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An economic analysis of transportation fuel policies in Brazil

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Abstract

Brazil uses taxes, subsidies, and blending mandates as policy instruments to manage its transportation fuel markets. Despite all the market stabilization efforts, the fuels sector has been very dynamic in recent years. In response to ethanol supply fluctuations, the ethanol blending rate is adjusted at times and complemented with fuel tax rates changes. In this paper, we analyze the impacts of such policy adjustments and market disturbances in the world ethanol and sugar markets on Brazilian producers' supply responses, consumers' driving demand and fuel choice, ethanol trade with the rest of the world, greenhouse gas (GHG) emissions, and social welfare. As the analytical tool, we use a large-scale spatially explicit price endogenous mathematical programming model which simulates the resource utilization in agriculture and finds the simultaneous equilibrium in food and fuel markets. The model results show that reducing the ethanol blending rate would reduce the driving demand by conventional vehicles while lowering the tax rate on gasoline would encourage flex fuel vehicle users to switch from pure ethanol to gasohol resulting in larger GHG emissions due to the consumption of a more carbon intensive fuel blend.

Keywords: Brazil fuel policy, mathematical programming, land use, greenhouse gas emissions

Resumen

Brasil utiliza impuestos, subsidios y mandatos de mezcla de etanol y gasolina como principales instrumentos económicos para controlar el mercado doméstico de combustibles. A pesar de todos los ajustes a dichos instrumentos para estabilizar el mercado, el sector de los combustibles ha tenido una gran dinámica en los últimos años. En este trabajo, se analizan los impactos en el mercado de combustibles, en las emisiones de gases de efecto invernadero (GEI) y en el bienestar social debido a ajustes en los impuestos y en el mandato y a posibles cambios en la productividad de la caña de azúcar y en los mercados mundiales del etanol y azúcar. Como herramienta de análisis, utilizamos un modelo de programación matemática a gran escala de equilibrio parcial de precios endógenos para los sectores agrícola y de transportes de Brasil y Estados Unidos. Los resultados del modelo muestran que la reducción del mandato de etanol reduce la demanda por distancia manejada por los vehículos convencionales, mientras que la disminución del impuesto sobre la gasolina conllevaría a los usuarios de vehículos "flex-fuel" a cambiar etanol puro por gasolina resultando en mayores emisiones de GEI.

Palabras clave: Política de combustibles en Brasil, Programación Matemática, Uso del Suelo, Emisiones de Gases de Efecto Invernadero.

Introduction

B
razil has the second largest biofuel industry in the world after the US. The government uses a variety of policy instruments to manage the transportation fuel markets. The Brazilian biofuels industry was initiated in mid-1970s by a government program, *Proalcool*, which provided economic incentives to ethanol producers and consumers through price supports and supply guarantees aiming to substitute gasoline with domestically produced sugarcane ethanol. By the end of 1980s, the subsidies and price supports were eliminated and the ethanol industry has been deregulated since then. The conventional transportation fuels markets, on the other hand, are administered strictly by the government through taxes, price controls, and blending mandates to achieve market stability, make ethanol competitive with gasoline, and control adverse effects of volatile fuel prices on other sectors of the economy. Despite all the efforts, however, the transportation fuels sector has been quite dynamic in recent years. In 2011, in response to the short supply of ethanol, the ethanol blending rate was reduced from its historical 25 percent level to 20 percent and the federal tax rate on gasoline was lowered first by 20 and then by 33 percent. In contrast, due to the projections for a record high sugarcane production and supply of ethanol in 2013, the government increased the blending mandate back to 25 percent. Simultaneously, to curb the substantial losses from subsidized domestic gasoline sales in the past few years the price of gasoline was raised by more than 10 percent. In this paper, we develop and use an economic simulation model to analyze the impacts of such policy changes on Brazil's fuel sector, producers' supply responses, consumers' driving demand and fuel choice, ethanol trade with the rest of the world, greenhouse gas (GHG) emissions, and social welfare. Being the largest two suppliers and consumers of biofuels, the US and Brazil biofuel economies interact with each other through trade. Consequently, a policy change or market disturbance in one of them directly affects the other. Therefore, along with the domestic factors, we also consider the US biofuel policies and their impact on the demand for Brazilian ethanol exports in our analysis. Lastly, the ethanol and sugar markets are interrelated in Brazil since sugarcane is the common feedstock for ethanol and sugar production. In the past decade the global sugar markets have been quite dynamic where the strong sugar demand and high prices observed prior to 2008 have now been replaced by a significant oversupply and low prices (Figure 1). This clearly has had an important impact on the Brazil ethanol sector. Therefore, for completeness we also incorporate the linkages between the domestic and global sugar markets and ethanol markets. The primary motivation of our analysis is to derive some general guidelines and provide policy insight under different market conditions affecting the transportation fuel sector.

Background

In the past four decades, Brazil has implemented a mandate for blending anhydrous ethanol into gasoline in the range of 4.5-25 percent ratio. The blended fuel (gasoline + anhydrous ethanol, called gasohol) is consumed by both conventional passenger vehicles (CV) and flex-fuel vehicles (FFV).The FFV category, along with ethanol-dedicated vehicles (EDV), can also run on pure ethanol (E100). Hence, FFV drivers have the flexibility to move from gasohol to E100 and vice versa. Although most cars are still of conventional type, the FFV category dominates the light-duty vehicle sales in Brazil since the Brazilian automotive industry introduced FFVs into the market in 2003. The flexibility thus acquired by fuel consumers makes the fuel policy a sensitive issue for all market participants including both fuel consumers and producers. The sugarcane ethanol producers in particular face a high uncertainty since the Brazil ethanol market is not regulated and competes with sugar production.[1]

During the period 2005-2011 the ethanol-blending ratio was set at 25 percent. Although the sugarcane area expanded by 30 percent in this period, the production of sugarcane and sugarcane ethanol could not keep up with the growing demand for fuel ethanol. Responding to the ethanol shortage, in October 2011 the government reduced the blending ratio to 20 percent. The short supply of ethanol was a result of : i) the low domestic price of gasoline relative to international prices which increased the consumption of transportation fuels in Brazil; ii) the strong global sugar markets which ramped up Brazil's sugar production and exports (Portal Brasil, 2011a), thus reducing the amount of sugarcane crushed for ethanol; and iii) the decline in total recoverable sugar and sugarcane yield (about 10 and 5 percent, respectively) particularly during the period 2007-2010 (MAPA, 2010). Consequently, although historically Brazil has been a net biofuel exporter, the country had to import corn ethanol from the US in the past three years to meet the domestic ethanol demand (Figure 2). In 2013, the sugarcane yield hit a record high and global sugar markets have been weaker compared to the pre-2010 prices and demand. Projecting a recovery in the sugarcane ethanol industry the government increased the blending ratio back to 25 percent in May 2013.

Another crucial fuel policy instrument in Brazil is the tax rate on transportation fuels. The taxes applied to gasoline and ethanol, which vary at federal and state levels, are often modified to make E100 competitive with gasohol and to avoid volatility in the fuel prices (Portal Brasil, 2011b). Thus, lower federal tax rates (CIDE[2], PIS/PASEP[3] and

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[1] It is important to mention that sugarcane mills have limited ability to switch their production line discretionally between sugar and ethanol. Currently, 72 percent of the sugarcane mills can produce both sugar and ethanol in a 60/40 proportion. Of the remaining mills, 26 percent produce ethanol only and the rest produce sugar only (MAPA, 2012).

[2] Contribuição de Intervenção no Domínio Econômico (Compulsory contributions for the purpose of achieving economic stability).

[3] Programa de Integração Social (Social Integration Program) and Programa de Formação do Patrimônio do Servidor Público (Civil Service Asset Formation Program).

COFINS[4]) are provided to E100 and anhydrous ethanol relative to gasoline. Some states also impose a lower ad-valorem tax rate (ICMS[5]) for ethanol (ANP, 2011). Overall, pure gasoline is taxed slightly more than 100 percent, while the tax on E100 and anhydrous ethanol is lower than 40 percent. When the ethanol blending rate was reduced in 2011, simultaneously the federal tax rate on gasoline was reduced by 20 percent to protect the domestic fuel consumers and reduce the inflationary effect of high fuel prices on other sectors of the economy.

To complete the 'tool box' of the fuel policy instruments, PETROBRAS, the main Brazilian oil refinery and domestic gasoline wholesaler which controls more than 90 percent of the gasoline market in Brazil (Fecombustíveis, 2011)[6], regulates the refinery price of gasoline (PETROBRAS, 2011). Figure 3 illustrates the price movements over 2005-2013 using weekly refinery prices of gasoline in Brazil (ANP, 2013) and the New York Harbor Conventional Gasoline Regular Spot Price FOB as a proxy for international prices (EIA, 2013), where the US prices are converted to Brazilian Reais (R$) at the ongoing exchange rates. Since 2005, PETROBRAS has kept the price almost constant and around the average international price until 2011, but after then the domestic price has been significantly lower than the global prices. In the third quarter of 2012, for instance, the price of gasoline in Brazil was 19 percent below the world price although part of the consumption was imported. In the past three years importing transportation fuels at higher world prices and selling in the domestic market at subsidized prices resulted in substantial losses which forced PETROBRAS to adopt a market driven price policy. The company announced recently that the gap between the domestic and international fuel prices would be closed gradually. As a first step in that direction the price of gasoline was raised twice, first by 6.6 and then by 4 percent, in 2013. Unlike gasoline, the consumer price of ethanol is not regulated in Brazil and has fluctuated over time depending on the adjustments in the fuel blending ratio and the tax rates determined by the federal and state governments.[7] Despite the tax incentives provided to ethanol consumers, low gasoline prices in recent years weakened the competitiveness of ethanol against gasoline and reduced the share of ethanol in the total fuel consumption from 56 (45) percent in 2009 to 39 (30) percent by volume (by energy equivalent) in 2012 (EPE, 2012).

