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

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Paper prepared for presentation at the EAAE 2014 Congress
'Agri-Food and Rural Innovations for Healthier Societies'

August 26 to 29, 2014
Ljubljana, Slovenia

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Abstract
We develop an economic model of flex plants, export demands and two domestic fuel demand curves: E25, a 25 percent blend of ethanol with gasoline consumed by conventional cars, and E100, ethanol consumed only by flex cars. This allows us to analyze the market impacts of specific policies, namely the E25 blend mandate, fixing gasoline prices below world prices, the high gasoline tax, and a higher tax exemption for ethanol used in E25. Because Brazilian and U.S. ethanol prices have become linked, a change in Brazilian ethanol policy or a shock in world sugar markets can now impact U.S. ethanol and corn prices.

Because of two demand curves, with flex car owners switching between fuels depending on relative prices, and because the mandate is for E25 only, the impact of each Brazilian policy in theory has an ambiguous impact on ethanol and sugar prices. Conventional wisdom is that a higher level of the mandate, gasoline tax exemptions for ethanol and gasoline price, and a lower gasoline tax, all help the ethanol industry. But for two policies, a low gasoline tax and a high tax exemption for ethanol used in E25, our empirical results show ethanol and sugar prices decline.

Overall, we find that the package of policy reforms implemented in 2010 offset the ethanol price increase due outward shifts in fuel transportation and sugar export demand curves, and reduced sugarcane supply due to bad weather, by about 27 percent. Our model illustrates the importance of Brazil's ethanol policies on world commodity markets and provides insights on how the Brazilian government can adjust policies to better control domestic inflation while minimizing impacts on investment.
Key words: Brazil, ethanol, flex plants, sugarcane, mandate, tax exemption

1. Introduction

The role of biofuel policies on food commodity prices has been a major source of controversy (FAO 2013). The literature contains detailed economic analysis of U.S. and EU mandates and tax credits/exemptions,[2] but little theoretical and detailed empirical analysis of the several ethanol policies in Brazil has been undertaken.

Brazil has developed a unique system of producing competing tradable products – sugar and ethanol – from non-traded sugarcane. Modern "flex-plants" can adjust their mix of the two products within a production year to 65-35 percent. Flex-plants can also extract up to 18.6 liters of ethanol from molasses, a by-product of sugar production, per tonne of sugarcane processed into sugar (Gopal and Kammen 2009), further linking ethanol and sugar markets. Hence, it is important to model the specifics of the Brazilian flex-plants as such flex plants are now being built in Africa.[3] There are two different demand curves for ethanol as a transportation fuel: an *anhydrous* ethanol-gasoline fuel mixture (which we define as "fuel" in this paper) that all cars can use, and E100 (100 percent *hydrous* ethanol) which only flex cars can use. Currently 23 percent of cars in Brazil are flex vehicles but the number is growing rapidly as over 80 percent of new car sales in recent years are flex.

The important Brazilian ethanol policies affecting the sugar/ethanol markets can be

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[1] All appendices are available from the authors upon request.
[2] See for example de Gorter and Just (2009) and Lapan and Moschini (2012).
[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.

classified into four categories. First, Brazil has a mandate for anhydrous ethanol mixed with gasoline, which varies by government decree. Historically, 18 to 25 percent of the total fuel mixture has been required to be anhydrous ethanol, depending on ethanol supply-demand conditions. 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 fuel mixture. The tax on anhydrous ethanol is even lower, although consumers only see the blended fuel price. Third, the government has often in the past, and again recently, held the price of gasoline below world gasoline prices to avoid adverse effects on inflation. Fourth, the federal government has recently eliminated the gasoline 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[4] for hydrous ethanol results in higher ethanol wholesale prices, but a lower gasoline tax and a higher tax exemption on anhydrous ethanol results in lower ethanol prices.

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. These features include: demand for two distinct fuel types; endogenous switch between E25 and E100 by consumers owning flex cars in response to changing relative prices of E100 and fuel; the anhydrous ethanol mandate; production of ethanol from molasses (a by-product of sugar production); and electricity production from bagasse (a by-product of sugarcane processing). We 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 share of sugarcane processed into ethanol declined.

2. Background

The fledgling literature on the market effects of Brazilian ethanol policies lacks detail on the economic structure of Brazil's flex plants and on the effects of various policies (e.g., Schmitz et al., 2003; Elobeid and Togkoz, 2008). Serra et al. (2011) use time-series econometric techniques to investigate the ethanol, sugar, and oil price volatility transmission in Brazil, and like Balcombe and Rapsomanikis (2008), fail to recognize gasoline prices link ethanol to sugarcane (and sugar) prices. The Brazilian government fixes gasoline prices through Petrobras (de Miranda, 2010; Zilberman, 2012), delinking gasoline prices from world oil prices. This econometrics literature investigating the long run relationships among the prices has thus far only used data up to 2008 after which significant changes began to affect the relationships (see Zilberman et al., 2013 and Serra, 2012 for surveys). Instead of focusing on commodity price linkages, structural models of the Brazilian ethanol industry analyze 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).

