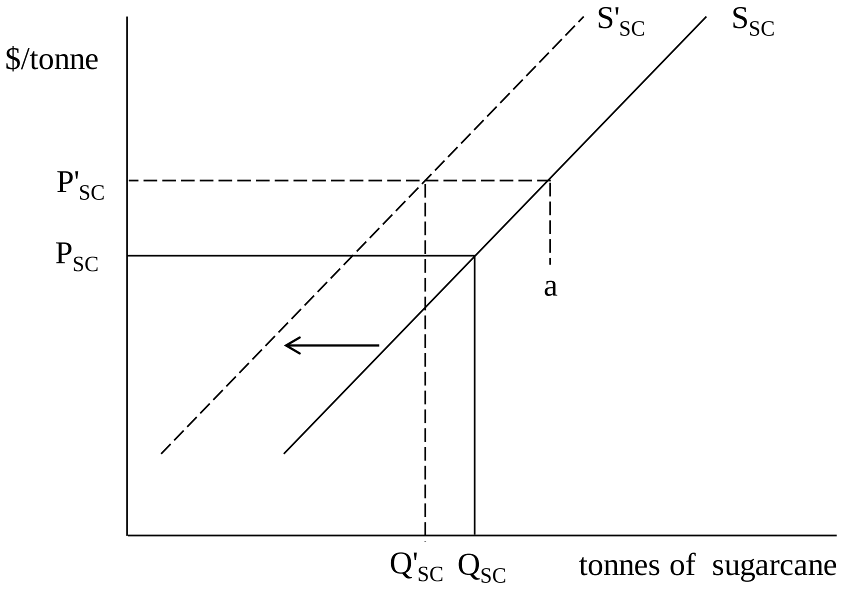
[16] This result holds also for non-linear curves, used in our numerical simulations because the shift is horizontally parallel.

[17] The elasticities vary across the literature. For example, the elasticities reported in Elobeid and Tokgoz (2008) are lower than our medium estimates: sugar supply = 0.19, fuel demand = -0.17, hydrous ethanol demand = -0.30, domestic demand for sugar = -0.08.

Figure 6a. Estimated Shifts in Sugarcane Supply and Sugar Demand

Sugarcane



Sugar

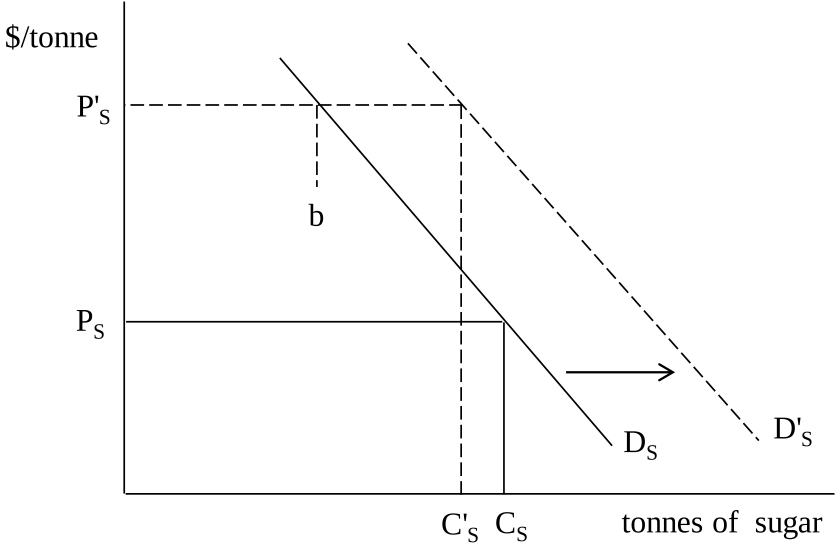
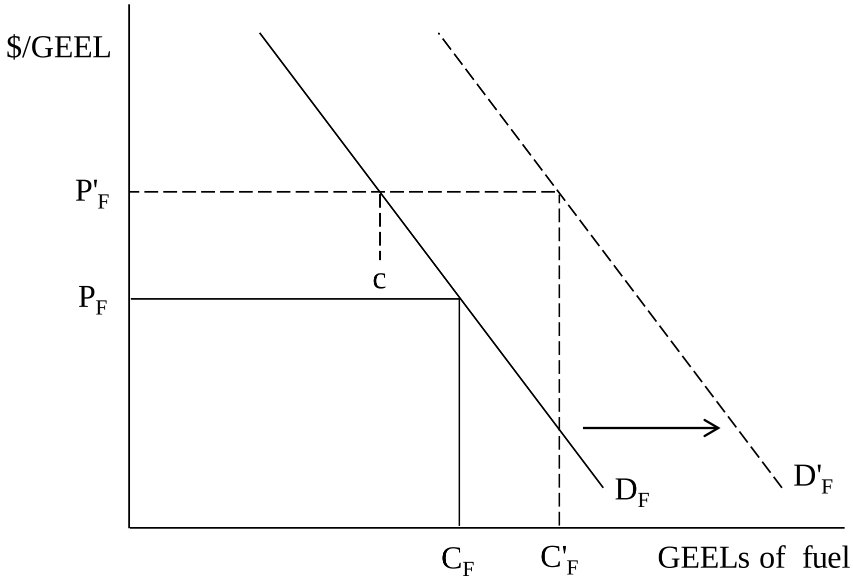


Figure 6b. Estimated Shifts in Fuel and Hydrous Ethanol Demand

Fuel



Hydrous ethanol

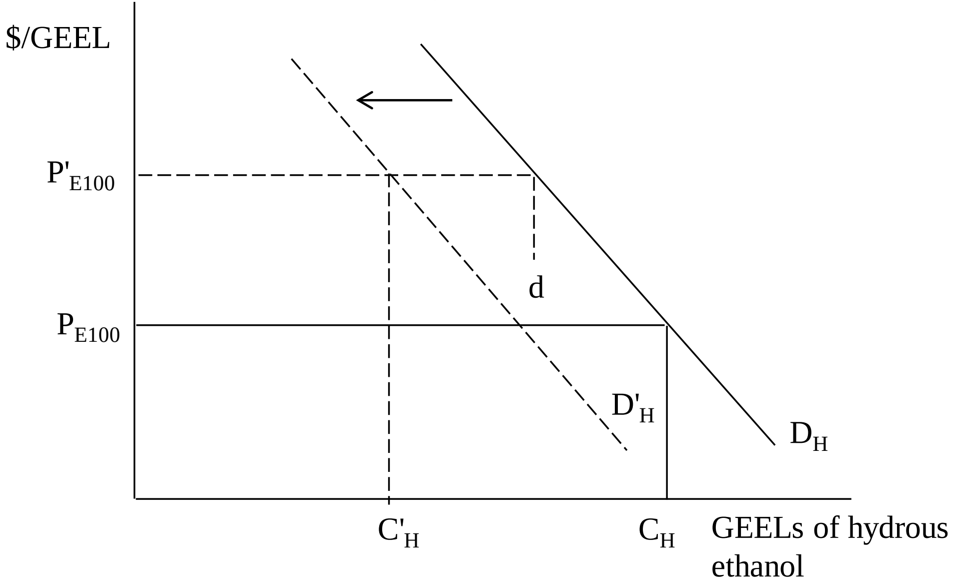


Table 2 presents estimates of the shifts in individual markets in absolute and relative terms (we measure the size of the shift as a percentage of the 2010/11 consumption/production level). We focus on the medium elasticity scenario (our central estimates of elasticities), noting that more elastic market curves are associated with greater shifts (with the exception of the hydrous ethanol demand, where the more elastic demand yields a smaller shift). The first column under each scenario presents the level of a shift. A negative value indicates a shift to the left. In the second column, we report the size of the shift as a percentage of the 2010/11 (baseline) production/consumption. Although all shifts are significant in magnitude, the 22.8 percent increase in the fuel demand and the 33.8 percent increase in the foreign demand (medium scenario) for Brazilian sugar are noticeably high.

Table 2. Estimated Shifts in Brazilian Sugar and Fuel Markets between 2010/11 and 2011/12

	Low elasticity		Medium elasticity		High elasticity	
Shift in…	Size*	% of 2010/11 quantity	Size	% of 2010/11 quantity	Size	% of 2010/11 quantity
Sugarcane supply (bil. tonnes)	-0.052	8.4	-0.114	18.3	-0.141	22.6
Fuel demand (bil. liters)	6.662	21.8	6.965	22.8	7.315	24.0
Hydrous ethanol demand (bil. liters)	-4.209	27.5	-3.144	20.6	-2.838	18.6
Domestic demand for sugar (bil. tonnes)	0.001	7.6	0.002	12.6	0.002	17.3
Export demand for sugar (bil. tonnes)	0.004	17.3	0.009	33.8	0.015	57.1

* A negative value denotes an inward shift.
Source: own calculations

The sizable changes (that must have occurred in combination to generate the surge in ethanol and sugar market prices from their 2010/11 levels) reported in Table 2 explain why the model developed earlier fails to approximate the 2011/12 outcome when only changes in Brazilian biofuel policies and technological parameters are considered.

This can better be seen in Table 3 where we decompose the observed change in Brazilian market prices between the 2010/11 (first column) and 2011/12 (second column) marketing years. The third column in Table 3 gives estimates of what the market prices would have been, had only the exogenous demand and supply shifts occurred (in combination) and policies been held at their 2010/11 levels. The magnitudes of the exogenous shocks correspond to those pertaining to the medium elasticity scenario in Table 2.

In the fourth column, we compute the observed price change as the difference between the second and first column. The price changes due to the exogenous shifts only (fifth column) are given by the difference between the third and first column. Finally, the share of the price change attributable to the shifts in the total observed price change is equal to the ratio of the values in the fifth and fourth columns.