The prices of ethanol and sugar are highly correlated due to the fact that sugar is one of Brazil's main export products in which it exerts a world market power. Therefore, the price of sugar drives the sugarcane price together with the price of ethanol. Sugar production has increased hand in hand with ethanol expansion reaching 38 million tons in 2012/2013 (UNICA, 2013), making Brazil the largest sugar producer and exporter in the world. The main difference between the two industries is the demand destination. While most of the sugar production goes to international

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[4] Contribuição para o Financiamento da Seguridade Social (Contribution for the Financing of Social Security).
[5] Imposto sobre Circulação de Mercadorias e Prestação de Serviços (Tax on the Circulation of Goods and Services).
[6] The Government of Brazil is the largest stockholder of PETROBRAS.
[7] More description on these policies changes in Brazil can be found in De Gorter et al. (2012).

markets, most of the ethanol production is consumed in the domestic market. Hence, the ethanol market has been subordinated to the sugar price since it was deregulated towards the end of the 1990s and both prices move together as pointed out by Serra, Zilberman, and Gil (2010). Brazilian sugarcane ethanol has a large share in the international markets since it is eligible for both the "advanced" and conventional renewable fuel categories in the US mandate (EPA, 2010), it is moving forward into the European Renewable Energy Directive (The European Parliament and Council of the European Union, 2009), and can fill other international mandates.

While Brazil's ethanol industry has been struggling lately, the US biofuel production has grown at a dramatic rate in the past decade, from 6.1 billion liters in 2000 to 14.7 billion liters in 2005 and 50.2 billion liters in 2012 (see Figure 4), due to the blending mandates imposed by the RFS. This made the US the largest biofuel producer in the world. The RFS aims to increase this amount to 136 billion liters by 2022. An important component of this target is the advanced biofuel mandate, which is set as 79 billion liters for 2022. According to the RFS provisions at least 60 billion liters of this amount must be derived from cellulosic biomass while the rest can be met by biodiesel and sugarcane ethanol. Due to the slow progress in the cellulosic biofuels production technology the cellulosic biofuel mandates have been reduced to negligibly small amounts year after year since the inception of the RFS. If an economically viable cellulosic biofuel production technology cannot be developed, much of the undifferentiated advanced biofuel mandate can be met by sugarcane ethanol imported from Brazil. This may be as much as one third of Brazil's projected ethanol production in 2022. Therefore, the RFS advanced biofuel mandate has very important implications for the Brazil ethanol industry as well.[8]

The complex policy climate described above poses serious uncertainties and leaves the public policy makers with unclear conclusions about the strength of the Brazilian biofuel economy, which is considered as a reliable source to meet the biofuel demand of many importer countries along with the domestic demand. The main motivation of this paper is to determine the extent Brazilian ethanol production can respond to such uncertainties over the next two decades and investigate the impacts of Brazil fuel policies on the supply, domestic consumption and trade of ethanol. We carry out our analysis considering two policy instruments currently employed by the government: 1) changes in the fuel blending rate, and 2) gasoline pricing through fuel taxes. For sugarcane productivity and demand for its end products, we consider the followings as possible scenarios: 1) an average versus low sugarcane productivity (the latter may result from an expansion of the sugarcane acreage beyond the traditional

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[8] A drastic policy change has been proposed recently by the EPA for the 2014 mandates, which faded away such expectations. For the first time since 2005, besides waiving the cellulosic biofuel target again, the proposal reduces the mandates for both advanced biofuels and corn ethanol. Specifically, if this proposal becomes the final rule, the total amount of biofuels blended with fossil fuels will be reduced from 68.6 billion liters (the original 2014 mandate) to 57.5 billion liters (16% reduction), while the advanced biofuel mandate will be reduced from 14.1 billion liters to 8.3 billion liters (41% reduction). Most of the latter will be met by biodiesel which leaves little room for Brazilian sugarcane ethanol. This proposal is motivated by the technical limitations in blending ethanol with gasoline (known as the 'blend wall') and the absence of economically viable non-ethanol (drop-in) biofuels in the US market.

production regions which are more suitable for sugarcane production), and 2) low versus high demands for both ethanol and sugar exports in the world markets. These possibilities are coupled to design four scenarios. Our analysis aims to address the following questions under each scenario: i) what would be the implications of the respective fuel prices and blending mandates for the mix of biofuels? ii) what would be the effects on the welfare of food and fuel consumers? iii) to what extent would these policies affect GHG emissions? iv) what would be the revenue/loss implications for the government?

The present study contributes to the related literature in three aspects. First, it combines detailed agricultural and transportation fuel sectors of Brazil through the supply of sugarcane ethanol as a substitute to gasoline. Second, it relates the government's fuel policies (i.e. blending mandates and fuel pricing/taxing) to consumers' behavior. Some previous studies have addressed the economic effects of the introduction of flex-fuel vehicles (e.g. Pacini & Silveira, 2011; Schmitt, Szklo, & Schaeffer, 2011; de Freitas & Kaneko, 2011a, 2011b), but to our knowledge no published study empirically analyzed the impacts of Brazilian fuel policies on the consumers' driving behavior, amount of fuel consumption, and fuel choice. Third, this study presents the first spatially explicit analysis of the Brazil and US biofuel policies in a unified framework. The literature on economic analysis and assessment of fuel pricing, blending mandates, and tax policies in Brazil relies on stylized models with a high degree of aggregation, such as de Gorter et al. (2013) and Babcock et al. (2013),. The present study differs from the above studies by considering a detailed spatial simulation of the feedstock supply structure and fuel delivery network along with a disaggregation of the light duty vehicle fleet into sub-categories with different fuel consumption capabilities.

We address the issues described above using a multi-market multi-product price endogenous economic simulation model which determines the simultaneous agricultural and fuel market equilibrium in Brazil, US, and the rest of the world. Since biofuel policies in Brazil directly affect the production of sugarcane, thus the production of other agricultural commodities, in particular corn and soybeans which are among the major products exported by Brazil, we incorporate a similar model component for Argentina who is another major supplier of these commodities and competitor of the US and Brazil in the global markets. For the rest of the world (ROW) and China (that is emerging as a large consumer of food and fuel commodities), the model includes aggregate demand and supply functions for food/feed and fuel commodities. In the Brazil component of the model, the supply and demand for transportation fuels are regionally disaggregated. In addition to the tax rate differences across the Brazil states, the transportation costs for delivering fuels between supply and demand regions are taken into account when simulating the consumers' fuel choice and consumption behavior. This is one of the unique features delineating the present study from the existing studies in the literature.

Some highlighted model results are as follows: i) under a decreased fuel blending rate conventional vehicles would be driven significantly less while driving by

flex-fuel and ethanol-dedicated vehicles would be affected at insignificant rates; ii) when a blending mandate reduction is implemented responding to a short supply of sugarcane ethanol, the distance driven by all vehicle categories would be reduced significantly. In both cases a significant loss of economic surplus (welfare) accrues to both agricultural producers and fuel consumers while the Brazilian government would be the only beneficiary due to higher tax revenues collected from gasohol containing more gasoline in it. Although the overall driving demand gets reduced, the total GHG emission goes up because the blended fuel includes a relatively dirty fuel (gasoline) at a larger proportion in its mix; iii) reducing the tax rate on gasoline increases the driving demand and compensates some of the social welfare loss resulting from a lower blending rate, but this increases the total GHG emission further.

The model

As the policy analysis tool we build on a price endogenous mathematical programming model developed earlier by Nuñez et al. (2013) by adding more policy details in the Brazilian component. The model is a multi-region, multi-market, multi-product, spatial equilibrium model including the agricultural and fuel sectors of Brazil and the US. Because of the importance of Argentina as a global corn, soybean and wheat exporter a similar component is developed for the agricultural sector of Argentina as well. In addition to bilateral trade between these countries the food/feed and biofuel demands of Rest of the World (ROW) are also included in the model. The objective function of the model represents the sum of producers' and consumers' surplus aggregated over all markets and countries, which is maximized subject to the regional resource limitations, material (demand and supply) balance constraints, technical constraints, and policy restrictions. Consumers' surplus is derived from the consumption of both agricultural commodities and transportation fuels by light-duty vehicles that generate vehicle-kilometers-traveled (VKT).

The demand functions for all commodities and VKT are assumed to be linear and separable. In the Brazil, US, and Argentina components the supply of primary crops and processed products (including biofuels) is modeled in detail by using Leontief production functions. The agricultural supply is regionally disaggregated at mesoregion level in the Brazil component, at Crop Reporting District level in the US component, and at province level in the Argentina component. The model includes production of fourteen major annual crops as well as beef-cattle production in Brazil under different pastures types and production systems. As the biofuel feedstocks, sugarcane, corn, crop residues (corn stover and wheat straw), switchgrass, and miscanthus are modeled again using Leontief production functions. The model also considers bagasse (which is burned to generate electricity) and Dried Distilled Grains with Solubles (used as a substitute to feed grains) as byproducts when processing sugarcane and corn into ethanol.

In the fuel sector, ethanol and gasoline are assumed to be perfect substitutes and combined in accordance with the specified blending regulations to generate VKT. The model assumes an upward sloping supply function for gasoline in the US and ROW components while in the case of Brazil a perfectly elastic supply function is assumed reflecting the constant pricing policy for pure gasoline. Because of the geographical size of Brazil and long distances between potential ethanol production regions and gasoline refineries to consumption/export locations, an ethanol and gasoline transportation module is included in the Brazil component. Specifically, each state in Brazil is assigned a VKT demand function for the three vehicle types (CV, FFV, and EDV) and the states are assumed to receive ethanol and gasoline from the nearest ethanol producing mesoregions, gasoline refineries[9] or ports. The model also considers an explicit cost for transportation of ethanol and gasoline from the mesoregions to the export ports.