Our paper provides a structural model that takes a broader account of the unique features of the Brazilian sugar-ethanol market including flex plants. Our paper also extends the existing literature (e.g., de Gorter and Just, 2009; Lapan and Moschini, 2012) by incorporating two demand curves for differentiated ethanol and by modeling the endogenous decision of flex cars

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

owners to shift between consumption of fuel and hydrous ethanol. Our unique model is better suited to explain market shocks and the effects of several policy changes.

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, within a feasible range, the allocation of sugarcane to these products depending on the relative market price of sugar and ethanol.[5] A by-product of sugarcane processing, regardless of the use of sugarcane, is bagasse, a fibrous matter that is burned in special boilers to cogenerate electricity and steam.[6] Sugar production also yields a by-product – molasses, which is further used to produce anhydrous and hydrous ethanol.

For proper comparison purpose, we express all quantities related to the fuel market (i.e., ethanol and gasoline) in gasoline energy-equivalent liters (GEEL). A typical Brazilian flexible sugarcane processing plant extracts a total of 6.20 GEELs of hydrous and anhydrous ethanol as a by-product from one tonne of sugarcane processed into sugar.[7]

The burning of bagasse makes Brazilian flex plants self-sufficient in the electricity they need to process sugarcane into sugar (S), hydrous (H) and anhydrous (A) ethanol. The excess supply of electricity is sold on the grid at the market price and yields profit Ψ_i per tonne of sugarcane processed into product $i = \{S, H, A\}$.

Production of sugar and ethanol is assumed to exhibits constant returns to scale. A competitive industry allocates the sugarcane into sugar, hydrous and anhydrous ethanol so that each production process earns zero marginal profits in equilibrium

$$P_{SC} = \phi_S P_S + \delta_H P_H + \delta_A P_A + \Psi_S - \phi_S \xi_S \qquad (1)$$

$$P_{SC} = \phi_H P_H + \Psi_H - \phi_H \xi_H \qquad (2)$$

$$P_{SC} = \phi_A P_A + \Psi_A - \phi_A \xi_A \qquad (3)$$

Equation (1) comes from a zero marginal profit condition for sugar production and takes into account the additional quantity of ethanol that can be produced from molasses. In equation (1), ϕ_S denotes the yield of sugar per tonne of sugarcane; P_{SC} and P_S denote market prices of sugarcane and sugar (measured in R$/tonne), respectively; and P_H and P_A denote market prices of hydrous and anhydrous ethanol (measured in R$/GEEL), respectively. The parameters δ_H and δ_A represent GEELs of hydrous and anhydrous ethanol from molasses. The parameter ξ_S denotes (constant) processing costs (other than the cost of feedstock and electricity) per tonne of sugar.

Equations (2) and (3) are marginal zero profit conditions for hydrous and anhydrous ethanol production. The parameters ϕ_H and ϕ_A represent yields of hydrous and anhydrous ethanol, respectively, from a tonne of sugarcane, and the parameters ξ_H and ξ_A denote processing costs per GEEL of hydrous and anhydrous ethanol, respectively.

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

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5 In a modern Brazilian "flex" sugarcane processing plant, the share of sugarcane going to sugar can vary between 35 and 65 percent.

6 The burning of the sugarcane straw (not bagasse, which is the by-product at the sugarcane plant) for electricity cogeneration is currently not economical because of low energy density of straw left on fields and substantial transportation and collection costs.

7 This corresponds to 9.25 liters.

$$P_A - P_H = \xi_A - \xi_H - \left(\frac{\Psi_A}{\phi_A} - \frac{\Psi_H}{\phi_H}\right) + \left(\frac{1}{\phi_A} - \frac{1}{\phi_H}\right) P_{SC} = \beta_0 + \beta_1 P_{SC} \quad (4)$$

Equation (4), obtained by the summation and rearrangement of equations (2) and (3), shows that the gap between anhydrous and hydrous ethanol market prices widens as the price of sugarcane increases. Empirically, the production parameters satisfy $\phi_A < \phi_H$, implying that production of a gallon of anhydrous ethanol is more costly. This puts anhydrous ethanol at a relative disadvantage because consumers have to pay a higher price to compensate producers of anhydrous ethanol for the higher production cost.

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

$$P_F = \alpha\left(P_A + t_A\right) + \left(1 - \alpha\right)\left(P_G + t_G\right) + m_F \quad (5)$$

where α denotes an energy-equivalent blend mandate for anhydrous ethanol, and t_A and t_G denote taxes on anhydrous ethanol and gasoline (measured in R$/GEEL), respectively.[8] We assume the gasoline price is exogenous to fuel blenders because the Brazilian government regulates gasoline prices through Petrobras,[9] and ethanol production is assumed not to affect world oil prices.