Table 3. Decomposition of a Change in Brazilian Market Prices between 2010/11 and 2011/12*

		Actual 2010/11	Actual 2011/12	2011/12 if market curves shifts only**	Observed price change	Change due to shifts	% of price change due to shifts in observed price change
Price of anhydrous ethanol	$/liter	1.18	1.42	1.43	0.24	0.25	101
Fuel price	$/liter	2.47	2.66	2.53	0.20	0.06	31
Market price of hydrous ethanol	$/liter	0.96	1.19	1.20	0.23	0.23	102
Consumer price of hydrous ethanol	$/liter	1.54	1.88	1.77	0.34	0.23	69
Price of sugarcane	$/tonne	56.11	67.83	73.69	11.72	17.58	150
Price of sugar	$/tonne	700.93	884.00	816.63	183.07	115.70	63

* These simulations assume market shocks (shifts) whose magnitudes correspond to the medium elasticity scenario in Table 2.
** Policies are held at their 2010/11 levels.
Source: calculated

The fact that half of the values in the last column of Table 3 are more than 100 percent indicates that there are considerable market interaction effects not only between Brazilian policies, but also between the policies and exogenous market changes. For example, if biofuel policies had not changed between 2010/11 and 2011/12 and only structural market changes had occurred, we would have observed an even higher rise in the ethanol price.

While Table 2 reports final shifts in market demand and supply curves that reflect all changes in the domestic Brazilian biofuel policy as well as changes in the rest of the world, from a policy analysis point of view, it is important to analyze market effects of a change in a biofuel policy, assuming all other factors, such as income growth or weather, are unchanged. But before we do so, let us model the endogenous shift in demand between E100 and fuel that is generated by a change in the parity gap between E100 and fuel prices when market changes occur.

4. Modeling the Shift in Demand Curves for E100 versus Fuel

Because a change in the biofuel policy (e.g., an increase in the blend mandate or a reduction in the tax on gasoline), among other things, will affect the relative price of the fuel blend and hydrous ethanol, the composition of fuels consumed will alter accordingly.[18] It is because when the price gap (in energy equivalent) between fuel and E100 narrows, some flex cars owners who previously used hydrous ethanol (e.g., because at then prices it paid them to travel to the nearest E100 pump station), will find it profitable to switch to the blended fuel.[19] In this case, the demand for fuel (measured in GEELs) shifts out by exactly the same amount as the

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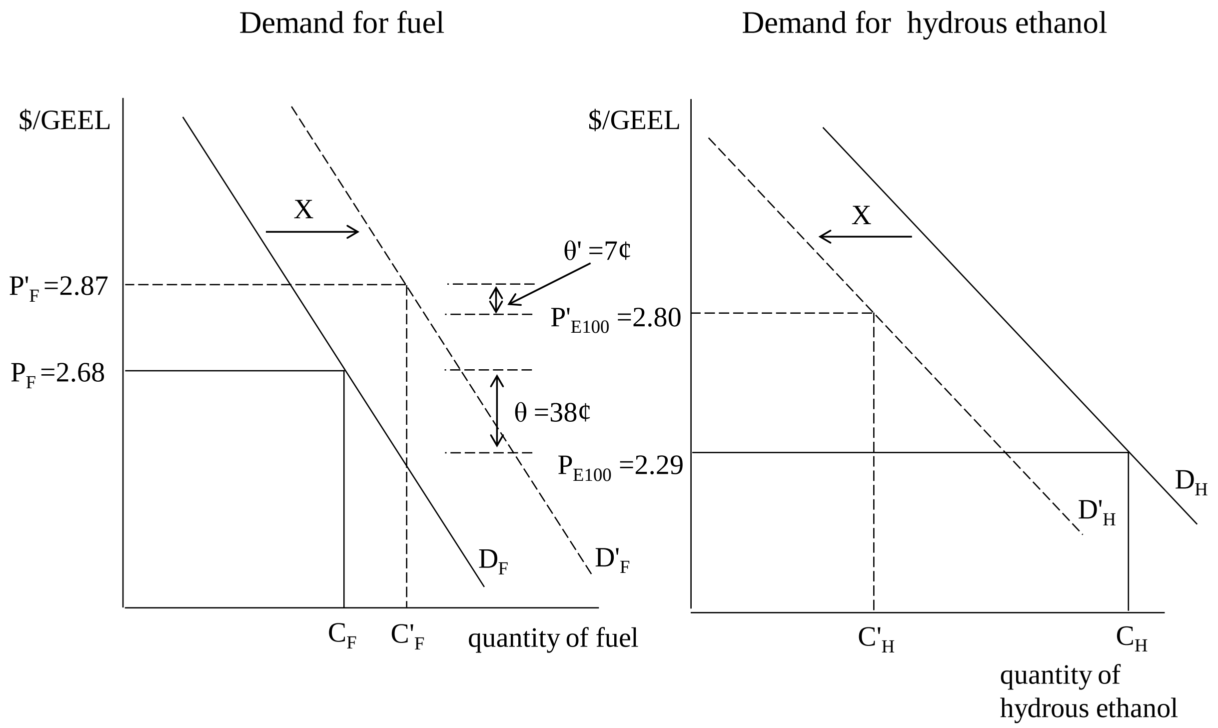
[18] A change in the price of fuel and hydrous ethanol affects the consumers' decision on how many miles to drive. Therefore, in the scenario analysis consumers not only shift between hydrous ethanol and fuel (anhydrous and gasoline) in response to shocks, but also change the total mileage driven.

[19] Note that this is only possible for flex cars, as regular fuel (non-flex) vehicles are not able to run on E100.

demand for E100 shifts in, keeping the total consumption of fuel and E100 unchanged. This is shown in Figure 7 which uses actual prices for the 2010/11 and 2011/12 marketing years (the latter marked by the prime). The horizontal shift *X* does not reflect the reality, however, as we assume a change in the biofuel policy is the only driver of the demand shift.

Figure 7. Symmetrical Shifts in Demand for Fuel and Hydrous Ethanol



In 2010/11, the price gap between fuel and E100 was 39¢/GEEL (= 2.68 - 2.29). Suppose a change in all biofuel policies (i.e., an increase in the mandate, change in fuels taxes, and manipulation of the gasoline price) resulted in a rise in fuel and E100 consumer prices to $2.88/GEEL and $2.80/GEEL, respectively, reducing the price gap to 8¢/GEEL. As the relative price changed in favor of fuel, demand for fuel shifts to D'_F, while that for E100 shifts in to D'_H.

The magnitude of the shift *X* depends on the price gap θ: the bigger the gap, the bigger the shift. Let $X(\theta)$ be a function characterizing the behavior of flex car owners when the price gap, $\theta = P_F - P_{E100}$, changes. We assume that $X(\square)$ is at least once continuously differentiable and satisfies $X' = dX/d\theta > 0$. We also assume that at any point in time the owners of flex cars are sorted according to their propensity to switch between blend fuel and hydrous ethanol, depending on the change in relative price of the two fuels. As the price gap widens, more flex car owners who currently consume blend fuel will find it preferable to switch to E100.

The model defined by equations (1) to (9) can readily be extended to incorporate the endogenous demand shift by specifying the demand curves for fuel blend, D_F, and E100, D_H, as follows[20]

$$D_F = f\left(P_F\right) - X\left(\theta\right) \tag{10}$$

$$D_H = g\left(P_{E100}\right) + X\left(\theta\right) \tag{11}$$

The functions $f\left(\cdot\right)$ and $g\left(\cdot\right)$ denote Marshallian demand functions for blend fuel and E100, respectively, and satisfy $f' = df/dP_F < 0$ and $g' = dg/dP_{E100} < 0$. The Marshallian demand curves shift horizontally by distance X whenever there is a change in the price gap θ. Because the shift occurs only when the price gap changes, we must have $X\left(\theta_0\right) = 0$, where θ_0 denotes the price gap in the baseline (when the policies do not change and the existence of any price gap has been internalized). This point of the X function is very important as it determines its position on the horizontal axis. Figure 8 depicts a family of logistic curves that satisfy the properties (i.e., continuity, differentiability, and monotonicity) imposed on the function X.

5. Comparative Statics Results

Equations (2) through (11) plus the definition $\theta = P_F - P_{E100}$ constitute a market equilibrium whose comparative statics results are presented in Appendix 1 and summarized in Table 4. In general, a change in a policy (i.e., mandate, gasoline price, gasoline tax, anhydrous and hydrous ethanol tax) has an ambiguous impact on market prices. The sign of most comparative statics results depends on the sign of the following expression

$$\frac{\alpha f'}{\phi_A} + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right) X' \equiv \frac{\eta_f \alpha f}{\phi_A P_F} + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right) \frac{dX}{d\theta} \tag{12}$$

where the slope of the fuel demand curve, f', has been expressed by means of the elasticity, η_f, of the Marshallian fuel demand. Intuitively, expression (12) represents two simultaneously