Equations (1) to (15) below illustrate the mathematical set up of the Brazil component of the model. For simplification purposes, the model presented here assumes a closed economy without regional disaggregation, two goods for consumption (*VKT* and sugar), one primary agricultural product (sugarcane), three processed agricultural products (sugar, hydrous and anhydrous ethanol) and gasoline. The actual model used in the empirical analysis includes many more primary agricultural products and processed commodities, spatial disaggregation in agricultural supply, and trade between countries/regions. A complete description of the model is provided in Nuñez et al. (2013). In the mathematical model presented below, lower case symbols denote exogenous parameters, upper case symbols represent endogenously determined variables, and superscripts are used for crops/fuels/commodities.

Maximize

$$
\sum_{vt} \int_0^{VKT^{vt}} (\alpha^{vt} + \beta^{vt} \cdot Y^{vt}) dY^{vt} + \int_0^S (\alpha^S + \beta^S \cdot Y^S) dY^S
$$

$$
- \bar{p}^g \cdot GS - (\pi^g + t^g) \sum_{vt} GD^{vt} - c^A \cdot ES^A - c^H \cdot ES^H
$$

$$
- \pi^A \sum_{vt} ED^{A,vt} - \pi^H \sum_{vt} ED^{H,vt} - c^{CN} \cdot CL^{CN} - c^S \cdot CS \qquad (1)
$$

The objective function described by (1) is the sum of producers' and consumers' surpluses. The first line represents the area under the linear demand curves for vehicle kilometer traveled (*VKT*) for vehicle type *vt* (the first integral, where *vt* includes CV, FFV and EDV) and for sugar (*S*) (second integral). The first term in the second line is the area under the supply curve for gasoline $\bar{p}^g GS$ (in the case when the

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[9] There are 13 gasoline refineries located in the mesoregions of Metropolitana de Porto Alegre, Metropolitana de São Paulo, Campinas, Vale do Paraíba Paulista, , Metropolitana do Rio de Janeiro, Centro Amazonense, Metropolitana de Fortaleza, Metropolitana de Belo Horizonte, Metropolitana de Curitiba, Metropolitana de Salvador, Sudeste Rio-grandense.

refinery price of gasoline is fixed, the slope parameter is zero; otherwise a positive value applies). The second line includes the internal transportation costs and marketing margins (π) for gasoline sales (GD); the symbol t^g represents the fuel tax which is considered as a policy instrument specified differently for gasoline and ethanol; the last two terms in line two represent the cost of producing anhydrous (ES^A) and hydrous (ES^H) ethanol from sugarcane. The first and second terms in line three include the internal transportation costs and marketing margins (π) applied to anhydrous (ED^A) and hydrous ethanol (ES^H) sales; the last two terms in that line are the production cost per hectare (c^{CN}) of sugarcane (CL^{CN}) and the cost per ton (c^S) of processing sugarcane to sugar (CS), respectively.

The maximization of (1) is subject to several constraints, but here we will show only the ones related to the fuel sector. Consumers obtain utility from VKT, which is produced from gasohol consumption by CV, from blended gasohol and E100 by FFV, and from E100 consumption by EDV. For each vehicle type, the total kilometers generated (*VKT*) results from the amount of each type of fuel consumed by that vehicle category, as shown in equation 2:

$$VKT^{vt} = k^{vt}(\gamma^h \cdot ED^{H,vt} + \gamma^a \cdot ED^{A,vt} + GD^{vt}) \qquad \forall\, vt \qquad (2)$$

where k is a parameter for fuel efficiency (kilometers generated per liter of gasoline equivalent amount of each fuel type). The symbols γ^h and γ^a correspond to the difference in pure energy contents of hydrous and anhydrous ethanol with respect to gasoline, and *ED* and *GD* denote the consumption of ethanol (by type) and gasoline, respectively. The model restricts the consumption of E100 to FFVs and EDVs and the consumption of gasohol to FFVs and CVs.

Equation (3) represents the blending rate (*bl*) for gasohol.

$$ED^{A,vt} = bl(ED^{A,vt} + GD^{vt}) \qquad\qquad For\ vt = CV, FFV \qquad (3)$$

Equations (4), (5) and (6) represent the gasoline, ethanol (anhydrous and hydrous) and sugar clearing market conditions.

$$\sum_{vt} GD^{vt} = GS \qquad (4)$$
$$\sum_{vt} ED^{A,vt} = ES^A \qquad (5)$$
$$\sum_{vt} ED^{H,vt} = ES^H \qquad (6)$$
$$S = y^S \cdot CS \qquad (7)$$

where y^S is the sugar yield per ton of sugarcane and CS is the amount of sugarcane used for sugar production.

Equations (8) and (9) express the anhydrous and hydrous ethanol supply, given by the ethanol yield (y) times the amount of sugarcane used for producing each type of ethanol:

$$ES^A = y^A \cdot CA \tag{8}$$
$$ES^H = y^H \cdot CH \tag{9}$$

Equation (10) balances the total use of sugarcane (crushed for ethanol and sugar) and sugarcane production. The latter is given by the sugarcane yield (tons per hectare, denoted by y^C) times the total land devoted to sugarcane (denoted by CL^C).

$$CA + CH + CS = y^C \cdot CL^C \tag{10}$$

Using the Karush-Kuhn-Tucker (KKT) first order optimality conditions[10], we can show that the Lagrangian multipliers associated with equation (2), denoted by $\lambda_{2,vt}$, represent the market equilibrium prices of VKT^{vt} for each vehicle type. Likewise, the Lagrangian multipliers λ_7 and λ_{10} related to equations (7) and (10) represent the market equilibrium prices of sugar and sugarcane, respectively. Furthermore, the market prices of hydrous ethanol, gasoline and anhydrous ethanol (LHS of equations 11, 12 and 13) can be derived by use of (11), (12) and (13), respectively, which are direct results of the KKT conditions[11]:

$$p^H = \lambda_{2,EDV} \cdot k^{EDV} \cdot \gamma^H \tag{11}$$
$$p^g = \lambda_{2,cv} \cdot k^{CV} - \lambda_3 \tag{12}$$
$$p^A = \lambda_{2,CV} \cdot k^{CV} \cdot \gamma^a + \lambda_3 \cdot \frac{1-bl}{bl} \tag{13}$$

where λ_3 is the multiplier related to the blending mandate restriction (equation 3). The price of gasohol is derived as a weighted average of gasoline and anhydrous prices by multiplying equation (12) by $(1 - bl)$ and (13) by bl and adding them up, namely:

$$(1 - bl)\, p^g + bl \cdot p^A =$$
$$(1 - bl)\left(\lambda_{2,CV} \cdot k^{CV} - \lambda_3\right) + bl\left(\lambda_{2,CV} \cdot k^{CV} \cdot \gamma^a + \lambda_3 \cdot \frac{1-bl}{bl}\right) \tag{14}$$

Simplifying equation (14) we find the gasohol price (P^{GH}) as:

$$P^{GH} = \lambda_{2,CV} \cdot k^{CV}(1 - bl(1 - \gamma^a)) \tag{15}$$

Data

The model is calibrated and validated using 2007 as the base year. The data inputs include the base year domestic and global commodity prices and quantities demanded,

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[10] The KKT conditions are both necessary and sufficient in this case since the objective function is strictly concave and the decision space is convex)

[11] Proofs of these statements are straightforward and can be available upon request from the authors.

historical crop patterns (areas planted to individual crops), crop yields, costs of production and processing, and cost of transportation.

For Brazil, the model includes sugarcane (a perennial crop), eight major annual crops/commodities (including soybeans, corn, wheat, sorghum, cassava, dry-beans, cotton and rice, and beef-cattle production.

Currently, ethanol can be produced in the US from corn and from sugarcane in Brazil. Corn ethanol productivity is 405 liters of anhydrous ethanol per ton of corn and 83 liters of hydrous ethanol and 80 liters of anhydrous ethanol per ton of sugarcane. Corn anhydrous ethanol processing cost is approximately $0.2 per liter, while sugarcane hydrous and anhydrous ethanol costs are R$0.3 and R$0.33 respectively (PECEGE, 2008). In addition to these costs, the model considers ethanol subsidies, co-product credits, costs of delivering feedstocks to refineries, marketing margins, and fuel taxes. The latter vary across the states in Brazil.

For the supply of gasoline in Brazil, the model assumes a fixed price of R$1.05 per liter for pure gasoline at the refinery gate, as reported by ANP (2013), which is approximately the refinery price before taxes, marketing margins of the blenders, and transportation costs from the refinery to the pump.

The VKT demand function is specified for each vehicle type (CV, FFV, EDV) using a uniform price elasticity (specified as -0.2 for all vehicle types), price per kilometer and total kilometers generated in the base year. The price is obtained by dividing the total cost of fuels consumed by total kilometers generated for each vehicle type. A demand function for VKT is specified for each state based on the registered car numbers. The ROW demand for ethanol is equivalent to the exports from Brazil excluding the exports to the US. The cost of ethanol transportation to the ROW markets is specified as $0.16 per liter (derived as the difference between the base year ROW prices and Brazil average domestic price). For ethanol exported to the US through the CBI countries the transportation margin per liter is $0.03 transportation cost plus $0.015 dehydration cost.

Direct lifecycle GHG emissions are calculated for all crops, fuels, and livestock based on the above-ground CO_2 equivalent emissions (CO_2e). These emission estimates do not include direct or indirect land use related emissions.

A complete description of the entire data set, the key supply and demand parameters, production costs and yields, and transportation costs between regions can be found in Nuñez et al. (2013) or can be available from the authors upon request.