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

$$P_{E100} = P_H + t_H + m_{E100} \quad (6)$$

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, hydrous and anhydrous ethanol

$$S_{SC}\left(P_{SC}\right) = C_{SC}^S + \frac{D_H + I_H}{\phi_H} - \frac{\delta_H C_{SC}^S}{\phi_H} + \frac{\alpha D_F + D_A^{ROW}\left(P_A\right)}{\phi_A} - \frac{\delta_A C_{SC}^S}{\phi_A} \quad (7)$$

The first term on the right-hand side of equation (7), 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 ; the latter is assumed to be exogenous. The third (negative) term accounts for the hydrous ethanol produced from molasses. This quantity needs to 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 (7) denotes allocation of sugarcane used for production of anhydrous ethanol. Akin to hydrous ethanol, anhydrous ethanol is used in the domestic transportation sector, the quantity αD_F, but is also exported. The term $D_A^{ROW}\left(P_A\right)$ therefore denotes an ethanol import demand curve of the rest of the world facing Brazil.[10] The last

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[8] 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.

[9] However, as a reviewer correctly pointed out, the price-setting by Petrobras does not happen in a vacuum and, presumably, changes in the world price of oil and in the domestic ethanol market have at least some impact on domestic gasoline prices. This is likely to occur even if there is not perfect price transmission from global markets, especially in the short run.

[10] In this paper, we do not analyze the implications of other countries' policies on the trade position of Brazil nor do we analyze the implication of Brazilian sugarcane ethanol reaping higher prices in the United States on sales to California's "low carbon fuel standard" or extra proceeds sugarcane ethanol receives in qualifying for the federal mandate of advanced biofuel.

(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

$$D_S^D\left(P_S\right)+D_S^W\left(P_S\right)=\phi_S C_{SC}^S \qquad (8)$$

The sugarcane supply curve S_{SC} in 2010/11 is depicted in the upper panel of Figure 1 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 1, this implies an inward shift in the sugarcane supply curve represented by S'_{SC}. The size of the parallel shift is given by distance aQ'_{SC} 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.[11]

The lower panel of Figure 1 depicts an outward shift in the import demand for sugar facing the Brazilian market. Unlike the upper panel, a decrease in sugar exports and an increase in sugar prices are not sufficient to conclude that this demand curve has shifted 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, data show that the import demand for sugar shifted out. The size of the shift is given by $C'_S-D_S\left(P'_S\right)$. Shifts in demands for fuel, hydrous ethanol, domestic sugar and import of anhydrous ethanol facing Brazil are determined in a similar way.

The quantitative estimates of the exogenous shifts in the demand and supply curves will inevitably depend on elasticities of these curves. The elasticities used are presented in the section on data and are also discussed later in the section on sensitivity analysis. To give the reader a flavor of the magnitudes of the exogenous supply and demand shifts, in this section we only give results corresponding to the central elasticities values as presented in the first row of Table 1 (the remaining rows are discussed in the section on sensitivity analysis). The estimates of the shifts are presented in absolute and relative terms relative to the 2010/11 consumption/production levels. A negative value in the first column under each demand/supply schedule indicates a shift to the left. The most significant shifts occurred in the ethanol export and fuel markets (44.3 and 24.0 percent, respectively), while the demand curves for domestic and exported sugar shifted by only 2.2 and 3.4 percent, albeit in opposite directions.

Because of these noticeable shifts in the Brazilian market between 2010/11 and 2011/12 marketing years, it is of interest to quantify to what extent the sole changes in biofuel policies contributed to the observed market price changes. The first row of Table 2 presents results for the central values of the model parameters. The first thing to notice is that all values are negative, meaning that the change in all biofuel policies in Brazil in the analyzed period reduced market prices, *ceteris paribus*. This implies that if the Brazilian biofuel policies had not changed, the final price effect of the exogenous shifts would have been even higher.

A second observation is that the combination of *all* policy changes, *ceteris paribus*, had sizable but heterogeneous effects, depending on the affected commodity. For example, the sugarcane price experienced the highest decrease of almost 40 percent, while the consumer price of hydrous ethanol decreased by 7 percent.

While Table 1 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

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

a policy analysis point of view, it is important to analyze market effects of a change in a biofuel policy separately, assuming all other factors, such as income growth or weather, are unchanged. But first, we 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) will affect the relative price of the fuel blend and E100, the composition of the fuel mix will also adjust.[12] When the price gap between fuel and E100 narrows, some flex car owners who previously used hydrous ethanol will find it attractive to switch to the blended fuel.[13] In this case, the demand for fuel (measured in GEELs) shifts out by exactly the same amount as the demand for E100 shifts in, keeping the total consumption of fuel and E100 unchanged. This is shown in Figure 2 which uses actual prices for the 2010/11 and 2011/12 years (the latter marked by the prime). The horizontal shift X is for illustration only as we assume a change in the biofuel policy is the only driver of the demand shift.