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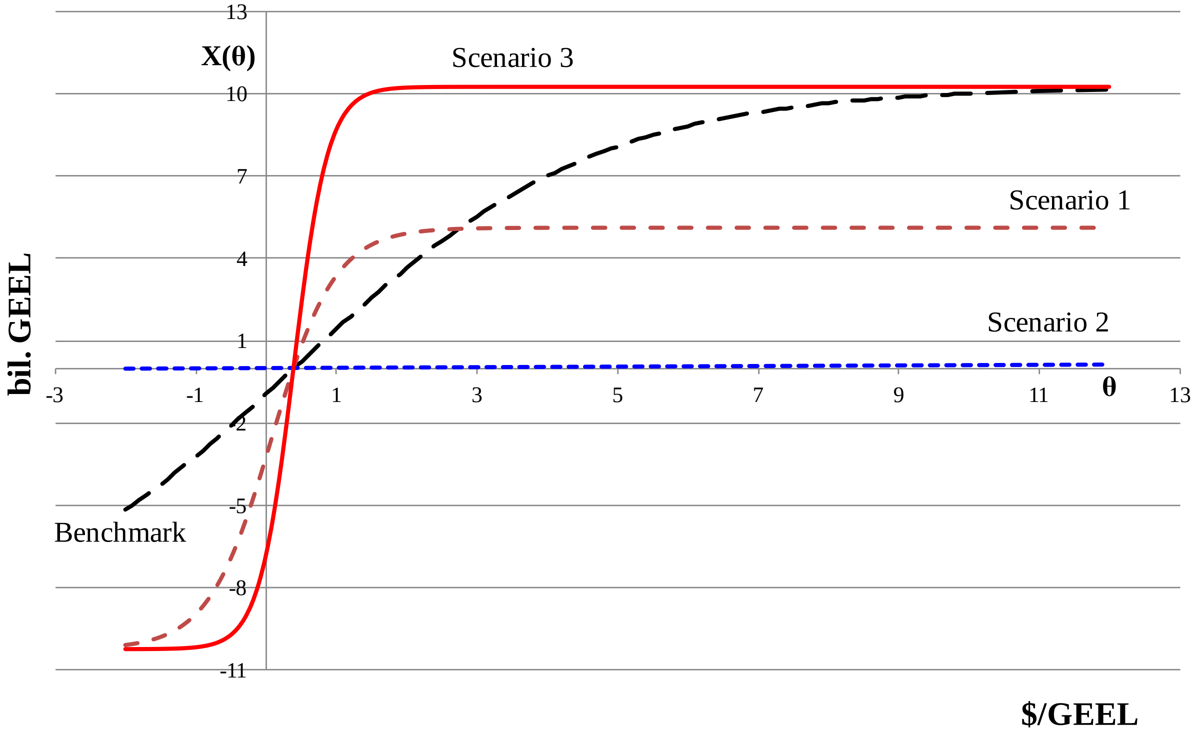
[20] Note that if the price gap decreases relative to the baseline, then the term $X\left(\theta\right) = 0$ becomes negative and the fuel demand curve shifts out, while that for E100 shifts in.

occurring effects. First, a change in any policy affects the price of fuel, which in turn results in a change in the quantity of fuel demanded; this is the shift along the fuel demand curve and is represented by the term f'. Second, a change in the fuel price P_F – combined with a change in the consumer price for hydrous ethanol – alters the price gap which affects flex cars owners' purchasing decision and so the demand curves for fuel and hydrous ethanol shift in opposite directions. The magnitude of the shift is represented by the term $dX/d\theta$.

Figure 8. Logistic Curves for an Endogenous Demand Shift under Various Scenarios



The first term on the right side of identity (12) is unambiguously negative while the second term is negative only if $\alpha > \phi_A / \phi_H$. Using the observed parameters values for 2010/11 and 2011/12 marketing years, the second term is negative only for $\alpha > 0.96$; this means the Brazilian ethanol mandate would have to be at least 96 percent for the expression (12) to be negative. We therefore do not consider this possibility further.

The probability of expression (12) being negative increases with a higher elasticity of the fuel demand, higher blend mandate, and smaller sensitivity of flex car owners to the change in the price gap (represented by the term $dX/d\theta$). However, the fuel demand is empirically found to be price inelastic and the observed blend mandate is around 25 percent. This suggests that expression (12) is very likely to be positive in reality. (It is so in our empirical model). This is best seen if we assume an extreme case of perfectly inelastic fuel demand, that is, $\eta_f = 0$, in which case the expression is (almost surely) positive. In our further analysis, we therefore use the following assumption

Assumption 1: $\frac{\alpha f'}{\phi_A} + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right) X' > 0$.

Given Assumption 1, an exogenous increase in the gasoline price unambiguously results in an increase in all analyzed prices (Table 4). The intuition behind this result is that a higher gasoline price necessitates a higher price of fuel (gasoline plus anhydrous ethanol) charged to the consumers. This gives a cost advantage to hydrous ethanol whose demand shifts out (by the same amount by which the demand for fuel shifts in), thus increasing the market and consumer prices of hydrous ethanol. But as equation (5) shows, market prices of anhydrous and hydrous ethanol are linked on the supply side, giving rise to a higher price of anhydrous ethanol. Owing to the higher competition for the feedstock, the prices of sugarcane and sugar increase.

Table 4. Effect of a Change in a Policy on Market Prices[a]

Increase in…	Market price of ethanol[b]	Consumer price of E100	Price of fuel	Gap in Fuel & E100 price
Gasoline price/tax[c]	+	+	+	+
Tax on anhydrous ethanol	+	+	+	+
Tax on hydrous ethanol	–	+/– [+][d]	–	–
Mandate	+/– [+]	+/– [+]	+/– [–]	+/– [–]

[a] The unambiguous signs are conditional on *Assumption 1.*
[b] We do not distinguish between anhydrous and hydrous ethanol prices nor report the effects on sugar and sugarcane prices as all four prices move in the same direction.
[c] These effects are equal not only in sign, but also in magnitude.
[d] Signs in square brackets refer to our empirical results.
Source: Appendix 1.

The tax on gasoline has identical (both magnitude and signs) market effects as the gasoline price. The directional effects of a higher tax (or equivalently a lower tax exemption) on anhydrous ethanol on the market prices are also the same as for the gasoline price. The explanation for the signs follows the same logic as above, because a higher tax on anhydrous ethanol increases the consumer price of fuel.

However, the price effects of an increase in the tax (or equivalently a reduction in a tax exemption) on hydrous ethanol exhibit an opposite pattern. The tax drives a wedge between the consumer and market price of hydrous ethanol. As this wedge grows larger, the market price of hydrous ethanol decreases. But because on the supply side it is linked to the anhydrous ethanol price, the latter decreases, too, making the blending of fuel less expensive for the blenders; hence, the decrease in the fuel price. Weaker competition for sugarcane pushes its price and production down. But the reduction in the sugarcane use due to a lower need for ethanol more than offsets the reduction in sugarcane production, thus diverting more feedstock to sugar production. As the supply of sugar increases, its market price falls.

Interestingly, a higher tax has an ambiguous effect on the consumer price of hydrous ethanol. Whether this price will increase or decrease depends on the relative magnitudes of the inward shifts in the demand and supply curves for hydrous ethanol. The demand curve shifts in because of a change in the relative prices in favor of fuel while the supply curve contracts because a lower market price of hydrous ethanol makes this product less profitable to producers, who subsequently divert the feedstock (sugarcane) to sugar production.

Finally, we note that Assumption 1 is not sufficient to draw unequivocal conclusions about the effect of a higher mandate on the market equilibrium (although, as we show later, a higher mandate empirically results in a higher ethanol price). Contrast this with the prediction of the model by de Gorter and Just (2009) where a higher mandate, given a perfectly elastic gasoline supply, unambiguously results in a higher ethanol price. The reason for this difference is the fact, that there are two separate, and mutually competing, demands for ethanol, while the de Gorter and Just's model for the United States has only one demand for corn ethanol.

6. Data and Calibration

The substantial proportion of hydrous ethanol in total ethanol consumption in Brazil (71 and 60 percent in 2010/11 and 2011/12, respectively) necessitates a consistent measurement of fuel-related quantities and prices in energy-equivalent terms (i.e., according to vehicle kilometers traveled). It is because the hydrous ethanol is typically sold as E100 (i.e., 100 percent ethanol) to owners of 'flex' cars.[21] The empirical evidence suggests that the owners of such cars buy fuel according to the price per kilometer traveled, not per liter bought. To that end, all prices and quantities related to anhydrous and hydrous ethanol as well as fuel (blend of anhydrous ethanol and gasoline) are expressed in gasoline energy-equivalent liters (Appendix 4).[22]

One liter of anhydrous and hydrous ethanol yields only 67 percent of kilometers traveled on one liter of gasoline. Because anhydrous ethanol cannot be used in its pure form, the number of kilometers traveled per liter of fuel is equal to the weighted average of kilometers per liter of anhydrous ethanol (if, hypothetically, in the pure form) and gasoline. The result will thus depend on the share of the anhydrous ethanol in the blend. Given the 2010/11 and 2011/12 mandate level the relative kilometrage of fuel is equal to 0.92 in both years.

The yield of sugar, anhydrous and hydrous ethanol from one tonne of sugarcane is not constant but depends largely on the quality of the cane and the way the juice is extracted; the quality in turn depends heavily on the weather in a given year. The data indicate that the weather conditions in 2011/12 adversely affected the yields of sugar, anhydrous and hydrous ethanol relative to 2010/11: 130kg, 68.6 liters, and 71.6 liters, respectively *vs* 133kg, 71.7 liters, and 75.0 liters in 2010/11.

The state-of-the-art production plants that process the sugarcane into sugar are able to make use of the sugar's by-product, molasses. Currently, as many as 9.25 liters of ethanol (anhydrous and hydrous combined) can be extracted from the molasses obtained from one tonne of sugarcane. Because the proportion of both ethanol types produced from molasses varies among individual producers, we assume that the ratio of the anhydrous and hydrous ethanol thus produced is the same as the observed ratio of these ethanol types in overall ethanol production. Thus, for example for 2010/11, the amount of anhydrous ethanol from molasses per tonne of sugarcane is equal to 0.29*9.25 = 2.69 liters, and that of hydrous ethanol is equal to 9.25 – 2.69 = 6.56 liters.