Results and Discussion

As mentioned at the outset, we consider four different policy scenarios for 2022 where strong and weak demand conditions for sugarcane products (ethanol and sugar) are coupled with average and poor feedstock supply (sugarcane yield) conditions. In each case, we investigate the impacts of two policy instruments on the Brazil biofuel economy, social welfare, and global environment (GHG emissions). The specific policy

instruments are: i) alternative blending rates varying between 15 percent and 25 percent, and ii) up to100 percent reductions in the federal gasoline tax (CIDE) and state tax (ICMS) (the 100 percent tax reduction means zero federal and state tax on domestic gasoline sales). We assume that the other charges on transportation fuels and other fuel taxes (PIS/PASEP and CONFIS) remain unchanged. The strong demand conditions for sugarcane products will be represented by the US demand for advanced biofuels as stated in the RFS provisions and the ROW sugar demand observed from 2007 to 2010 where the sugar export demand was 44 percent higher than the historical average demand. In this case, we also include the projected imports by the ROW reflecting the mandates imposed by Europe and China. To represent the weak world market conditions we assume that the RFS advanced biofuel mandate will be abandoned, ROW imports will be as in 2010, and the global sugar demand will grow at the average rate of last ten years. For the feedstock supply, we consider the historical average sugarcane yield in Brazil as the strong supply condition and a 9 percent reduction in the average sugarcane yield (reflecting the observed yields from 2007 to 2010) as the weak supply condition.

The model simulation results regarding the effects of alternative taxation and blend rate specifications on the transportation fuels sector, sugarcane industry, GHG emissions, government incomes, and social welfare are summarized in the following.

Effects on the Fuel Sector
Some selected model results are reported in Table 1. The reference case shown in column (a) assumes strong ethanol and sugar demands in global markets, average sugarcane yield, 25 percent ethanol blending rate and the fuel tax rates observed in the base year (2007) in Brazil. The remaining four blocks formed by columns (b)-(k) display percentage changes with respect to the base case under alternative scenarios for demand and supply conditions for the Brazil sugarcane industry and fuel market. Each block assumes one of the two extreme ethanol blending rates (namely, 15 and 25 percent) coupled with two extreme taxing alternatives (namely, the base year fuel tax rates and 100 percent reduction in the fuel taxes)[12].

Several general conclusions can be made based on the results displayed in Table 1. The first and most striking fact is the role of fuel taxes in the transportation fuels sector as a whole and in particular in the biofuel industry of Brazil. The second column of each block (columns c, e, h, and j) corresponds to the case where the fuel taxes are reduced by 100 percent, which implies that Brazil applies the world price on gasoline sold in the domestic market. The results show that everything about the fuel markets would be affected dramatically by this single policy change. As expected, the total VKT (summed across all vehicle categories) increases (ranging between 5.0-5.4 percent relative to the base case) as a result of the reduced gasohol consumer price (ranging between 32.3-37.2 percent). The impacts on the sugarcane ethanol sector would be

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[12] These are the federal gasoline (CIDE) and state (ICMS) tax rates, which were 0.23 Reais (about 10% of the final price of gasoline before blending) and 25 percent, respectively, in the base year 2007. All other taxes are kept at the observed base year levels.

detrimental. The consumption of E100 by FFVs totally disappears, because FFV users switch to gasohol, and ethanol is produced only to meet the blending mandate rather than to substitute gasoline. Consequently, the total gasoline consumption goes up enormously, varying between 72.8 – 89.1 percent depending on the availability of ethanol in the domestic market. This occurs because removing the taxes makes gasohol a more appealing fuel than pure ethanol (recall that gasoline is more heavily taxed than ethanol in the base case), which leads to the substitution of ethanol with gasoline in the fuel mix. Therefore, the total consumption of ethanol goes down accordingly (by 61.9-77.2 percent).

Unlike the tax instrument, the impacts of a reduced blending mandate on the transportation fuels sector and social welfare are not uniform, rather they vary across the scenarios considered in Table 1. Nonetheless, some general conclusions can be made. Columns (b), (f), (g), and (k) report the results obtained with a reduced 15 percent blending mandate where the fuel taxes are maintained at the base case levels. Therefore, the results in these columns leave out the role of fuel taxes and provide a meaningful evaluation of the impact of blending mandate alone. It is clear from these results that the impact of a reduced mandate rate on the total VKT demand (summed across all vehicle categories) would be insignificant (the changes vary between a 0.6 decline -column f, and 0.3 increase -column g). However, the composition and prices of transportation fuels would be impacted seriously. A reduced blending rate makes gasohol more expensive since it contains a more expensive fuel (gasoline) in a larger proportion. This encourages FFVs to switch from gasohol to pure ethanol, thus substituting the gasoline in the gasohol mix consumed by this car category with pure ethanol (while E100 consumption by FFVs goes up by 45-55 percent the consumption of gasoline goes down by about 40 percent in three out of the four cases, namely columns b, g, and k). An unintuitive result reported in Table 1 is the impact of reducing the blending rate on Brazil's ethanol exports. One would expect an increase in the ethanol exports because when the blending rate is reduced less ethanol would be needed in the gasohol mix, thus releasing some ethanol for exports which would otherwise be consumed in the domestic market. While this is true for the ethanol used as a complementary fuel by conventional fuels, a reduced blending rate changes the fuel choice for FFVs which switch from gasohol to E100. Therefore, in the aggregate the total demand for ethanol in the domestic market goes up substantially because the increase in E100 demand as a substitute to gasohol is far more than the reduction in the demand for ethanol as a complementary fuel additive. This interesting result is due to the large share of FFVs in the light duty vehicle fleet[13], a unique feature of the Brazil transportation sector, which makes the fuel policy analysis more complex and justifies the use of the model we developed here.

The results presented in Table 1 correspond to the combinations of the extreme values of fuel tax rate change (base rate and 100 percent reduction) and

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[13] The share of FFVs in the Brazil light duty vehicle fleet is projected to increase to 85 percent by 2022. We assumed this share in the model simulations.

ethanol blending rate (15 and 25 percent) considered in the analysis. The entire spectrum of the model results for the fuels sector under all combinations of the blending rate (ranging from 15 to 25 percent) and fuel tax rate changes (ranging between 100 percent reduction and no tax rate change) are illustrated in figures 5-8, where each sheet in the figures corresponds to one of the four market conditions (namely a strong versus weak market demand for sugarcane products coupled with an average versus poor feedstock supply). The directions of changes are as outlined above except that changes in the sectoral performance indicators, environmental impacts, and welfare measures occur gradually as the two policy instruments are varied systematically. Figure 5 shows that the total VKT in Brazil would go down when either the blending rate is reduced or the fuel tax is increased under all four scenarios. Although the average VKT reduction (from red to blue sheet in Figure 5) may seem insignificant, in practical terms it would be equivalent to one and half days of no driving by all light-duty vehicles in Brazil. The gasoline consumption by FFVs would shift upward when the amount of sugarcane converted to ethanol is reduced due to a yield decline (from the copper sheet to the blue sheet, or from the red sheet to the yellow sheet in Figure 6), while it would rise when the tax rate is reduced. The price of ethanol would decline as the tax rate is reduced up to 50%, but after that it would increase again because of the higher demand for gasohol which also increases the demand for anhydrous ethanol. This complex result is illustrated in Figure 7. In terms of international trade, the copper and blue sheets in Figure 8 show that Brazil would keep the dominant position in the international ethanol market with exports ranging from 30 to 70 billion lt under a strong world ethanol demand, otherwise exports would be lower than 20 billion lt (the red and yellow sheets in Figure 8).

Effects on Sugarcane Land Use
One would expect that farmers would switch their crop pattern responding to agricultural market conditions, and in the long term strong sugar and ethanol demands in the global markets would increase the sugarcane area in Brazil. In contrast, substantial acreage reductions would occur when the world demands for sugarcane products are weak. This is depicted by the blue and copper sheets in Figure 9. This fact is also apparent in Table 1 when columns (g) and (h) are compared against columns (b) and (c) (weak demand and strong demand scenarios, respectively, coupled with average feedstock supply). The simulation results show that the land allocated to sugarcane can go down to as much as half of the base year land allocation when the global demand for sugarcane products is weak. Similar comparisons can be made under the low feedstock supply conditions also (columns d-f vs columns i-k). Table 1 also shows that the land allocated to sugarcane is highly sensitive to fuel policies, in particular to fuel taxes. For instance, even under the strong global market conditions, the sugarcane acreage contracts by more than 15 percent with respect to the base level when the fuel tax is eliminated (column c). An acreage reduction under strong global demands for sugar and ethanol and favorable sugarcane yield may seem surprising, but it is explained easily by the reduced demand for ethanol in the domestic

market. As discussed earlier, elimination of the fuel taxes makes gasohol a more appealing fuel and encourages FFVs to switch from E100 to gasohol, which in turn reduces the demand for sugarcane ethanol and therefore the demand for sugarcane feedstock.   The reductions in columns (d)-(f) are mainly due to the low yield assumption, which reduces the attractiveness of sugarcane vis-à-vis the other major field crops considered in the model. This is pronounced more when the fuel tax is reduced (column e). The drastic acreage reductions in columns (g) and (h) (even when the yield is set at the historical average level) are due to the low foreign demand for sugarcane products and low blending rate in the domestic market, both of which reduce the demand for sugarcane. This effect is pronounced further when the tax rate on fuels is eliminated (column h), which is again an expected result. Perhaps the only unintuitive result that needs to be explained is the slight increase in sugarcane acreage when the ethanol blending rate is reduced while all else is the same as in the base case (column b). As discussed earlier, reducing the blending rate reduces the demand for ethanol as a complementary fuel, but increases the demand for E100 by FFVs which would switch from gasohol to pure ethanol. This increases the aggregate demand for ethanol, thus the land allocated to sugarcane.

The changes in the total sugarcane area shown in Figure 9 are not reflected to the regional land allocations uniformly. Rather, the production moves across regions depending on the sugarcane yield differences (regional comparative advantage) and competition between sugarcane and other major crops on agricultural land. Since the main emphasis is placed on the fuels sector in this paper, those details will not be discussed here.