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 fuel 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 out to D'_F, while E100 shifts in to D'_H.

The magnitude of the shift X depends on the gap between fuel and E100 prices, θ: the greater the gap, the greater the shift. Let $X(\theta)$ be a function characterizing the behavior of flex car owners when the price gap changes. We assume that $X(\theta)$ 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 prefer to switch to E100.

The model defined by equations (1) to (8) can be extended to incorporate the endogenous demand shift by specifying the demands for fuel blend, D_F, and E100, D_H, as follows[14]

$$D_F = f\left(P_F\right) - X\left(\theta\right) \tag{9}$$

$$D_H = g\left(P_{E100}\right) + X\left(\theta\right) \tag{10}$$

The functions $f(P_F)$ and $g(P_{E100})$ denote Marshallian demand functions for blend fuel and E100, respectively, and satisfy $f' = df/dP_F < 0$, $g' = dg/dP_{E100} < 0$. 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). Figure 3 depicts a family of logistic curves that satisfy the properties (i.e., continuity, differentiability, and monotonicity) imposed on the function X.

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[12] 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 total miles driven.

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

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

5. Comparative Statics Results

Equations (1) through (10) 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 3. In general, a change in a Brazilian biofuel policy has an ambiguous impact on market prices. Most signs in Table 3 depend on the sign of the following expression

$$\frac{\alpha f'}{\phi_A} + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right) X' \equiv \frac{\eta_D^F \alpha f}{\phi_A P_F} + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right)\frac{dX}{d\theta} \qquad (11)$$

where the slope of the fuel demand curve, f', has been expressed in terms of the elasticity, η_D^F, of the Marshallian fuel demand. Intuitively, expression (11) represents two simultaneous 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 $dX/d\theta$.

The first term on the right side of identity (11) is unambiguously negative while the second term is negative only if $\alpha > \phi_A/\phi_H$. Using the observed parameter values for 2010/11 and 2011/12 marketing years, the second term is negative only for $\alpha > 0.96$; this means the ethanol mandate would have to be at least 96 percent for expression (11) to be unambiguously negative.

The probability of expression (11) 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 price inelastic and the observed blend mandate is approximately 25 percent. This suggests that expression (11) is very likely to be positive in reality. This is most easily seen in the case of perfectly inelastic fuel demand, $\eta_D^F = 0$, in which case the expression is positive. In our further analysis, we therefore use the following assumption

Assumption 1: $\frac{\eta_D^F \alpha f}{\phi_A P_F} + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right)\frac{dX}{d\theta} > 0$

Given Assumption 1, an exogenous increase in the gasoline price unambiguously results in an increase in (almost) all prices in the simulations (Table 3). The intuition behind this result is that a higher gasoline price necessitates a higher price of the blended fuel. This gives a cost advantage to hydrous ethanol whose demand shifts out, thus increasing the market and consumer prices of hydrous ethanol. But as equation (4) 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.

The tax on gasoline has market effects identical (in both magnitude and sign) to the effects of a change in 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 changes in 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.

The effect of an increase in the tax (or equivalently a reduction in a tax exemption) on hydrous ethanol prices 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. Because the supply side links the price of hydrous to the anhydrous ethanol price, the latter decreases, 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 lower ethanol demand 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 on hydrous ethanol 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. 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 model for the United States has only one demand for corn ethanol.

6. Data and Calibration

We model the effects of four Brazilian biofuel policies: the anhydrous ethanol mandate, differential gasoline tax exemptions on anhydrous versus hydrous ethanol, a change in the gasoline tax and the setting of gasoline prices below world levels. 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. Because the system of Brazilian fuel taxes is complex, we document calculations of the individual taxes on gasoline and the two ethanol types in Appendix 3.

7. An Empirical Illustration

The Shift Function

We use the logistic function of the form

$$X(\theta) = \frac{A}{1 + Be^{-C\theta}} + D \qquad (12)$$

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 C to its shape. (For a discussion of these parameters and their calibration see Appendix 2). The logistic function (12) is increasing in its argument, meaning that a higher gap between fuel and hydrous consumer prices 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 (12) to be the negative of consumption of hydrous ethanol in the baseline. This 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. To determine the upper asymptote, we use the result in Oliveira (2009) that 65 percent of the flex-fuel vehicles in Brazil regularly used hydrous ethanol in 2009. This means, for example, that the maximum hydrous ethanol consumption in 2010/11 is 15.29/0.65 = 23.52 bil. liters and the difference between the potential hydrous consumption by flex cars and the actual level of hydrous consumption in 2010/11 gives the volume of fuel (blend of gasoline and anhydrous ethanol) consumed by the flex cars, i.e., 23.52 – 15.29 = 8.23 bil. gallons. We therefore set the upper asymptote of the logistic function to be 8.23 bil. gallons (equal to 5.51 bil GEELs) in 2010/11.[15] This would be the maximal shift of the hydrous demand curve if the price gap between fuel and E100 grew very large.