Using bagasse for electricity cogeneration significantly improves the economics of all products derived from sugarcane. To illustrate this, the Brazilian Sugarcane Industry Association (UNICA) reports that one tonne of sugarcane produces 250 kilograms of bagasse worth 85.6

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[21] A flex car can run on a fuel with the share of ethanol between zero and 100 percent.

[22] Sources of the data used or formulas for their calculation are listed in Appendix 4. In the text, we therefore abstain from reporting these sources.

kWh of electricity.[23] The excess supply of electricity not used in the plant, approximately 63 kWh, is currently sold on the grid for about $R100/MWh (price varies).[24] This price needs to be adjusted for the losses of electricity during distribution, however. (It is estimated that the above price would be reduced by as much as 25 percent).

In this paper, we model three biofuel policies: ethanol mandate, tax exemption on anhydrous ethanol (i.e., the difference between the tax levied on gasoline and anhydrous ethanol), and fuel taxes. We calibrate our model to the observed mandate as represented by the actual share of anhydrous ethanol in total fuel consumption, that is, 24.6 and 23.1 percent for 2010/11 and 2011/12, respectively. The system of Brazilian fuel taxes is complex. Appendix 3 presents calculations of the individual taxes on gasoline and the two types of ethanol.

Our (non-linear) demand and supply curves exhibit constant price elasticities. The central estimates of these elasticities come from recent studies analyzing the Brazilian market. In particular, the sugarcane supply elasticity is assumed to be 0.5 (Schmitz et al, 2003), reflecting the fact that sugarcane is a perennial and its replanting requires significant investments. The elasticity of the domestic demand for sugar is set to -0.75 (de Freitas and Kaneko, 2011) while that for export demand is substantially higher, -2. Menezes et al. (2008) report the elasticity of demand for fuel of -0.23. This value is close to the estimate (for the Unites States) reported by Hamilton (2009), as well as to the medium/long run meta-analysis estimate by Havranek (2011). Predictably, the demand for hydrous ethanol is more elastic, -0.68 (Menezes et al. 2008). This is because hydrous ethanol can only be used in the flex cars which can easily change the fuel used according to the relative fuel prices.

We compute the price of fuel as the weighted average of anhydrous and gasoline prices adjusted for the respective taxes. The weights are equal to the shares of ethanol and gasoline in the final fuel blend. The observed fuel price is higher than the computed. We attribute the difference to the marketing margin and treat the margin as a constant. The same applies for the consumer price of hydrous ethanol.

The gap between the price of fuel and hydrous ethanol was $0.39/GEEL in 2010/11 but dropped to $0.08/GEEL in 2011/12. Given the relatively big gap in 2010/11, one can hypothesize that the owners of the flex cars were less sensitive, compared to 2011/12, to a

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[23] http://cavalierecapital.com/yahoo_site_admin/assets/docs/Ethanol_A_sustainable_alternative_for_transport.51114446.pdf

[24] This corresponds to approximately $50/MWh.

change in the relative fuel price. This implies that any shock in the price gap in 2010/11 would have been more likely to induce a smaller shift in the demand for hydrous ethanol than in 2011/12.

The sugarcane production is used for sugar and anhydrous and hydrous ethanol. The production of both anhydrous and hydrous ethanol exceeds their domestic use. The difference is due to trade and industrial use of the ethanol. We assume that this part of ethanol production is exogenous, that is, the biofuel policies do not affect those markets. Brazil exports about two thirds of its sugar production.

7. An Empirical Illustration

The Shift Function

We use the logistic function of the form

$$X\left(\theta\right)=\frac{A}{1+Be^{-C\theta}}+D \tag{13}$$

to model the propensity of flex cars owners to switch between consumption of fuel and E100. Parameters *A* and *D* relate to the asymptotes of the logistic function and parameters *B* and *D* to its shape. (For a discussion of these parameters and their calibration see Appendix 2). This function is increasing in its argument, meaning that a higher gap between consumer prices of fuel and hydrous ethanol leads to a greater shift-out of the demand for hydrous ethanol (coupled with an opposite shift-in of the demand for fuel).

We set the lower asymptote of function (13) to be the negative of consumption of hydrous ethanol in the baseline. It is because the maximum reduction in the demand for hydrous ethanol occurs when all flex cars using hydrous ethanol in the baseline switch to the fuel blend. The upper asymptote is more uncertain, however. It depends on how much fuel the flex cars consume in the baseline; this information is, not readily available, however. We therefore perform a sensitivity analysis with respect to the upper asymptote, as well as to the curvature of the function *X*. Parameter values under various scenarios are summarized in Table 5.

Table 5. Summary of Parameters of the Logistic Function used in Simulations

	Benchmark	Scenario 1	Scenario 2	Scenario 3
Upper asymptote	10.24	5.12	12.28	10.24
Lower asymptote	-10.24	-10.24	-10.24	-10.24
A	20.48	15.36	22.52	20.48
B	1.20	1.20	1.20	5.00
C*	0.46	2.23	0.00	4.10
D	-10.24	-10.24	-10.24	-10.24
Price gap (θ)	0.39	0.39	0.39	0.39

* calibrated value
Source: own calculations

In the benchmark, we assume that the upper asymptote is equal to the negative of the lower asymptote (-10.24 bil. GEELs), meaning that half of flex cars consumes hydrous ethanol and the other half consumes fuel in the baseline. The higher is the gap between consumer prices of fuel and hydrous ethanol in a given point in time, the less sensitive flex cars owners are to changes to this gap. Consider, for instance, the actual price gap of \$0.39/GEEL observed in 2010/11. In this case, a small perturbation in the price differential is likely to result in a small change in the proportion of fuel and hydrous ethanol use because flex car owners already "incline" to hydrous ethanol. Contrast this with the price differential of \$0.08/GEEL observed in 2011/12. It is reasonable to assume that the inclination to hydrous ethanol is not as strong now as in the previous case, hence a greater sensitivity to a change in the price gap.

To reflect the arguments above, we set the value of the shape parameter *B* to be 1.2 in the Benchmark and Scenario 1 and 2, but set it much higher (*B* =5) in Scenario 3.[25] The parameter *C* is calibrated (Appendix 2) to ensure that given the values of other parameters, the following condition holds: $X\left(\theta_0\right)=0$. The logistic curve corresponding to the benchmark specification is depicted in Figure 8.

In Scenario 1, we set the upper asymptote to one-half of its benchmark level (5.12 bil. GEELs), while in Scenario 2 we set it to 12.28 bil. GEEL, which is the highest possible value

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[25] The values for the shape parameter *B* were arbitrarily chosen to illustrate the point that the sensitivity of flex cars owners to the observed price gap can differ depending on the size of the gap. The relative size of the two values of the shape parameter matters more that their levels. But it should be noted that the choice of this parameters is not completely arbitrary because if the shape parameters is less than unity, the logistic curve becomes decreasing, which runs afoul of our assumption about the monotonicity of this curve.

that is consistent with the assumptions on the signs of the other parameters.[26] As shown in Figure 8, under this scenario, flex cars owners hardly respond to the change in the price gap. The opposite is true for Scenario 3 (where $B = 5$), where a small deviation from the current price gap makes many flex cars switch to an alternative fuel.

Policy Simulations

We run a battery of simulations to analyze the impacts of individual biofuel policies and market shocks quantitatively. All price changes possess the predicted signs presented in Table 4. The first set of simulations (columns denoted by B = 1.2 in Table 6 and 7) assumes the behavior of owners of flex cars is described by the benchmark logistic curve in Figure 8, whereas the second set (columns denoted by B = 5) uses the Scenario 3 logistic curve to investigate how the market outcome differs if flex cars owners are very sensitive to a change in the fuel price gap. The vector of baseline policies (in effect in the 2010/11 marketing year) comprises the volumetric blend mandate $\alpha = 0.246$; the tax on gasoline t_G = \$1.28/liter; the tax on anhydrous ethanol t_A = \$0.048/liter; the tax on hydrous ethanol t_H = \$0.262/liter; and the gasoline price P_G = \$1.05/liter.

Table 6. Policy Simulations Results*

		Difference relative to baseline									
	Baseline	28 ¢ reduction in gasoline tax**		5 percentage point reduction in mandate		Parity between anhydrous and gasoline tax		Parity between hydrous and fuel taxes		No mandate, and all taxes at parity	
		B = 1.2	B = 5	B = 1.2	B = 5	B = 1.2	B = 5	B = 1.2	B = 5	B = 1.2	B = 5
Fuel price (\$/liter)	2.47	-0.21	-0.23	0.05	0.05	0.20	0.22	-0.02	-0.05	0.27	0.08
Market price of anhydrous ethanol (\$/liter)	1.18	-0.01	-0.06	-0.03	-0.02	0.01	0.06	-0.07	-0.19	-0.21	-0.18
Market price of E100 (\$/liter)	0.96	-0.01	-0.06	-0.03	-0.01	0.01	0.06	-0.07	-0.18	-0.20	-0.17
Consumer price of E100 (\$/liter)	1.54	-0.01	-0.06	-0.03	-0.01	0.01	0.06	0.38	0.27	0.40	0.42
Price of sugarcane (\$/tonne)	56.11	-0.59	-4.50	-1.96	-1.12	0.58	4.50	-5.26	-13.56	-14.73	-13.03
Price of sugar (\$/tonne)	700.93	-3.88	-29.64	-12.93	-7.39	3.83	29.59	-34.60	-89.26	-96.95	-85.78

* Mandate binding in all simulations except the last one.

** Or the same reduction in gasoline price.

B = 1.2 means that flex cars owners are less sensitive, and B = 5 that they are very sensitive to a change in the fuel price gap.

Source: own calculations

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[26] If the upper asymptote were higher than 12.2 bil. GEELs, the logistic function would be decreasing, thus contradicting our assumption that the bigger the price gap, the bigger the shift. This happens because by requiring that $X(\theta_0) = 0$, we are imposing structure on the logistic function that does not allow for any choice of the upper asymptote.