Environmental Effects

It may be expected that mandating a smaller blending rate would increase the total GHG emissions (in CO_2e terms) from transportation fuels since this would increase the amount of gasoline (a dirtier fuel) in the fuel consumption by conventional vehicles. However, a simultaneous effect of a reduced blending rate is the possibility of a switch from gasohol to E100 by FFVs. Thus, the net effect would be ambiguous. This is shown explicitly in Table 1, by columns (b), (c), (f), (g), (h) and (k). The simulation results show that under the same market demand and feedstock supply conditions the adverse effect of a more gasoline-intensive (85 percent) gasohol mix on GHG emissions is dominated by the emission reduction effect of increased ethanol consumption resulting from FFVs' switching to E100 if the tax rates are maintained at the base case levels (e.g. columns b, f, g, and k)

A tax rate change reverses the story, however, because the effect of taxes on fuel consumption and particularly on fuel choice is much stronger. Tax rate reductions beyond a certain level makes gasohol a more appealing fuel for consumers (due to its reduced price after the tax reduction is accounted for). This in turn affects the total GHG emissions. When the fuel taxes are totally eliminated, the domestic GHG emissions from transportation fuels would go up by about 10-19 percent under different scenarios as indicated in Table 1, columns (c), (e), (h) and (j). A comparison of

column (c) against column (b) (or column e against column d, or column h against column g, or column j against column i) demonstrates that eliminating the fuel taxes along with reducing the blend rate reverses the fuel choice by FFVs back to gasohol, which consequently increases the GHG emissions substantially. That would occur regardless of the global market demands for sugarcane products and feedstock supply conditions. A strong global demand for sugarcane products exacerbates the situation further. When the sugarcane ethanol and sugar markets are strong, a larger portion of the sugarcane production is crushed for sugar and the amount of ethanol available in the domestic market becomes less. Augmenting the increased ethanol exports to this raises the price of ethanol in the domestic market further, thus E100 becomes a more expensive and less appealing fuel relative to gasohol, which consequently increases the GHG pollution. This fact is displayed clearly in Figure 10 by the copper and red sheets and is also reflected in Table 1 by the columns which differ only in terms of the global demands for sugarcane products. For instance, a comparison of columns (c) and (h) (or columns j and e).show that a stronger world demand for sugar and ethanol would lead to an additional 4.5 percent increase in the GHG emissions compared to the emissions that would occur under a weak demand situation (18.9 percent increase relative to the base case –column c, as opposed to 14.4 percent –column h; the respective figures for columns e and j are 14.5 and 10.1 percent).

The phenomenon described above has occurred recently in Brazil. The strong global sugar and ethanol markets and poor sugarcane yields reduced the supply and increased the price of ethanol in the domestic market during 2007-2011. Responding to this Brazil government reduced the blending rate from 25 to 20 percent between October 2011 and May 2013. Simultaneously, to protect the fuel consumers and control potential inflationary effects of higher fuel prices the federal fuel tax rates were also reduced significantly (9 percent?). Referring to the copper sheet in Figure 10, this must have led to a roughly 10 percent increase in the GHG emissions from transportation fuels consumed in Brazil. If, however, the blending rate and fuel tax rates were maintained at their base levels this would reduce the VKT (by 0.3 percent) and therefore the GHG emissions (by 0.8 percent), but this would be at the expense of consumers' welfare loss (0.7 percent, see column d in Table 1). Clearly, this was an immediate policy response to a crisis situation and there may be good reasons that justify such a policy in the short term. Our analysis implies that continuation of this policy over a long term would have damaging impacts on the global environment. Recently, the global sugar and ethanol markets have become weaker (the first is due to an oversupply of sugar in the world, while the latter is due to a decrease in the US demand as a result of the adjustment in the RFS mandates, particularly in the advanced biofuel mandate which requires less sugarcane ethanol to be imported from Brazil). Simultaneously, the sugarcane yield (therefore supply) has gone above the historical average. This increased the ethanol supply in the domestic market and reduced its price. Our results shown in column (g) call for mandating a high blending ratio since otherwise the sugarcane area would shrink substantially (40 percent) relative to the base case if a low blending rate (15 percent in that column) were implemented over a

long term. The results also show that a low fuel tax rate would be harmful for global environment because of the increased GHG emissions. Eliminating the fuel taxes all together would be extremely discouraging for sugarcane and ethanol production and consumption where FFVs would switch completely to gasohol, which would increase the GHG emissions from fuels by about 14 percent (column h). Low sugarcane yields would not alter the situation much (see columns i-k). Under such circumstances a high-rate blending mandate and high fuel taxes would be beneficial for both the global environment and the Brazil sugarcane/ethanol industry since this would promote the sugarcane production and consumption of ethanol by FFVs as a substitute to gasohol (compare column i against columns g and h). However, it should be noted that this policy has unfavorable consequences for consumers due to higher prices they pay for transportation fuels, as will be discussed below.

Economic Surplus Effects
The two fuel policy instruments considered here have important welfare distribution effects. As discussed earlier, fuel consumers would be significantly worse off when the ethanol blending rate is reduced while the ethanol sector benefits from it. This is evident in Table 1 when column (b) is compared against the base case shown in column (a). Lowering the blending rate alone (while keeping all else -in particular the fuel taxes- the same) reduces the domestic social surplus (by 0.7 percent) despite the significant surplus gains accruing to ethanol producers (as much as 20 percent). This is mainly because of the higher gasohol prices consumers have to pay (7.5 percent more) and therefore the reduced amount of driving (0.4 percent). A comparison of columns (k) and (i) (which differ only in the blending rates) leads to the same conclusion. When the blending rate is reduced from 25 to 15 percent, the social surplus loss relative to the base case increases from 1.0 to 2.1 percent while the surplus gain by ethanol producers goes up from 11.1 to 27.4 relative to the base case.

On the other hand, a lower tax rate helps fuel consumers greatly under all circumstances while producers suffer welfare losses from it. This justifies the tax reduction implemented by the Brazil government together with the blending mandate reduction in response to the ethanol supply shortages and high ethanol prices that occurred during 2010-2011 where global markets for sugarcane products were strong and the sugarcane yields were low. Figure 11 displays the welfare implications of alternative fuel tax rate and blending rate combinations on ethanol producers' economic surplus. As depicted in the figure, a lower blending mandate worsens producers' surplus gradually, but the changes are relatively insignificant compared to the gains resulting from an increase in the fuel taxes. Columns (c) and (b) in Table 1 also indicate this. Elimination of the fuel taxes (column c) offsets the consumers' welfare loss resulting from a more gasoline-intensive fuel mix (E15~85 percent gasoline, column b), and even provides a significant positive welfare gain (~1 percent). However, this results in a dramatic economic surplus loss (~82 percent) for ethanol producers. This conclusion remains the same under low feedstock supply conditions and high blend rates. Comparing column (e) against column (d), which differ only in

terms of the fuel tax rates, we see that the producers' surplus loss relative to the base case goes up from 4.2 percent to 73.3 percent while the aggregate social surplus moves from a net loss of 0.7 percent to a net gain of 0.8 percent. This occurs because of the substantially reduced amount of ethanol sold as a result of FFVs switching from E100 to gasohol. Figure 11 shows the entire spectrum of model results in terms of gains/losses for ethanol producers under all combinations of the blending rate and fuel tax rate reductions. A slight gradual increase is observable in producers' surplus as the blending rate is increased, while sharp gains occur when the taxes are higher (low tax reduction rates in the figure).

Columns (g) and (h) demonstrate that when the foreign demands for sugarcane products are not as strong while the feedstock supply is strong, implementing a low blending rate would not be a good policy since this raises the price of fuels (particularly gasohol price) and shrinks the ethanol industry together with sugarcane production (the latter declines by 40 percent relative to the base case). The largest social economic surplus loss occurs in this case (5.2 percent, column g). Reducing the fuel taxes together with the blending mandate rate would be a disaster for the ethanol industry, which would produce ethanol only as a complementary fuel to meet the blending mandate. The sugarcane production would shrink further (to 55 percent of the base level), and the ethanol producers' surplus would be substantially lower (as much as 76 percent relative to the base level).

Finally, reducing the fuel taxes not only affects the economic surplus of ethanol producers and fuel consumers, but it also affects the government's tax revenues considerably (see Figure 12). In the extreme case, elimination of the fuel taxes totally would reduce the government revenues from transportation fuel sales by about 70 percent under all scenarios considered here. This is also shown in Table 1, columns (c), (e), (h), and (j). Thus, a low profile biofuel policy (low taxes and low blending rates) would damage the biofuel sector, environment, government and society as a whole. It is important to recall that this not just a one variable game, when government combines lowering moderately the blending rate and fuel tax rates can be at a point where its revenues remain marginally affected such as central part of Figure 12 illustrates.