To illustrate the responsiveness of the logistic function to the shape parameter B, in Table 4 we present three cases for that parameter, and in Figure 3 we present the corresponding logistic curves. In the benchmark (the central value of the B parameter in this paper), we set B = 5; in Scenario 1, B = 1.2; and in Scenario 2, B = 50. Scenarios 1 and 2 represent two extreme cases.

Policy Simulations

In this section, we present results for central parameters' values (Table 5).[16] We investigate the sensitivity of our results to simultaneous changes in parameters in the next section. All price changes possess the predicted signs presented in Table 3. 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.

The first policy scenario presented in Table 5 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 6.6 to 10.6 percent. This policy change has also considerable negative spillover effects on the welfare of sugarcane producers as the sugarcane price decreases by almost 14 percent. As gasoline becomes less costly relative to hydrous and anhydrous ethanol, the total consumption of ethanol declines by 5 bil. liters which leaves more sugarcane available for sugar production, thereby reducing the sugar price by approximately 7 percent.

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 4. 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. 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}, ensuing fuel consumption would correspond to C'_F. But because the hydrous and anhydrous ethanol prices are linked on the supply side, the

[15] 3.68 bil. GEELs in 2011/12.

[16] For comparison, Table 5 also presents results based on central elasticities and B =50 but we do not discuss these in the text.

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 ($a + b + c$) < $e – d$, the total use of ethanol declines, resulting in a decrease in both hydrous and anhydrous ethanol prices. This is what occurs in the first scenario presented in Table 5.

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 4 where the demand for hydrous ethanol shifts out first to D'_H.

In the second scenario, we analyze what would happen if the 2010/11 mandate decreased by 5 percentage points.[17] Currently, the mandate can range between 18 and 25 percent in Brazil. Results reported in Table 5 suggest that the sensitivity of flex cars owners (approximated by the curvature of the shift function) does not have a substantial effect on the market outcome for this market shock. For example, the market price of hydrous ethanol decreases (relative to the baseline) by 1.6 percent when flex cars owners are less sensitive (B = 5), and it decreases by 0.7 percent for the same policy change and more sensitive flex car owners (B = 50).

Notice also that a reduction in the mandate has associated with it an increase in the fuel price by 2.2 percent. This just illustrates our earlier finding that an exogenous change in the blend mandate, *given an exogenous gasoline price*, 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. 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 what matters is the tax rate on blended fuel. If the anhydrous ethanol tax exemption were eliminated, all market prices analyzed would increase by 6 to 13 percent; for instance, anhydrous and hydrous ethanol market prices are predicted to rise by 9 and 9.8 percent, respectively. In particular, for ethanol producers this result implies that they are currently being implicitly taxed by the existing generous anhydrous tax exemption. Sugarcane producers would significantly benefit from such an adjustment of the anhydrous tax as the market price of sugarcane could rise by as much as 13 percent. Total ethanol consumption increases in spite of an increase in the prices of both ethanol types. It is because E100 becomes less expensive relative to the fuel and the outward (horizontal) shift in the E100 demand curve outweighs both the reduction in anhydrous consumption and the reduction in the E100 consumption due to a higher price (the move along the E100 demand curve).

On the other hand, when the tax on hydrous ethanol is raised so as to obtain parity between hydrous ethanol and tax on fuel (gasoline and anhydrous ethanol taxes are held at their baseline levels), hydrous ethanol prices decline by almost 42 percent, making the producers worse-off. This occurs because the (increased) E100 tax drives a wedge between the consumer and producer prices, pushing the producer price down. Because the fuel price decreases while the consumer price of E100 increases, some flex cars owners divert to fuel; in addition, the total

[17] Some observers say that the optimal anhydrous ethanol blend mandate is as high as 30 percent. We, therefore, simulated an increase in the baseline mandate to that level (not reported) and found out that the price changes reported in Table 5 change the sign (as expected) while the magnitudes of the changes are very similar, albeit not identical because of non-linearities in our model.

availability of ethanol declines because its lower market prices. These two effects combined results in a decline in total ethanol consumption by almost a quarter. Sugarcane producer welfare is likely to decline as the sugarcane price is predicted to drop by more than 50 percent.

In the last three scenarios presented in Table 5, we assume the Brazilian market experiences a shock in sugarcane supply; in demands for fuel, E100 and export demand for anhydrous ethanol; and in demand for sugar, respectively. The magnitudes of the shocks correspond to the central scenario values presented in Table 1. Both shocks in sugarcane supply and sugar demand (for B = 5) mean that the availability of the feedstock decreases (the demand for the feedstock increases). This necessitates rationing of the feedstock use which translates into higher sugarcane and, therefore, products' prices. However, the total amount of ethanol consumed decreases as a result of the feedstock rationing.