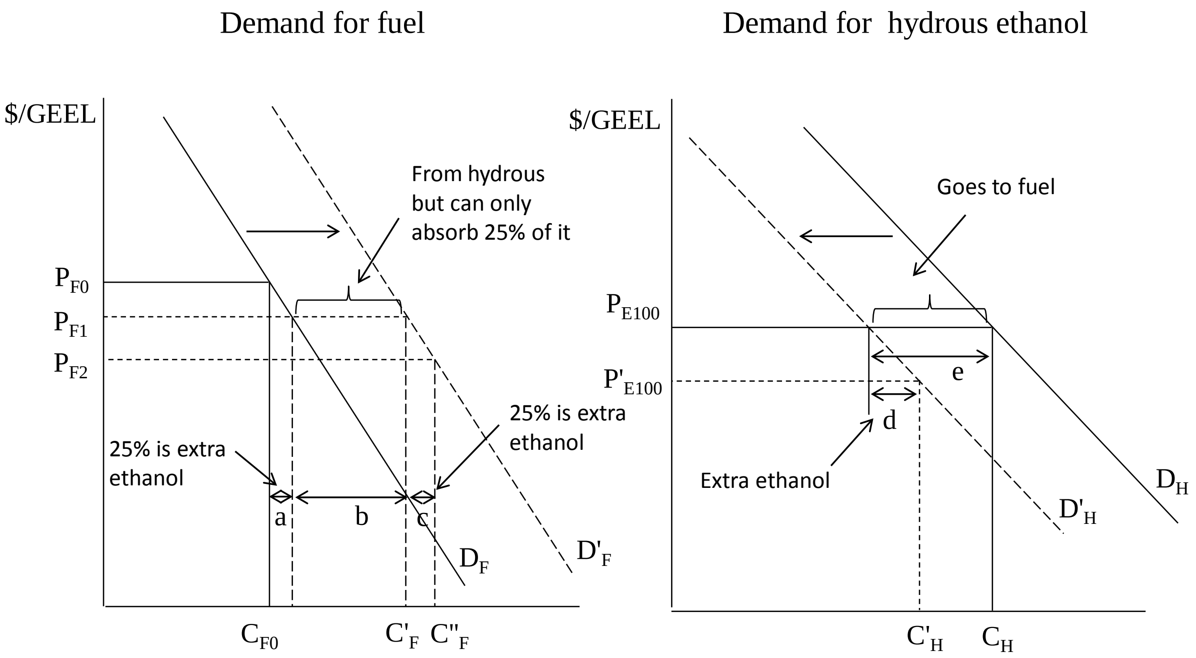
The first policy scenario presented in Table 6 models a recent 28 cent per liter reduction in the gasoline tax (assuming it occurred in the 2010/11 marketing year); ethanol prices decline by 1 cent as a result. The comparative statics results presented in Appendix 1 show that a decrease in the gasoline tax has identical effects – in both sign and magnitude –as a reduction in the gasoline price. This makes our exposition easier because the gasoline price in Brazil is believed to be below its world market counterpart by approximately the same amount as the recent reduction in the gasoline tax. Thus, the results for the first scenario are not only informative of the magnitudes of the market effects of a gasoline tax shock, but also of the effects of exogenously pegging the gasoline price in Brazil below the world prices.

The instantaneous effect of a lower gasoline tax is a reduction in the price of fuel from P_{F0} to P_{F1} in Figure 9. This results in an increase in the consumption of fuel by the distance a, 25 percent of which is anhydrous ethanol when the mandate is 25 percent (i.e., with E25). With this decline in the fuel price, the parity gap between fuel and E100 prices declines to $P_{F1} – P_{E100}$ and so some E100 consumers switch to fuel consumption. As a result, the hydrous demand curve shifts in by the same amount (distance e) as the fuel demand curve shifts out (distance b); the distances are measured in gasoline energy-equivalent liters.

The reduced demand for hydrous ethanol results in a new demand curve D'_H, with a decline in the price of hydrous ethanol to P'_{E100} , thus partially offsetting the decline in hydrous ethanol consumption by distance d to yield a net reduction in hydrous ethanol consumption of distance $e – d$. If the fuel price stayed at P_{F1}, resulting fuel consumption would correspond to C'_F. But because the hydrous and anhydrous ethanol prices are linked on the supply side, the anhydrous ethanol falls, resulting in a further reduction in the fuel price, denoted by P_{F2}. Of the additional fuel consumption associated with this price decrease, 25 percent is anhydrous ethanol. In total, a reduction in the gasoline tax brought about an increase in fuel consumption of $a + b + c$, and hence a higher need for anhydrous ethanol of 0.25 x ($a + b + c$). On the other hand, the net decrease in the use of hydrous ethanol is $e – d$. Therefore, if 0.25 x ($a + b + c$) < $e – d$, then the total use of ethanol declines, resulting in a decrease in both hydrous and anhydrous ethanol prices.

The effect of the government arbitrarily reducing the gasoline price below world prices follows the same set of arguments as the reduction in the gasoline tax while an increase in the tax exemption (equivalent to a decrease in the tax) for hydrous ethanol has the reverse logic of Figure 9 where the demand for hydrous ethanol shifts out first to *D'*$_H$.

Figure 9. Effects of a Decrease in the Gasoline Tax



In the second scenario, we analyze what would happen if the 2010/11 mandate decreased by 5 percentage points.[27] Currently, the mandate can range between 18 and 25 percent in Brazil. Results reported in Table 6 suggest that the sensitivity of flex cars owners (proxied by the curvature of the shifter function) has a minimal effect on the market outcome. For example, while the market price of hydrous ethanol decreases by 3 cents (relative to the baseline) when the mandate is reduced and flex cars owners are less sensitive, it decreases by 2 cents for the same policy change and more sensitive flex car owners.

Notice also that a reduction in the mandate has associated with it an increase in the fuel price by 5 cents. This just illustrates our earlier finding, presented in the section on the

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[27] Some observers say that the optimal anhydrous ethanol blend mandate is as high as 30 percent. While our baseline value is lower, we expect no qualitative difference between the simulations using our baseline and the 30 percent mandate. Moreover, in the ensuing analysis we show that a change in one policy at a time does not explain much of the observed price changes in Brazil.

comparative statics that an exogenous change in the blend mandate, *given a perfectly elastic supply of gasoline*, can have opposite effects in different market environments. To reiterate, in a market with only one demand for ethanol, like in the United States, a lower mandate would unambiguously result in a lower fuel price; this might, however, not be the case in an environment with two competing demand for ethanol (as we show in Table 6).[28] In sum, the mandate in Brazil operates very differently than in the traditional blend mandate model.

The anhydrous ethanol in Brazil enjoys a significant tax exemption *vis-à-vis* gasoline (as much as \$1.21/GEEL). But fuel consumers benefit from it only to the extent that it lowers the final fuel price which they see (it is because anhydrous ethanol cannot be purchased in its pure form and is always blended with gasoline). If anhydrous ethanol were taxed on parity with gasoline (so that the tax exemption is eliminated), all market prices would increase (third scenario in Table 6), although only marginally; for instance, ethanol prices are predicted to rise by 1 cent. In particular, for ethanol producers this result implies that they would be better-off with a higher tax on anhydrous ethanol; or alternatively that they are being implicitly taxed by the existing generous anhydrous tax exemption.

On the other hand, when the tax on hydrous ethanol is raised so as to obtain parity between hydrous ethanol and tax on fuel (where the gasoline and anhydrous ethanol taxes are held at their baseline levels), ethanol prices decline by R\$0.07 per liter, making the producers worse-off. This occurs because the tax drives a wedge between the consumer and producer price of hydrous ethanol, pushing the latter down.

The last scenario presented in Table 6 analyzes the effects of the elimination of the blend mandate and all tax exemptions (i.e., the tax on anhydrous ethanol is on parity with that on gasoline while the tax on hydrous ethanol is on parity with the fuel tax, where the fuel tax is given by the weighted average of gasoline and anhydrous taxes). A significantly higher anhydrous price makes the marginal cost to fuel blenders rise, resulting in an increase in the fuel price. A higher consumer price for hydrous ethanol leads to a net decrease in the demand for hydrous ethanol, resulting in lower ethanol production, and thus its lower market price. The sum total effect of eliminating Brazilian ethanol mandate and tax exemptions (gasoline prices and

---

[28] The blend mandate model by de Gorter and Just (2009) predicts that a higher gasoline price (given a perfectly elastic gasoline supply curve) unequivocally reduces the ethanol price, while Lapan and Moschini's (2012) model (with a fixed consumption mandate) would predict no change in ethanol price. Moreover, both previous models predict that a higher mandate results in a higher fuel price (provided the gasoline price is fixed).

taxes held constant) is to reduce hydrous ethanol prices by 21 percent (= – 0.20/0.96 [x100%]). Our other research (Drabik, 2011) finds a comparable effect of eliminating U.S. ethanol policies for the same time period (a 24 percent reduction in U.S. ethanol prices), although ethanol prices are higher in Brazil and U.S. ethanol consumption is twice that of Brazil.

Unlike the United States, where the mandate always acts as a lower bound on the ethanol price (i.e., it determines the minimum price), the mandate in Brazil may be either a lower or an upper bound. The latter may occur, for example, if sugar demand is low and sugarcane supplies plentiful. In that case, the removal of the mandate would increase the ethanol price.