Therefore, our analysis here shows that staying on course and pursuing the goals of the renewable fuel program in Brazil is a good policy regardless of the world market conditions for sugarcane products. This is especially the case when the global markets are weak and sugarcane supply is strong, which is the current situation in Brazil. Responding to better than average sugarcane yields (thus expected increases in sugar and ethanol production) and unfavorable conditions in world sugar markets and ethanol markets (the latter is due to the anticipated reduction in sugarcane ethanol demand in the US), the Brazilian government increased the blending mandate rate back to 25 percent in May 2013 and simultaneously increased the refinery price of gasoline to encourage the consumption of ethanol in the domestic market. Although the conventional vehicle users would be harmed by these changes, overall the impact on the ethanol producers, FFV users, and society as a whole would be positive. The

environmental benefits in terms of GHG emission reduction would also be substantial. If these policy changes have not been implemented and the current market trends continue for a time period longer than a few years one would expect a contraction in the sugarcane area because low sugarcane prices would encourage farmers not to replant their old sugarcane plots, instead they would switch to alternative crops. This could be detrimental for the continuity of the biofuel industry, global environment, and social welfare

TABLE1: SIMULATED ECONOMIC, LAND USE AND ENVIRONMENTAL IMPACTS OF BRAZIL FUEL POLICIES UNDER ALTERNATIVE DEMAND AND SUPPLY CONDITIONS FOR THE SUGARCANE INDUSTRY, 2022

| | | STRONG ETHANOL DEMAND STRONG WORLD SUGAR DEMAND | | | | | WEAK ETHANOL DEMAND AVERAGE WORLD SUGAR DEMAND | | | | |
| | | AVERAGE | | LOW | | | AVERAGE | | LOW | | |
SUGARCANE YIELD BLENDING RATE TAX RATE	BASE CASE	15% BASE	15% NO TAX	25% BASE	25% NO TAX	15% BASE	15% BASE	15% NO TAX	25% BASE	25% NO TAX	15% BASE
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
Vehicle Km Traveled (Bil Km)	727.5	-0.4	5	-0.3	5.1	-0.6	0.3	5.1	0.2	5.4	-0.2
Eth Consumption Total (Bil lt)	36.8	22.2	-77.2	-4	-62	-2.9	29.5	-77.2	6	-61.9	24.8
Gas Consumption Total (Bil lt)	23.1	-22.9	88.9	3.5	72.8	2.2	-28.9	89.1	-5.7	73.4	99
E100 Consumption by FFV (Bil lt)	28.4	44.8	-100	-6.1	-100	8.6	55	-100	9.4	-100	48.5
Gas Consumption by FFV (Bil lt)	15	-39.9	130.2	5.4	110.5	-1.2	-49.1	130.5	-8.7	111.3	-43.3
E100 Consumer Price ($/lt)	0.76	6.6	6.6	2.3	11	4.6	1.3	-4	-1.4	-3	4.8
Gasohol Consumer Price ($/lt)	1.17	7.5	-32.3	0.5	-35.3	8.6	6.8	-33	-0.3	-37.2	7.4
Ethanol Exports (Bil lt)	61.9	-4.3	10.1	-29.1	-13.9	-29.2	-96.6	-67.7	-100	-95	-100
Sugarcane Area (Mil Ha)	15.8	3.8	-15.9	-6.6	-15.5	-6.4	-40	-55	-42.9	-60.2	-37.7
GHG Emissions (Mil Tons CO2e)	294.2	-4.8	18.9	-0.8	14.5	-1.1	-12	14.4	-7.1	10.1	-11.2
Ethanol Producers' Surplus (Bil $)	15	20	-81.5	-4.2	-73.3	-6.9	29.6	-76.1	11.1	-58.8	27.4
Government Tax Revenue (Bil $)	21.4	-1.9	-68.2	0.6	-69.7	4.4	-2.3	-68.2	-1	-69.6	-2.1
Social Surplus (Bil $)	833.3	-0.7	1	-0.7	0.8	-1.2	-5.2	-3.1	-4.5	-3.5	-5.1

Notes: 1) The base case assumes strong ethanol and sugar demand in world markets, average sugarcane yield, 25% blending rate, and base year fuel tax rates, 2) The figures reported in columns (b)-(k) are percentage changes with respect the base case (column a).

FIGURE 1. WORD SUGAR SUPPLY AND CONSUMPTION IN 1979-2012
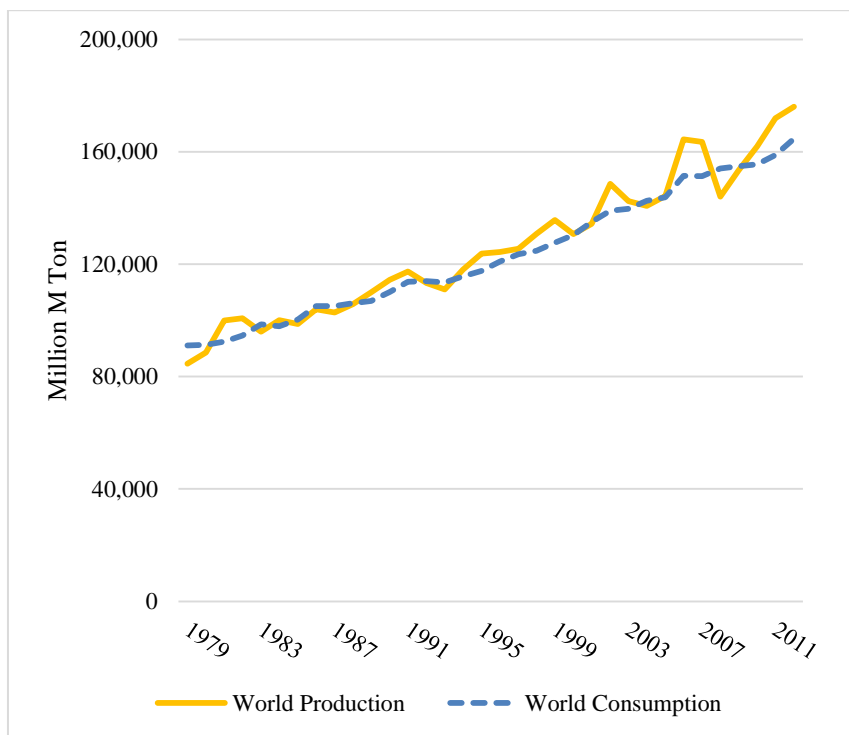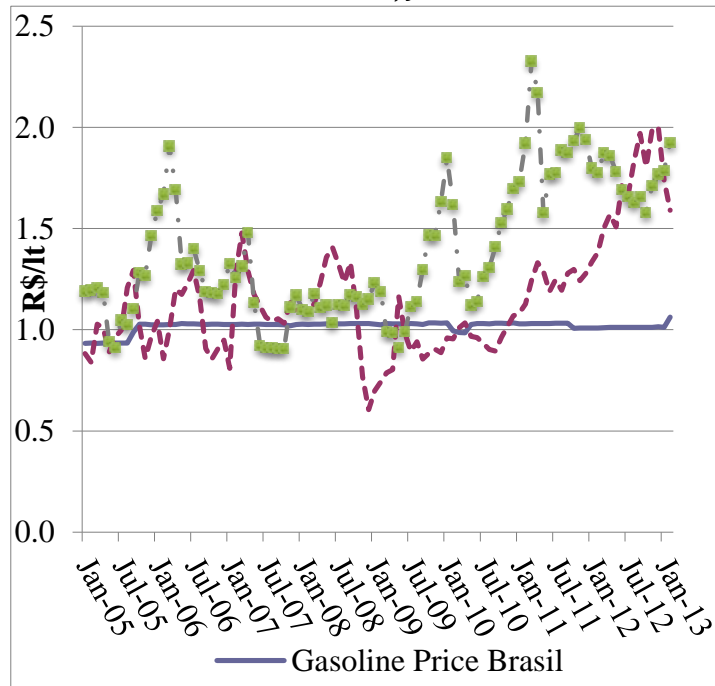

Fuente de las figuras: USDA-FAS (2013)

FIGURE 2. BRAZIL AND US ETHANOL EXPORTS BY DESTINATION
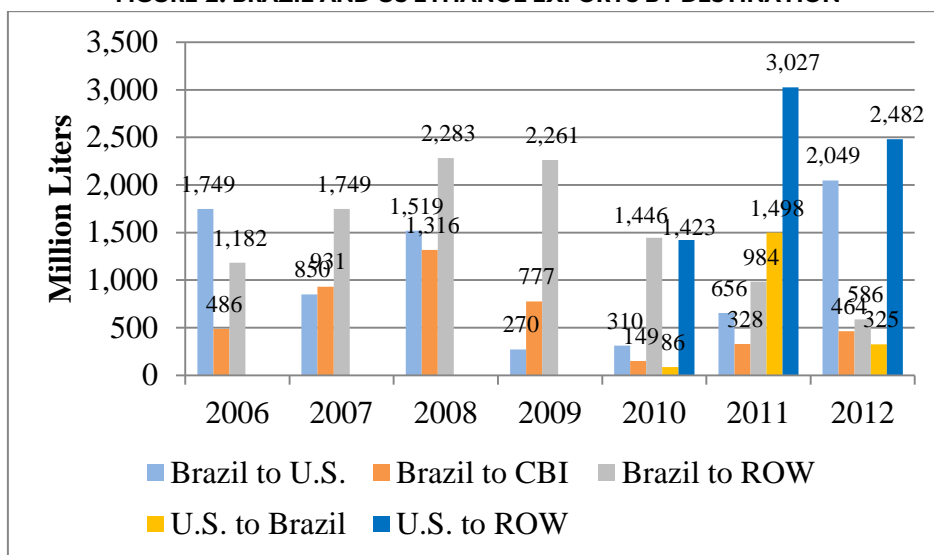
Source: EIA (2013) and UNICA (2013)

FIGURE 3. BRAZILIAN AND INTERNATIONAL WHOLESALE GASOLINE PRICES AND BRAZILIAN HYDROUS ETHANOL PRICE*, JAN 2005 TO FEB 2013
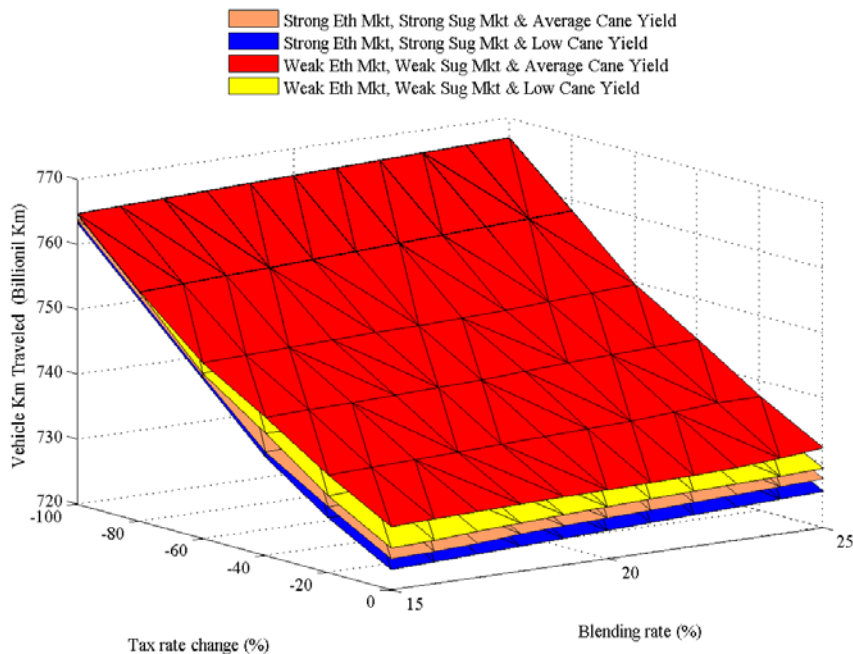

Source: EIA (2013), ANP (2013) and CEPEA/ESALQ/USP (2013). International prices were transformed from US Dollars to Brazilian Reais (R$). *Hydrous price is expressed in gasoline energy equivalents.