8. Sensitivity Analysis

The central values of elasticities and the shape parameter are uncertain so we perform Monte Carlo simulations to investigate the intervals for (*i*) the sizes of the exogenous market shocks (Table 1); and (*ii*) the effects of the biofuel policies alone on the observed changes in the prices (Table 2). The parameters of the model were randomly drawn 100 times from a beta distribution whose shape parameters were derived from the values reported in Table 6 using the PERT (Program Evaluation and Review Technique) methodology (Davis 2008).

The descriptive statistics from the sensitivity analysis on the estimated shifts in the market curves are presented in the final three rows in Table 1. The average shifts are very close to our central estimates. The sensitivity results show that the greatest uncertainty of the results is associated with the inward shift of the export demand for Brazilian ethanol (the difference between the maximum and minimum shift relative to the 2010/11 value of the ethanol exports is almost 20 percent). Other estimates of the exogenous shifts are rather robust.

Table 2 presents sensitivity results for effects of observed changes in biofuel policies alone on the observed price changes. The Monte Carlo simulations confirm that the total change in biofuel policies had a negative and significant effect the observed market prices. In particular, in the absence of exogenous market shocks, the anhydrous and hydrous market prices would decrease by approximately one third and the sugarcane prices by almost 40 percent.

9. Concluding Remarks

Brazil is a major player in world ethanol markets and therefore its policies can directly impact U.S. ethanol and crop prices. Dramatic changes have occurred recently in Brazilian ethanol and sugar markets and policies. In order to combat inflation in late 2010, Brazil lowered the E25 mandate, increased gasoline prices, reduced gasoline taxes, and reduced the gasoline tax exemption for ethanol used in E100. But E25 prices still increased by almost 8 percent from 2010/11 to 2011/12, while ethanol, sugar and sugarcane prices increased by more than 20 percent. This means supply/demand shocks dominated the markets.

This paper presents a general economic model of the Brazilian sugar/ethanol nexus from the processing of sugarcane, where the world prices of sugar and ethanol are uniquely determined. We specify two demand curves for ethanol – 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.

We isolate the effects of all policy changes together from the effect of market shocks and find policies to offset the observed price increases by 7-40 percent, depending on the price. For example, the ethanol price increase was offset by about 27 percent.

Although the effects of policies taken together reduce prices, we show that in theory this needs not be the case. 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.

Conventional wisdom is that higher levels of each of the mandate, tax exemptions for ethanol and gasoline prices, and a lower gasoline tax, all help the ethanol industry. But for two of these policies, a low gasoline tax and a high gasoline tax exemption for ethanol used in E25, our empirical results show ethanol and sugar prices decline. Our theory and empirical framework gives a basis to predict market effects of individual policies and the effectiveness of Brazilian policy makers to achieve their goals.

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Table 1. Estimated Supply and Demand Shifts (2010/11 to 2011/12)

	Sugarcane supply		Fuel demand		Hydrous ethanol demand		Domestic demand for sugar		Export demand for sugar		Export demand for ethanol	
	Bil. tonnes	% of 2010/11	Bil. liters	% of 2010/11	Bil. liters	% of 2010/11	Mil. tonnes	% of 2010/11	Mil. tonnes	% of 2010/11	Bil. liters	% of 2010/11
Central values	-0.064	10.3	7.313	24.0	-1.712	11.2	-0.282	2.2	0.854	3.4	-0.799	44.3
Sensitivity analysis:												
average	-0.064	10.3	7.330	24.0	-1.756	11.5	-0.289	2.3	0.920	3.6	-0.812	45.1
max	-0.055	11.8	7.520	24.7	-1.143	16.7	-0.012	3.4	1.717	6.7	-0.607	52.9
min	-0.074	8.8	6.809	22.3	-2.558	7.5	-0.426	0.1	0.020	0.1	-0.954	33.7

Source: calculated

Table 2. Impact of All Policies on Prices (as a % of Total Price Change)*

	Anhydrous ethanol	Fuel	Hydrous ethanol (market)	Hydrous ethanol (consumer)	Sugarcane	Sugar
Central values	-26.9	-19.0	-27.0	-7.0	-39.6	-16.7
Sensitivity analysis:						
average	-27.1	-19.0	-27.2	-7.1	-39.8	-16.8
max	-24.2	-18.2	-24.3	-5.2	-35.6	-15.0
min	-30.2	-19.9	-30.3	-9.2	-44.4	-18.7

* Assuming supply and demand curves do not shift.