Table 7 presents results for simulations where the Brazilian market experiences a shock in supply of sugarcane; demands for fuel and hydrous ethanol; and demand for sugar. The magnitudes of the shocks correspond to the medium scenario values presented in Table 2. Both "increase in demand for sugar" and "reduction in supply of sugar" scenarios yield the same qualitative conclusions: the price of sugarcane increases, making production of anhydrous and hydrous ethanol and sugar more expensive; thus the market prices of these commodities rise. A higher market price of anhydrous ethanol increases the marginal cost for fuel blenders; hence the increase in the consumer price of fuel blend.

Table 7. Market Shocks Simulations Results*

		Difference relative to baseline					
	Baseline	Reduction in supply of sugarcane**		Increase in demand for fuel & reduction in demand for E100 ***		Increase in demand for sugar ****	
		B = 1.2	B = 5	B = 1.2	B = 5	B = 1.2	B = 5
Fuel price ($/liter)	2.47	0.04	0.03	-0.01	0.00	0.02	0.01
Market price of anhydrous ethanol ($/liter)	1.18	0.15	0.10	-0.02	-0.02	0.09	0.06
Market price of E100 ($/liter)	0.96	0.15	0.10	-0.02	-0.01	0.08	0.06
Consumer price of E100 ($/liter)	1.54	0.15	0.10	-0.02	-0.01	0.08	0.06
Price of sugarcane ($/tonne)	56.11	11.07	7.47	-1.58	-1.11	6.29	4.29
Price of sugar ($/tonne)	700.93	72.88	49.14	-10.42	-7.31	41.38	28.23

* Mandate binding in all simulations.

** Reduction of 18.3%.

*** Increase of 22.8%; reduction of 20.6%.

**** Increase in domestic demand of 12.6% and increase in export demand of 33.8%.

B = 1.2 means that flex cars owners are less sensitive, and B = 5 that they are very sensitive to a change in the fuel price gap.

Source: own calculations

8. Concluding Remarks

Dramatic changes have occurred recently in Brazilian ethanol and sugar markets. This paper presents a general economic model of the Brazilian sugar/ethanol nexus from the processing of sugarcane, where the world price of sugar and the Brazilian market price for ethanol are uniquely determined. Domestic ethanol demand is depicted in two specified demand curves – one for fuel (a mixture of anhydrous ethanol and gasoline) and the other for hydrous ethanol (E100). We incorporate an endogenous switching model for E100 consumers as they respond to changes in the relative price of E100 and fuel. On the supply side, we incorporate the economics of electricity production from bagasse, ethanol production from molasses (a by-product of sugar production), and also incorporate the differential cost of producing hydrous and anhydrous ethanol, thereby keeping a specific price link between the two types of ethanol. We do not model Brazil's trade in ethanol – but with U.S. and Brazilian ethanol markets becoming closely linked when the U.S. became a major exporter to Brazil in 2011, the importance of our detailed model of Brazil's sugarcane-ethanol-sugar complex takes on added importance as developments in world sugar markets were directly affecting Chicago futures prices for corn. Clearly, the next step is to integrate models of the two ethanol sectors.

This paper has several key findings. Unlike biofuel mandates and tax exemptions elsewhere, Brazil's fuel-ethanol-sugar markets and fuel policies are unique in that each policy, in theory, has an ambiguous impact on the market price of ethanol and hence on sugarcane and sugar prices. The Brazilian market is complex with two mutually competing demands for ethanol so any initial change in ethanol price due to a policy change can be offset with shifts in demand for E100 versus fuel. Furthermore, the feedstock is sugarcane which produces two competing products, sugar and ethanol, giving processors more flexibility. But we find that under plausible assumptions regarding the elasticity of the fuel demand curve and the responsiveness of flex car owners to changes in relative prices, most of the policies analyzed have an unambiguous impact on ethanol prices.

Our empirical analysis shows there are two policies that seemingly help the ethanol industry but do otherwise in reality: a low gasoline tax and a high anhydrous tax exemption result in lower ethanol prices (unlike in the U.S. where lower gasoline tax will increase ethanol prices regardless and a lower gasoline price increases the ethanol price in the case of a binding blend mandate). On the other hand, as expected, higher mandates, tax exemptions for hydrous ethanol and gasoline prices in Brazil means higher ethanol and sugar prices.

Eliminating Brazilian ethanol tax exemptions and mandates reduces ethanol prices by 21 percent in 2010-11, very similar to the estimated effects of U.S. ethanol policies by Drabik (2011) for the same time period. But the marginal changes in Brazilian policies on ethanol prices between 2010-11 and 2011-12 are shown in this paper to be relatively small both individually and collectively. We find that observed market changes can only be explained by outward shifts in fuel transportation and sugar export demand curves, and reduced sugarcane supply due to bad weather.

Although the hydrous ethanol tax exemption always increases both anhydrous and hydrous ethanol prices (with or without the mandate), in principle it is very possible that the mandate in Brazil can also act as upper bound on ethanol consumed, (rather than a lower bound as is always the case in the United States), depending on the year and market circumstances. This outcome is more likely, *inter alia*, when sugar demand is low and sugarcane supplies plentiful. In that case, the removal of the mandate will increase the ethanol price. The number of years in which this has happened in the past (if ever) and the extent to which ethanol prices would have risen with the elimination of the mandate await further research.

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Appendix 1. Comparative Statics Results

Totally differentiating the system of equations (2) to (4) and (6) to (11) and recalling that $\theta = P_F - P_{E100}$, we arrive at

$$
\begin{aligned}
&dP_{SC} = \phi_S dP_S + \delta_H dP_H + \delta_A dP_A \\
&dP_{SC} = \phi_H dP_H \\
&dP_{SC} = \phi_A dP_A \\
&dP_F = \left(P_A + t_A - P_G - t_G\right) d\alpha + \alpha dP_A + \alpha dt_A + \left(1-\alpha\right) dP_G + \left(1-\alpha\right) dt_G \\
&dP_{E100} = dP_H + dt_H \\
&S_{SC}\, 'dP_{SC} = \left(1 - \frac{\delta_H}{\phi_H} - \frac{\delta_A}{\phi_A}\right) dC_{SC}^S + \frac{1}{\phi_H} dD_H + \frac{D_F}{\phi_A} d\alpha + \frac{\alpha}{\phi_A} dD_F \\
&\left(D_S^D\, ' + D_S^W\, '\right) dP_S = \phi_S dC_{SC}^S \\
&d\theta = dP_F - dP_{E100} \\
&dD_F = f\, 'dP_F - X\, 'd\theta \\
&dD_H = g\, 'dP_{E100} + X\, 'd\theta
\end{aligned}
$$

where the prime (') denotes the derivative of a function with respect to its argument.

Using the Implicit Function Theorem, we obtain changes in the prices of interest with respect to a marginal change in a policy variable. To simplify the expressions to follow, we define

$$
Z = \phi_H \left[S_{SC}\, ' - \left(\frac{g\, '}{\phi_H{}^2} + \frac{\alpha^2 f\, '}{\phi_A{}^2} \right) + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A} \right)^2 X\, ' - \left(1 - \frac{\delta_H}{\phi_H} - \frac{\delta_A}{\phi_A} \right)^2 \frac{\left(D_S^D\, ' + D_S^W\, '\right)}{\phi_S{}^2} \right] > 0
$$

The individual derivatives take the following forms:

$$\frac{dP_H}{d\alpha} = \frac{dP_{E100}}{d\alpha} = \frac{\left(P_A + t_A - P_G - t_G\right)\left[\frac{\alpha f'}{\phi_A} + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right)X'\right] + \frac{D_F}{\phi_A}}{Z}$$

$$\frac{dP_A}{d\alpha} = \frac{\phi_H}{\phi_A}\frac{dP_H}{d\alpha}$$

$$\frac{dP_F}{d\alpha} = \frac{\alpha\phi_H}{\phi_A}\frac{dP_H}{d\alpha} + \left(P_A + t_A - P_G - t_G\right) \qquad \text{(A1.1)}$$

$$\frac{d\theta}{d\alpha} = \left(P_A + t_A - P_G - t_G\right) - \phi_H\left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right)\frac{dP_H}{d\alpha}$$

$$\frac{dP_{SC}}{d\alpha} = \phi_H\frac{dP_H}{d\alpha}$$

$$\frac{dP_S}{d\alpha} = \frac{\phi_H}{\phi_S}\left(1 - \frac{\delta_H}{\phi_H} - \frac{\delta_A}{\phi_A}\right)\frac{dP_H}{d\alpha}$$

$$\frac{dP_H}{dP_G} = \frac{dP_{E100}}{dP_G} = \frac{\left(1-\alpha\right)\left[\frac{\alpha f'}{\phi_A} + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right)X'\right]}{Z}$$

$$\frac{dP_A}{dP_G} = \frac{\phi_H}{\phi_A}\frac{dP_H}{dP_G}$$

$$\frac{dP_F}{dP_G} = \alpha\frac{\phi_H}{\phi_A}\frac{dP_H}{dP_G} + \left(1-\alpha\right) \qquad \text{(A1.2)}$$

$$\frac{d\theta}{dP_G} = \left(1-\alpha\right) - \phi_H\left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right)\frac{dP_H}{dP_G}$$

$$\frac{dP_{SC}}{dP_G} = \phi_H\frac{dP_H}{dP_G}$$

$$\frac{dP_S}{dP_G} = \frac{\phi_H}{\phi_S}\left(1 - \frac{\delta_H}{\phi_H} - \frac{\delta_A}{\phi_A}\right)\frac{dP_H}{dP_G}$$