FIGURE 4. WORLD FUEL ETHANOL PRODUCTION IN 1975-2012
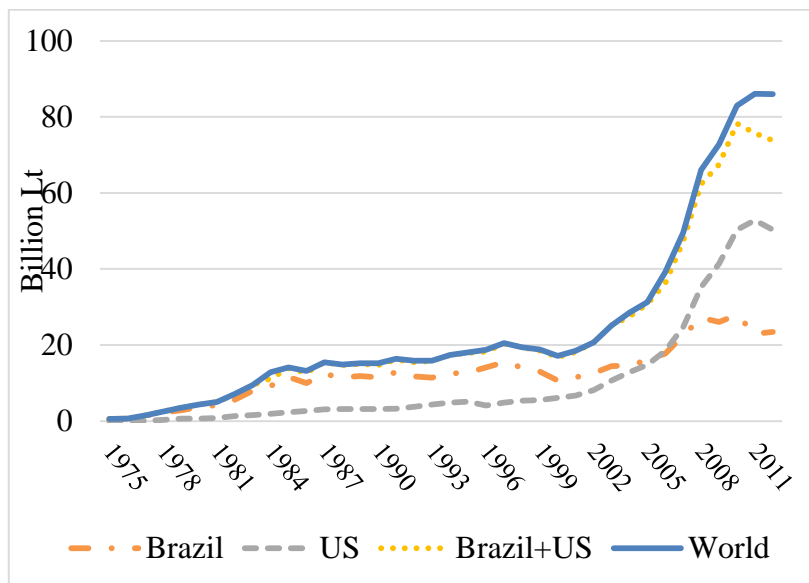
Source: EPE (2012), Earth Policy Institute (2012) and RFA (2012)

FIGURE 5. TOTAL VEHICLE KILOMETERS TRAVELED (SIMULATED, 2022)

FIGURE 6. GASOLINE CONSUMPTION BY FLEX FUEL VEHICLES (SIMULATED, 2022)
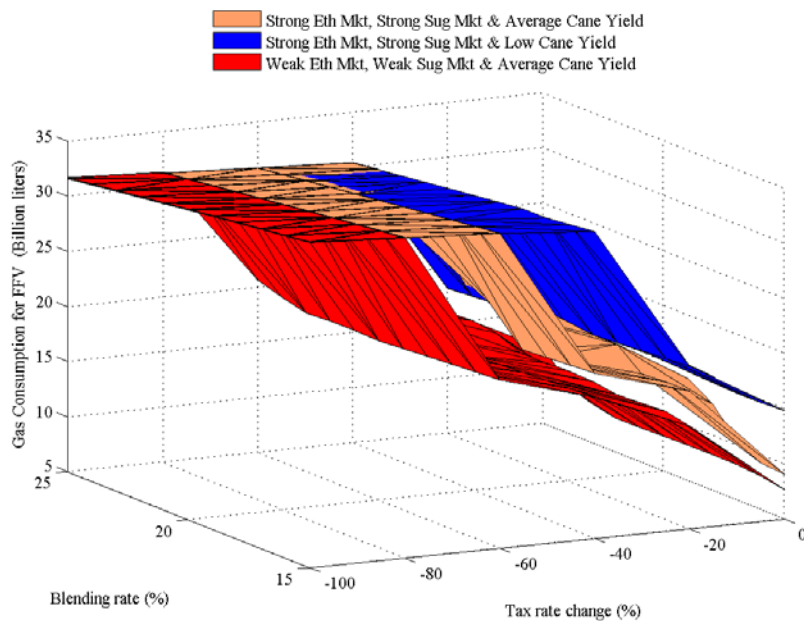
Note: For convenience of interpretation, the scenario under weak ethanol and sugar world demand and low cane yield is not shown in this figure. The corresponding sheet is crossing between the red and copper sheets.
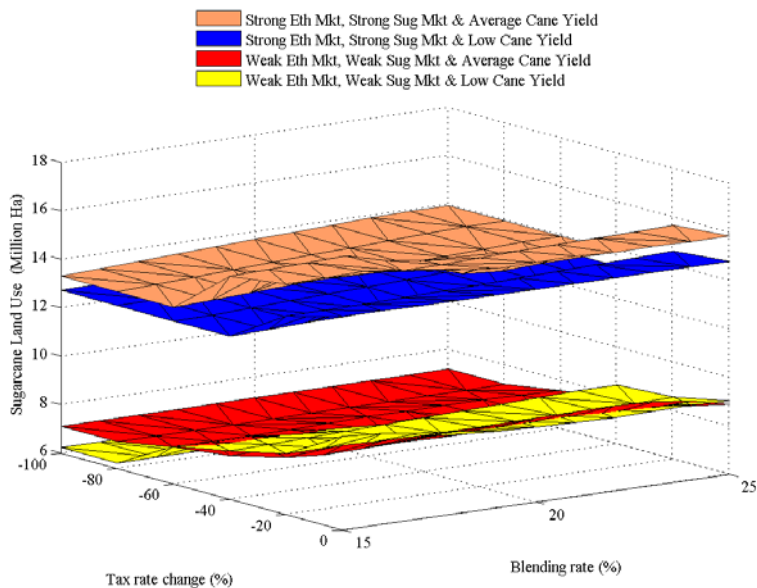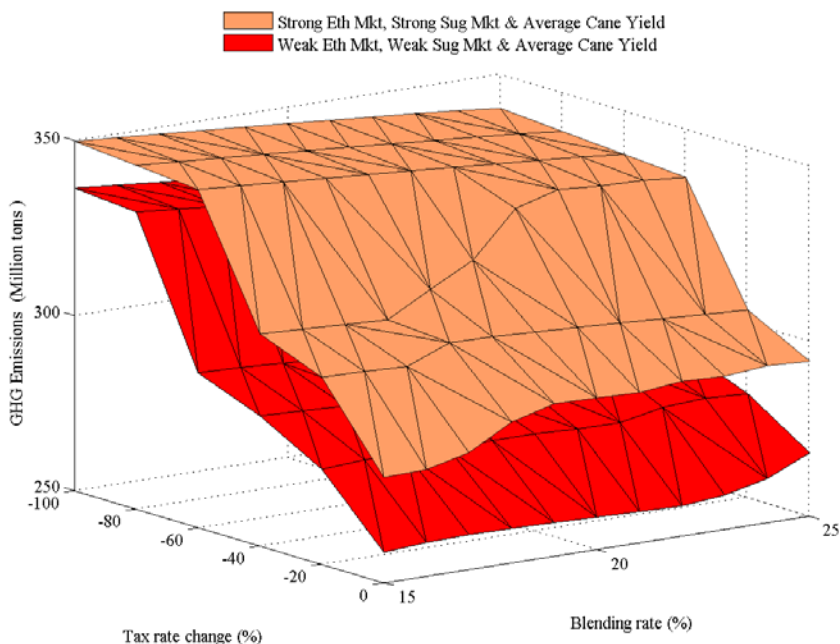
FIGURE 7. E100 PRICE (SIMULATED, 2022)
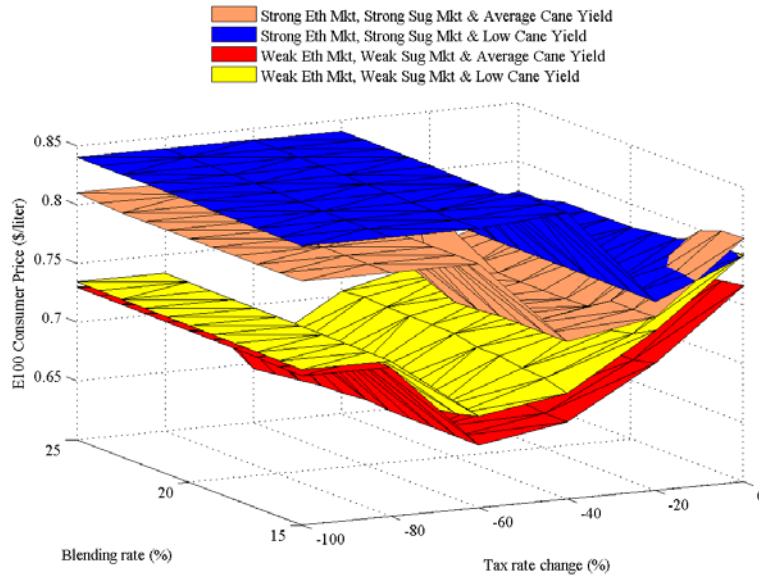
FIGURE 8. ETHANOL EXPORTS FROM BRAZIL (SIMULATED, 2022)
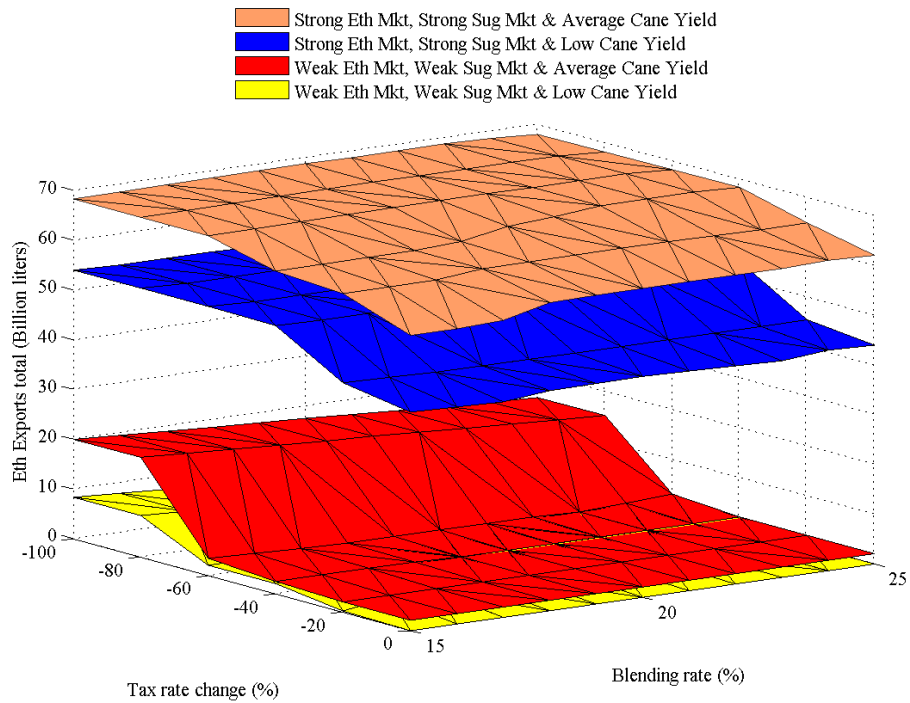
**FIGURE 9. SUGARCANE AREA (SIMULATED, 2022)**