Table 3. Theoretical Effect of Policies on Market Prices under *Assumption 1*[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] $\frac{\eta_D^F \alpha f}{\phi_A P_F} + \left(\frac{1}{\phi_H} - \frac{\alpha}{\phi_A}\right)\frac{dX}{d\theta} > 0$

[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.

Table 4. Summary of Parameters of the Logistic Function Used in Simulations

	Benchmark	Scenario 1	Scenario 2
Upper asymptote (bil. GEELs)	5.51	5.51	5.51
Lower asymptote (bil. GEELs)	-10.24	-10.24	-10.24
A	15.76	15.76	15.76
B	5.00	1.20	50.00
C*	5.67	2.04	11.53
D	-10.24	-10.24	-10.24
Price gap (θ)	0.39	0.39	0.39

* calculated value

Source: own calculations

Table 5. Results of Policy and Market Shocks Simulations*

	Baseline	Policy simulations: 28 ¢ reduction in gasoline tax** B = 5	B = 50	5 percentage point reduction in mandate B = 5	B = 50	Parity between anhydrous and gasoline tax B = 5	B = 50	Parity between hydrous and fuel taxes B = 5	B = 50	Market shocks simulations: Reduction in supply of sugarcane*** B = 5	B = 50	Increase in dem. for fuel, reduction in dem. for E100 & anhyd. export **** B = 5	B = 50	Reduction in dem. for dom. sugar & increase in dem. for exports of sugar***** B = 5	B = 50
		% difference relative to baseline													
Fuel price (R$/liter)	2.47	-9.6	-10.0	2.2	2.3	9.1	9.4	-4.2	-4.7	0.9	0.6	-0.1	-0.1	0.1	-1.9
Market price of anhydrous ethanol (R$/liter)	1.10	-9.7	-12.7	-2.3	-1.0	9.0	11.8	-38.0	-42.9	8.6	5.3	-1.2	-0.8	0.5	-17.1
Market price of E100 (R$/liter)	0.96	-10.6	-13.9	-2.5	-1.1	9.8	12.9	-41.6	-47.0	9.4	5.8	-1.3	-0.8	0.6	-18.7
Consumer price of E100 (R$/liter)	1.54	-6.6	-8.7	-1.6	-0.7	6.1	8.1	3.4	0.0	5.9	3.6	-0.8	-0.5	0.3	-11.7
Price of sugarcane (R$/tonne)	56.1	-13.6	-17.8	-3.2	-1.4	12.6	16.6	-53.5	-60.4	12.1	7.4	-1.7	-1.1	0.7	-24.0
Price of sugar (R$/tonne)	700.9	-7.2	-9.4	-1.7	-0.8	6.6	8.7	-28.2	-31.8	6.4	3.9	-0.9	-0.6	0.4	-12.7
Total ethanol consumption (bil. liters)	22.8	-5.0	-6.7	-0.7	-0.1	4.2	5.4	-24.3	-29.0	-17.5	-19.0	-1.0	3.0	-1.0	-10.5

* Mandate binding in all simulations except for the 'no mandate' scenario.
** Or the same reduction in gasoline price.
*** Reduction of 10.3%.
**** fuel: (+)24.0%; E100: (-)11.2%, anhydrous export: (-)44.3%.
***** domestic demand: (-)2.2%, export demand: (+)3.4%.
Source: own calculations

Table 6. Parameter Values Used in Sensitivity Analysis

	Min	Central	Max
Elasticity of sugarcane supply	0.00	0.10	0.20
Elasticity of domestic demand for sugar	-0.20	-0.05	0.00
Export demand elasticity for sugar	-0.50	-0.30	0.00
Elasticity of demand for fuel (E25)	-0.50	-0.40	0.00
Elasticity of demand for hydrous ethanol (E100)	-1.50	-1.25	-0.50
Export demand elasticity of anhydrous ethanol	-1.66	-0.59	0.00
Shape parameter B of the logistic function	1.20	5.00	50.00

Note: Sources of the elasticities are reported in section on Data and Caliration.