$$
\begin{aligned}
\frac{dP_H}{dt_G} &= \frac{dP_{E100}}{dt_G} = \frac{(1-\alpha)\left[\frac{\alpha f'}{\phi_A} + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right)X'\right]}{Z} \\
\frac{dP_A}{dt_G} &= \frac{\phi_H}{\phi_A}\frac{dP_H}{dt_G} \\
\frac{dP_F}{dt_G} &= \frac{\alpha\phi_H}{\phi_A}\frac{dP_H}{dt_G} + (1-\alpha) \\
\frac{d\theta}{dt_G} &= (1-\alpha) - \phi_H\left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right)\frac{dP_H}{dt_G} \\
\frac{dP_{SC}}{dt_G} &= \phi_H\frac{dP_H}{dt_G} \\
\frac{dP_S}{dt_G} &= \frac{\phi_H}{\phi_S}\left(1 - \frac{\delta_H}{\phi_H} - \frac{\delta_A}{\phi_A}\right)\frac{dP_H}{dt_G}
\end{aligned}
\tag{A1.3}
$$

$$
\begin{aligned}
\frac{dP_H}{dt_A} &= \frac{dP_{E100}}{dt_A} = \frac{\alpha\left[\frac{\alpha f'}{\phi_A} + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right)X'\right]}{Z} \\
\frac{dP_A}{dt_A} &= \frac{\phi_H}{\phi_A}\frac{dP_H}{dt_A} \\
\frac{dP_F}{dt_A} &= \frac{\alpha\phi_H}{\phi_A}\frac{dP_H}{dt_A} + \alpha \\
\frac{d\theta}{dt_A} &= \alpha - \phi_H\left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right)\frac{dP_H}{dt_A} \\
\frac{dP_{SC}}{dt_A} &= \phi_H\frac{dP_H}{dt_A} \\
\frac{dP_S}{dt_A} &= \frac{\phi_H}{\phi_S}\left(1 - \frac{\delta_H}{\phi_H} - \frac{\delta_A}{\phi_A}\right)\frac{dP_H}{dt_A}
\end{aligned}
\tag{A1.4}
$$

$$
\begin{aligned}
\frac{dP_H}{dt_H} &= \frac{\dfrac{g'}{\phi_H} - \left(\dfrac{1}{\phi_H} - \dfrac{\alpha}{\phi_A}\right) X'}{Z} \\
\frac{dP_{E100}}{dt_H} &= \frac{dP_H}{dt_H} + 1 \\
\frac{dP_A}{dt_H} &= \frac{\phi_H}{\phi_A} \frac{dP_H}{dt_H} \\
\frac{dP_F}{dt_H} &= \alpha \frac{\phi_H}{\phi_A} \frac{dP_H}{dt_H} \\
\frac{d\theta}{dt_H} &= -\phi_H \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right) \frac{dP_H}{dt_H} - 1 \\
\frac{dP_{SC}}{dt_H} &= \phi_H \frac{dP_H}{dt_H} \\
\frac{dP_S}{dt_H} &= \frac{\phi_H}{\phi_S} \left(1 - \frac{\delta_H}{\phi_H} - \frac{\delta_A}{\phi_A}\right) \frac{dP_H}{dt_H}
\end{aligned}
\tag{A1.5}
$$

Appendix 2. Calibration of the Shift in the Demand for Fuel and Hydrous Ethanol

We use a logistic function of the form

$$X(\theta) = \frac{A}{1 + Be^{-C\theta}} + D \qquad \text{(A2.1)}$$

where parameters A, B, and $C > 0$ and $D < 0$. As $\theta \to \infty$, $X \to A + D$; therefore, the value $A + D$ represents the upper asymptote of the function (A2.1). Similarly, $\theta \to -\infty$ implies $X \to D$, which defines the lower asymptote of the logistic function.

In calibrating the curve (A2.1), we set the upper asymptote to equal to the quantity of the fuel blend consumed by flex cars in the baseline. It is because flex cars are capable of running on the fuel blend (a mixture of gasoline and anhydrous ethanol), but non-flex cars cannot use hydrous ethanol. If the relative price changes in favor of hydrous ethanol, the maximum outward shift in the demand for hydrous ethanol is equal to quantity of fuel consumed by flex cars in the baseline, denoted as U_0; therefore

$$A + D = U_0 \qquad \text{(A2.2)}$$

The lower asymptote is equal to the quantity of hydrous ethanol in the baseline because this is the maximal shift in hydrous demand if the relative price changes in favor of fuel blend. This quantity is directly observable and is denoted as L_0

$$D = L_0 \qquad \text{(A2.3)}$$

It follows directly from equations (A2.2) and (A2.3) that the parameter A equals

$$A = U_0 - L_0 \qquad \text{(A2.4)}$$

We use the parameter B to change the curvature of the logistic function; thus it is assumed to be known. Recognizing that the observed baseline represents a situation with no shift in the fuel and hydrous ethanol demand (the shifts have already occurred and thus are not observed), we must have $X(\theta_0) = 0$, where θ_0 denotes the difference between fuel and hydrous ethanol price in the baseline. Then, invoking equation (A2.1), for the parameter C we obtain

$$C = -\frac{1}{\theta_0} \ln\left[-\frac{1}{B} \frac{U_0}{L_0} \right] \qquad \text{(A2.5)}$$

Appendix 3: Documentation of Fuel Taxes in Brazil for Gasoline and Ethanol

There are two "fuels" consumed in Brazil: E100 (100 percent hydrous ethanol consumed by flex cars) and "fuel" (a mixture of anhydrous ethanol and petroleum based gasoline). The price of E100 is given by

$$P_{E100} = P_H + t_H + m_{E100}$$

where, P_{E100} denotes the consumer price of hydrous ethanol, P_H denotes the wholesale market price of hydrous ethanol, t_H denotes the E100 fuel tax, and m_{E100} denotes a constant marketing margin.

The price of fuel P_F is a weighted average of the anhydrous ethanol price P_A and gasoline prices P_G

$$P_F = \alpha\left(P_A + t_A\right) + \left(1-\alpha\right)\left(P_G + t_G\right) + m_F$$

where α denotes the mandated volume of anhydrous ethanol in total fuel, and t_A and t_G denote taxes on anhydrous ethanol and gasoline, respectively.

In general, the value of α varies. In 2010/11 (marketing year beginning April 1), there were three months where the blending mandate of anhydrous ethanol was 20 percent; it was 25 percent for the other months. Up to October in the 2011/12 marketing year, the mandate was 25 percent after which it has been 20 percent.

The taxes in Brazil vary by state. In this study, we use taxes in the state of São Paulo because most of the ethanol in Brazil is produced and consumed in São Paulo. It is important to realize that there are four taxes on gasoline and three on hydrous ethanol, some of which are *ad valorem* and others specific. The anhydrous tax is an *ad valorem* tax.

The tax on gasoline has four components. First, there are two federal *per unit taxes*: the *CIDE* tax of R$0.23/liter and the *PIS/COFINS* tax of R$0.2626/liter. The CIDE value can vary between years and within years according to the perceived political need to adjust the final price paid by fuel consumers. In 2010/2011 the average CIDE is R$0.2186 and it is R$0.1708 in 20011/12 (from March 1 2011 to February 2012 as data for March 2012 is not yet available).

Because the wholesale gasoline price reported by the ANP — a government agency— includes the *CIDE* and *PIS/COFINS* taxes, we first need to calculate the gasoline price without these two specific taxes. The reported gasoline price with taxes was R$1.54/liter and R$1.53, for 2010/11 and 2011/12, respectively. This means that the implied wholesale market price of gasoline equals R$1.0451 and R$1.099 for each season (before any marketing margin to the retail gas pump is added).

Second, we calculate the *ad valorem* tax called the ICMS which is 25 percent of the gasoline price given by ANP at R$1.54 and R$1.53, for 2010/11 and 2011/12, respectively. Therefore, the ICMS for gasoline A was R$0.512/liter and now it is R$0.5104/liter.

Third, we calculate the ICMS- ST tax, which is 56.35 percent of the ICMS tax calculated above. It is the total cost that is directly attributed to the ICMS. The value of this ICMS-ST is therefore R$0.289 for 2010/201 and R$0.288 for 2011/12. While there is no sales tax *per se* in Brazil, every manufacturer, distributor, retailer, or provider of almost every type of merchandise or service pays the state *ICMS* and passes the cost along to the consumer. It is largely a “hidden” tax, in that it is not reported on any receipt or directly on the price of the goods.

Finally, we add all the gasoline taxes to have the total gasoline taxes at R$ 1.2827 and R$1.2305 for these two periods, respectively.

The tax applied on anhydrous ethanol t_A is only the PIS/COFINS of R$0.048/liter.

The tax on hydrous ethanol t_H has three components. First, we have *PIS/COFINS for the producers* R$0.0048/l and PIS/COFINS for distributers at R$0.072. The producer price is given by CEPEA (Center for Advanced Studies on Applied Economics) at R$0.982 in 2010/11 and R$1.207 in 2011/12.

The margin for the distributer is R$0.05 for both periods. We add the PIS/COFINS taxes and the margin to the producer price (it give us R$1.04 for 2010/11 and R$1.26 for 2011/12) and from there we calculate the second tax that is the *ICMS*.

To calculate the ICMS at 12 percent, we add the number we got above to the PIS/COFINS for the distributers (R$0.072) and multiply the sum by 12 percent. For 2010/11 the ICMS is R$0.151 and for 2011/12 it is R$ 0.182/liter.

Finally, we calculate the third tax, that is, the *ICMS ST*. It is 25 percent of the values we got from the ICMS described above. The values calculated are R$0.038 and R$0.045 for 2010/22 and 2011/12, respectively.

The total hydrous tax is R$0.26 for 2010/11 and R$0.30 for 2011/12 (from March to February). In summary, the total hydrous tax is the sum of the PIS/COFINS for the producer and distributer and the ICMS taxes.