**FIGURE10. DIRECT LIFECYCLE GHG EMISSIONS (CO2E) IN BRAZIL (SIMULATED, 2022)**

Note: For convenience of interpretation, the scenarios under low cane yield are not shown in this figure. The corresponding sheet for the strong sugar and ethanol world demand are similar to the copper sheet while that for weak sugar and world demand almost overlaps the red sheet.

FIGURE11. ETHANOL PRODUCERS´ECONOMIC SURPLUS (SIMULATED, 2022)
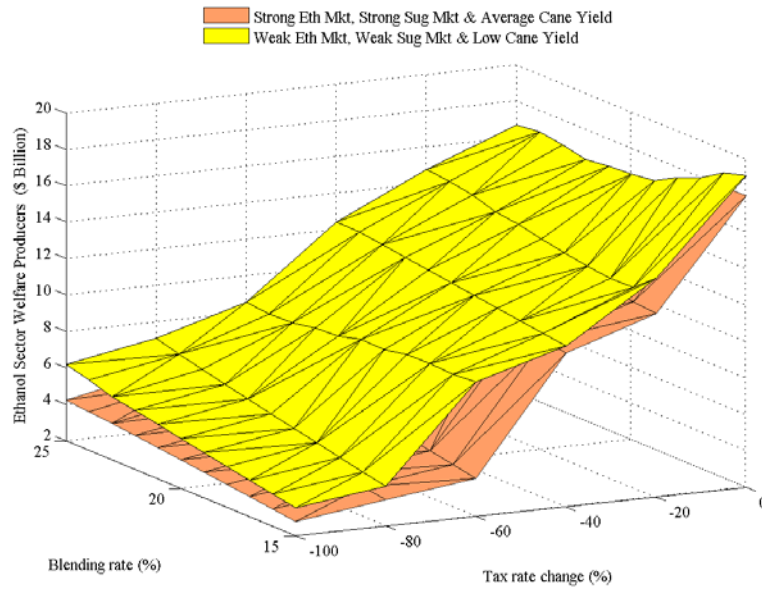
Note: For convenience of interpretation, the scenarios under weak sugar and ethanol world demand and low cane yield and strong sugar and ethanol world and average cane yield are not shown in this figure. The corresponding sheets are very similar to the yellow and copper sheets, respectively.

FIGURE12. GOVERNMENT FUEL TAX REVENUE (SIMULATED, 2022)
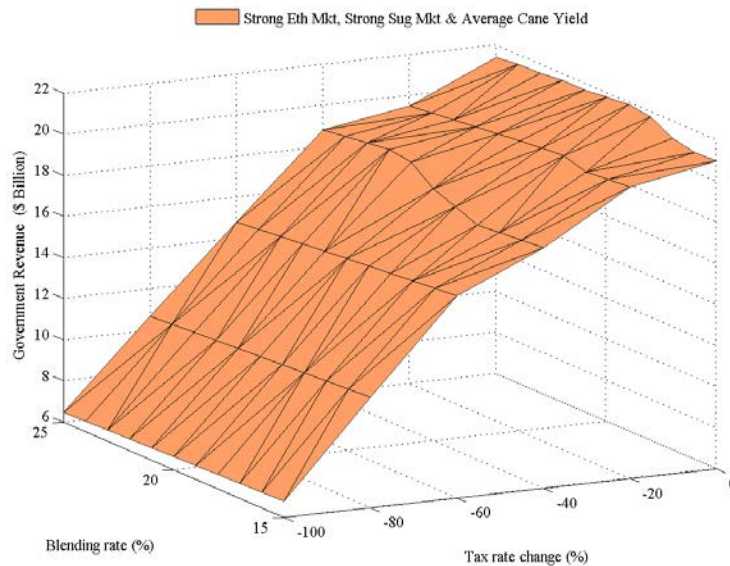
Note: For convenience of interpretation, the rest of scenarios are not shown in this figure. The corresponding sheets are very similar to the copper sheet.

Conclusions

This paper highlights how sensitive the fuel policy instruments in Brazil can be. The model results show that under a lower blending rate conventional light duty vehicles would be driven significantly less, while flex-fuel and ethanol-dedicated vehicles would be affected at an insignificant rate. However, when the reduced supply of sugarcane for ethanol and reduced ethanol blending mandates are incorporated together, the distance driven by both categories would be reduced significantly. On the other hand, fuels taxes appear to be very strong and effective policy instruments. Our simulation results demonstrate that lowering the fuel tax rates adversely affects the competitiveness of sugarcane ethanol against gasoline blends, and beyond a certain level it completely eliminates the possibility of substituting gasoline with ethanol because lower tax rates encourage flex-fuel car users to switch from E100 to gasohol. The two policy instruments have important economic impacts on producers' and consumers' welfare. Specifically, i) reducing the blending rate alone always reduces consumers' economic surplus while increasing producers' surplus, ii) a reduction in fuel taxes is always beneficial for consumers, but it lowers producers' surplus. The net effect of a combined policy with lower taxes and lower blending rates depends on the individual effects of each policy. Our model results provide estimates of those effects for a full spectrum of changes in these two policy instruments (Figures 5-12). While being advantageous in terms of social welfare the reduced tax policy has dramatic environmental impacts in terms of GHG emissions from transportation fuels consumed in Brazil. Our empirical results show that the increases in GHG emissions can go up as much as 19 percent.

Based on these results, we conclude that the reduction in ethanol blending rate during 2010-2012 harmed the light-duty vehicle users (because of consuming a more gasoline-intensive fuel that became more expensive because of the higher tax on gasoline relative to ethanol), but some of that may have been compensated by the tax rate reduction. However, this policy definitely has caused some environmental damage because of the increased GHG emissions from fuel consumption. Our model results also suggest that significant economic surplus losses may occur under a negative ethanol supply shock (low feedstock yields, as observed in 2010/12). Although the distribution of welfare losses between consumers and producers would vary depending on the tax rate and blend rate adjustments in response to such supply shocks, as a whole society incurs a considerable loss, which may be as much as 3-5 percent. Easing the fuel taxes can improve the aggregate social welfare (measured as the sum of producers' and consumers' economic surplus) because of the positive impact on fuel consumers which may outweigh the losses accruing to agricultural producers and the ethanol industry. The downside of lower fuel tax rates is the potential increase in GHG emissions from transportation fuels making a very costly trade-off for society.

These results clearly demonstrate (and quantify) how important fuel taxes are in terms of the adoption of renewable fuels even in a country like Brazil endowed with vast amount of natural resources (land in particular) and a relatively mature and efficient biofuel industry. While adjustments in the fuel tax rates and ethanol blending rate can be useful policy instruments to deal with serious ethanol supply shortages in the short term, introducing policy measures to improve agricultural productivity (e.g., shorter sugarcane replanting cycle, adoption of higher yield cane varieties, livestock intensification, etc.) and achieve a resource allocation scheme that is consistent with renewable fuel policy objectives can be more desirable in the long term. Another policy option may be expanding the storage capacity of both sugar and ethanol to deal with short run volatilities in the world markets. The perennial nature of sugarcane does not allow producers to match short term fluctuations in the sugar and ethanol markets, but reasonably large buffer stocks would be effective means to meet the global demands with little disturbance in the domestic markets. This would be beneficial for both domestic producers and consumers and for the global environment. The purpose of this study is not to prescribe a single best solution. Rather, the solutions would vary depending on the socioeconomic objective(s) of the public policy makers. The empirical results of the model used here can provide useful guidance if the demand and supply conditions in the sugarcane product markets can be predicted with reasonable certainty.

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