Figure 1. Estimated Shifts in Sugarcane Supply and Sugar Demand

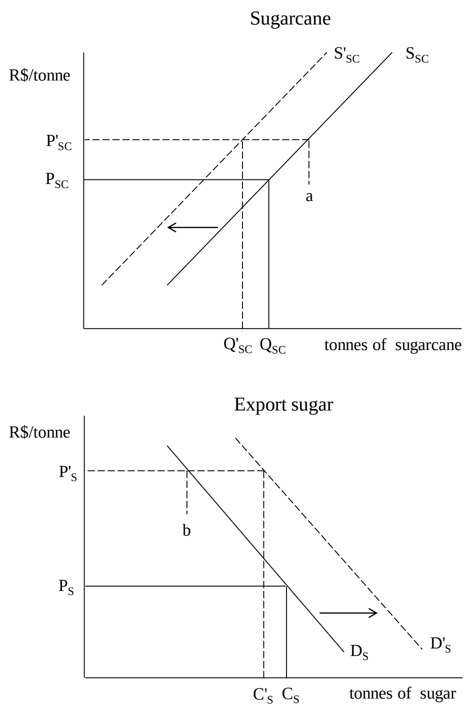

Figure 2. Symmetrical Shifts in Demand for Fuel and Hydrous Ethanol

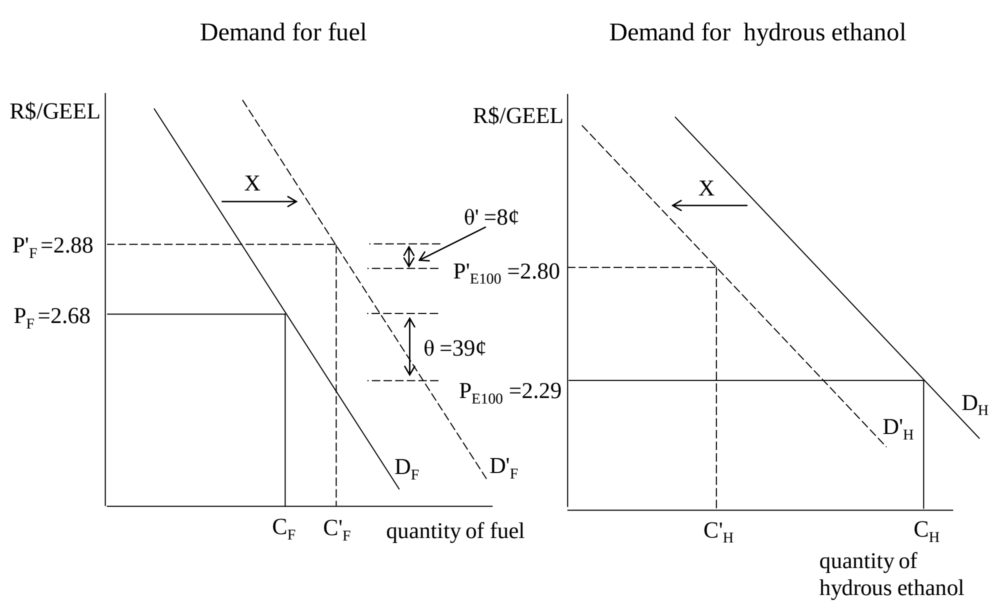

Figure 3. Logistic Curves for an Endogenous Demand Shift under Various Scenarios

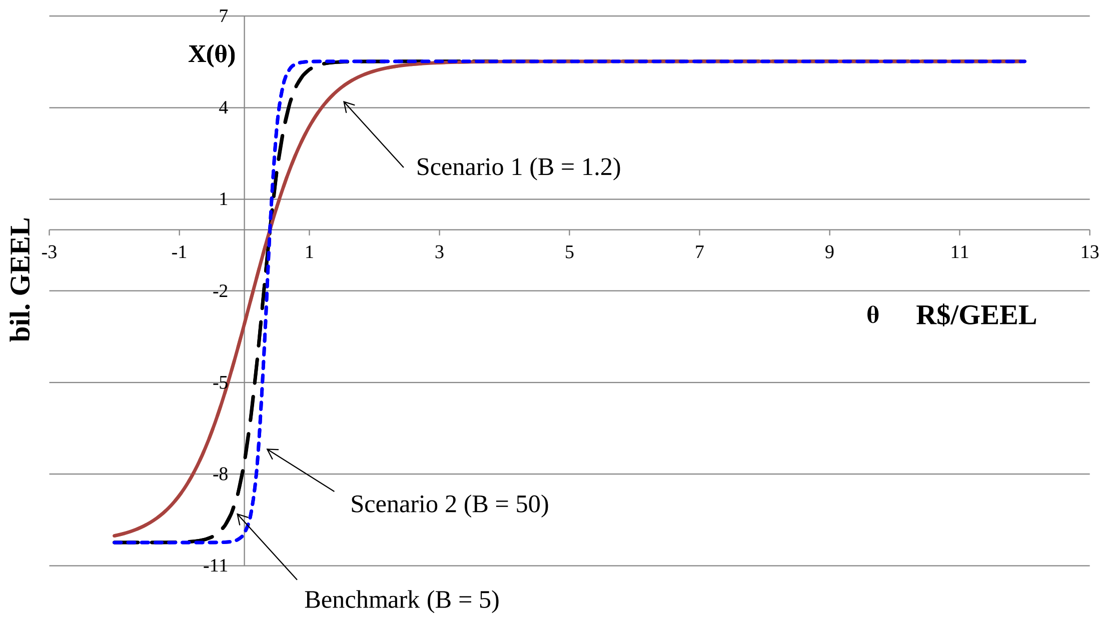

Figure 4. Effects of a Decrease in the Gasoline Tax