Data Sources

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ICMS-ST *substituição tributária*, available at
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Taxes on Goods and Services — ICMS — Impostos Sobre Circulação de Mercadorias e Prestação de Serviços (Merchandise and Services Circulation Tax) data available at
http://www.planalto.gov.br/ccivil_03/Leis/LCP/Lcp87.htm

Appendix 4. Data Used to Calibrate the Model

Variable/parameter	Symbol	2010/11	2011/12	Unit	Source
PARAMETERS					
Kilometers per liter of anhydrous ethanol relative to gasoline	λ_A	0.67	0.67		UNICA
Kilometers per liter of hydrous ethanol relative to gasoline	λ_H	0.67	0.67		UNICA
Kilometers per liter of fuel blend relative to gasoline	λ_F	0.92	0.92		$\lambda_F = \alpha_v\lambda_A + (1-\alpha_v)$
Tonnes of sugar per tonne of sugarcane	ϕ_S	0.133	0.130		CONAB
Liters of anhydrous ethanol per tonne of sugarcane	ϕ_A'	71.74	68.59	liter/tonne	CONAB
Liters of hydrous ethanol per tonne of sugarcane	ϕ_H'	75.03	71.56	liter/tonne	CONAB
GEELs of anhydrous ethanol per tonne of sugarcane	ϕ_A	48.07	45.96	GEEL/tonne	$\phi_A = \lambda_A\phi_A'$
GEELs of hydrous ethanol per tonne of sugarcane	ϕ_H	50.27	47.95	GEEL/tonne	$\phi_H = \lambda_H\phi_H'$
Liters of ethanol from molasses per tonne of sugarcane	δ'	9.25	9.25	liter/tonne	CONAB
GEELs of ethanol from molasses per tonne of sugarcane	δ	6.20	6.20	GEEL/tonne	$\delta = \lambda_A\delta'$
Liters of anhydrous ethanol from molasses per tonne of sugarcane	δ_A'	2.69	3.67	liter/tonne	$\delta_A' = \mu_A\delta'$
GEELs of anhydrous ethanol from molasses per tonne of sugarcane	δ_A	1.80	2.46	GEEL/tonne	$\delta_A = \lambda_A\delta_A'$
Liters of hydrous ethanol from molasses per tonne of sugarcane	δ_H'	6.56	5.58	liter/tonne	$\delta_H' = \mu_H\delta'$
GEELs of hydrous ethanol from molasses per tonne of sugarcane	δ_H	4.40	3.74	GEEL/tonne	$\delta_H = \lambda_H\delta_H'$
Share of anhydrous ethanol in total ethanol production	μ_A	0.29	0.40		$\mu_A = C_A'/(C_A' + D_H')$
Share of hydrous ethanol in total ethanol production	μ_H	0.71	0.60		$\mu_A = D_H'/(C_A' + D_H')$
Share of sugar production consumed domestically	$1 - \sigma$	0.33	0.33		$1 - \sigma$
Share of sugar production exported	σ	0.67	0.67		UNICA/CONAB
Net processing cost of sugar per tonne of sugarcane	$\phi_S\xi_S - \psi_S$	46.56	58.87	\$/tonne	$\phi_S\xi_S - \psi_S = \phi_S P_S + \delta_A P_A + \delta_H P_H - P_{SC}$
Net processing cost of anhydrous ethanol per tonne of sugarcane	$\phi_A\xi_A - \psi_A$	28.54	29.67	\$/tonne	$\phi_A\xi_A - \psi_A = \phi_A P_A - P_{SC}$
Net processing cost of hydrous ethanol per tonne of sugarcane	$\phi_H\xi_H - \psi_H$	16.01	17.33	\$/tonne	$\phi_H\xi_H - \psi_H = \phi_H P_H - P_{SC}$
POLICY VARIABLES					
Tax on gasoline (volumetric)	t_G	1.28	1.23	\$/liter	SINDICOM
Tax on anhydrous ethanol (volumetric)	t_A'	0.05	0.05	\$/liter	SINDICOM
Tax on anhydrous ethanol (energy)	t_A	0.07	0.07	\$/GEEL	$t_A = t_A'/\lambda_A$
Tax on hydrous ethanol (volumetric)	t_H'	0.26	0.30	\$/liter	SINDICOM
Tax on hydrous ethanol (energy)	t_H	0.39	0.45	\$/GEEL	$t_H = t_H'/\lambda_H$
Blend mandate (volumetric)	α_v	0.246	0.231		$\alpha_v = C_A'/D_F'$
Blend mandate (energy)	α_E	0.18	0.17		$\alpha_E = \lambda_A\alpha_v/(1 + \lambda_A\alpha_v - \alpha_v)$
ELASTICITIES					
Elasticity of sugarcane supply	η^S_{SC}	0.50			Schmitz et al. (2003)
Elasticity of domestic demand for sugar	η^D_{DS}	-0.75			de Freitas and Kaneko (2011)
Elasticity of export demand for sugar	η^D_{XS}	-2.00			Schmitz et al. (2003)
Elasticity of demand for fuel (E25)	η^D_F	-0.23			Menezes et al. (2008)
Elasticity of demand for hydrous ethanol (E100)	η^D_H	-0.68			Menezes et al. (2008)

Note: The data sources are documented below.

Appendix 4. Data Used to Calibrate the Model (continued)

Variable/parameter	Symbol	2010/11	2011/12	Unit	Source
PRICES					
Price of gasoline (volumetric)	P_G	1.05	1.10	\$/liter	ANP
Fuel price (volumetric)	P_F'	2.47	2.66	\$/liter	ANP
Fuel price (energy)	P_F	2.68	2.88	\$/GEEL	$P_F = P_F'/\lambda_F$
Price of anhydrous ethanol (volumetric)	P_A'	1.18	1.42	\$/liter	CEPEA
Price of anhydrous ethanol (energy)	P_A	1.76	2.12	\$/GEEL	$P_A = P_A'/\lambda_A$
Price of hydrous ethanol (volumetric)	P_H'	0.96	1.19	\$/liter	CEPEA
Price of hydrous ethanol (energy)	P_H	1.43	1.78	\$/GEEL	$P_H = P_H'/\lambda_H$
Consumer price of hydrous ethanol (volumetric)	P_{E100}'	1.54	1.88	\$/liter	ANP
Consumer price of hydrous ethanol (energy)	P_{E100}	2.29	2.80	\$/GEEL	$P_{E100} = P_{E100}'/\lambda_H$
Price of sugarcane	P_{SC}	56.11	67.83	\$/tonne	IEA
Price of sugar	P_S	700.93	884.00	\$/tonne	ERS
Marketing margin for fuel (volumetric)	m_F'	0.41	0.53	\$/liter	$m_F' = P_F' - \alpha_v(P_A' + t_A') - (1 - \alpha_v)(P_G + t_G)$
Marketing margin for fuel (energy)	m_F	0.44	0.57	\$/GEEL	$m_F' = P_F - \alpha_E(P_A + t_A) - (1 - \alpha_E)(P_G + t_G)$
Marketing margin for E100 ethanol (volumetric)	m_{E100}'	0.31	0.39	\$/liter	$m_{E100}' = P_{E100}' - P_H' - t_H'$
Marketing margin for E100 ethanol (energy)	m_{E100}	0.47	0.57	\$/GEEL	$m_{E100} = P_{E100} - P_H - t_H$
Price gap between fuel and hydrous ethanol	θ	0.393	0.082	\$/GEEL	$\theta = P_F - P_{E100}$
QUANTITIES					
Consumption of anhydrous ethanol (volumetric)	C_A'	7.51	8.49	billion liters	$C_A' = D_F' - C_G$
Consumption of anhydrous ethanol (energy)	C_A	5.03	5.69	billion GEELs	$C_A = \lambda_A C_A'$
Consumption of hydrous ethanol (volumetric)	D_H'	15.29	10.19	billion liters	UNICA
Consumption of hydrous ethanol (energy)	D_H	10.24	6.83	billion GEELs	$D_H = \lambda_H D_H'$
Consumption of gasoline (volumetric)	C_G	22.99	28.31	billion liters	UNICA
Consumption of fuel (volumetric)	D_F'	30.50	36.80	billion liters	UNICA
Consumption of fuel (energy)	D_F	28.02	34.00	billion GEELs	$D_F = \lambda_F D_F'$
Production of sugarcane	S_{SC}	0.62	0.57	billion tonnes	CONAB
Production of anhydrous ethanol (volumetric)	Q_A'	8.32	8.59	billion liters	UNICA
Production of anhydrous ethanol (energy)	Q_A	5.58	5.76	billion GEELs	$Q_A = \lambda_A Q_A'$
Production of hydrous ethanol (volumetric)	Q_H'	19.05	14.05	billion liters	UNICA
Production of hydrous ethanol (energy)	Q_H	12.77	9.42	billion GEELs	$Q_H = \lambda_H Q_H'$
Residual anhydrous ethanol (volumetric)	I_A'	0.40	1.22	billion liters	UNICA
Residual anhydrous ethanol (energy)	I_A	0.27	0.82	billion GEELs	$I_A = \lambda_A I_A'$
Residual hydrous ethanol (volumetric)	I_H'	0.68	1.62	billion liters	UNICA
Residual hydrous ethanol (energy)	I_H	0.46	1.09	billion GEELs	$I_H = \lambda_H I_H'$
Quantity of sugarcane devoted to sugar production	C^S_{SC}	0.29	0.28	billion tonnes	Derived from equation (8)
Domestic consumption of sugar	D^D_S	0.01	0.01	billion tonnes	$D^D_S = (1-\sigma)\phi_S C^S_{SC}$
Foreign consumption of sugar	D^W_S	0.03	0.02	billion tonnes	$D^W_S = \sigma\phi_S C^S_{SC}$

Note: The data sources are documented below.

Data Sources:

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