



Center for Agricultural and  
Rural Development (CARD)

October 2006

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## Removal of U.S. Ethanol Domestic and Trade Distortions: Impact on U.S. and Brazilian Ethanol Markets

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**Working Paper 06-WP 427**  
October 2006 (Revised)

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*Amani Elobeid and Simla Tokgoz are associate scientists at the Food and Agricultural Policy Research Institute (FAPRI), Center for Agricultural and Rural Development (CARD), Iowa State University. Without implicating them, we thank John Beghin, Chad Hart, and Frank Fuller for discussion, information, and comments.*

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## **Abstract**

We analyze the impact of trade liberalization and removal of the federal tax credit in the United States on U.S. and Brazilian ethanol markets using a multi-market international ethanol model calibrated on 2005 market data and policies. The removal of trade distortions induces a 23.9 percent increase in the price of world ethanol on average between 2006 and 2015 relative to the baseline. The U.S. domestic ethanol price decreases by 13.6 percent, which results in a 7.2 percent decline in production and a 3.6 percent increase in consumption. The lower domestic price leads to a 3.7 percent rise in the share of fuel ethanol in gasoline consumption. U.S. net ethanol imports increase by 199 percent. Brazil responds to the higher world ethanol price by increasing its production by 9.1 percent on average. Total ethanol consumption in Brazil decreases by 3.3 percent and net exports increase by 64 percent relative to the baseline. The higher ethanol price leads to a 4.9 percent increase in the share of sugarcane used in ethanol production. The removal of trade distortions and 51¢ per gallon tax credit to refiners blending ethanol induces a 16.5 percent increase in the world ethanol price.

**Keywords:** biofuels, ethanol, renewable fuels, trade liberalization.

**JEL code:** F13, F17, Q17, Q18, Q42

## **Introduction**

In the past few years, interest in biofuels has greatly increased, which can be attributed to environmental, economic, and geo-political factors. Harmful emissions, high crude oil prices, and the growing dependency on foreign oil supplies all have provided incentives for pursuing alternative fuel sources, such as ethanol and biodiesel. Furthermore, the rising importance of biofuels can also be attributed to the desire by countries to develop new markets for agricultural products. This push is currently policy driven, for example, in the United States through the U.S. Energy Bill of 2005 and in the European Union (EU) through the Renewable Fuels Directive of 2003. Even Brazil, an established producer and consumer of ethanol, used mandates to encourage the use of ethanol when it launched its ethanol program, the National Alcohol Programme (PROALCOOL), in the mid-1970s.

Ethanol is the most visible of the biofuels that is benefiting from this recent surge in interest. It can be produced from a variety of feedstocks such as cereals, sugarcane, and cellulosic material. In general, renewable fuels are more expensive to produce than fossil-based fuels, and so both production and consumption have been encouraged for the most part with government policy intervention through mandates and/or market incentives.

Many countries are taking an increased interest in ethanol as an alternative fuel, with the U.S. and Brazil currently leading the way. Ethanol production and consumption in both countries have been increasing rapidly in recent years. In 2005, Brazil produced 4.8 billion gallons of ethanol and the U.S. produced 3.9 billion gallons, making these countries the two largest producers in the world, accounting for over 90 percent of the total world production.

The recent rise in demand for ethanol in the U.S. has been fueled by higher crude oil prices, the Energy Bill of 2005, which introduced a Renewable Fuel Standard (RFS), and the

replacement of MTBE (methyl tertiary butyl ether) with ethanol as an additive in refining. The volatility of the domestic prices and the occasional spikes in price caused by this recent hike in demand have led to discussions of eliminating the tariff on ethanol imports to the U.S. In this context, this study has two objectives. The first is to set up an international ethanol model and to create a baseline. The second is to analyze the impact of the removal of trade and domestic distortions in the U.S. on the world ethanol market.

There are a limited number of studies on ethanol markets, as the industry has experienced a boom only in recent years. Gallagher et al. (2006) look at the competitive position of Brazilian ethanol produced from sugar processing vis-à-vis the U.S. ethanol produced from corn under the assumption of no tariffs in the ethanol market. The results suggest that there are no trends, but there are cyclical periods of advantage for both industries. Koizumi and Yanagishima (2005) establish an international ethanol model and examine the implications of a change in the compulsory ethanol-gasoline blend ratio in Brazil on world ethanol and sugar markets. Their simulation suggests moderate impacts on world ethanol and sugar markets. Gallagher, Otto, and Dikeman (2000) analyze the impact of introducing a minimum oxygen content for fuel in Midwestern states. The study finds that ethanol can compete with MTBE in the oxygenate market with the aid of federal tax incentives for ethanol blending. The loss in federal tax revenues is offset by the benefits gained by consumers, producers, and local economies.

This study offers a number of contributions to the literature on ethanol markets. The first contribution is that, in addition to examining the impact of trade liberalization in the U.S. on international ethanol markets, we also endogenize the prices of crops used in ethanol production, i.e., sugar and corn, which previous studies have tended to hold constant (Gallagher et al., 2006; Koizumi and Yanagishima, 2005). To achieve this, the international ethanol model is linked to

an international sugar model and a U.S. crops model. Given that the ethanol market is an emerging one with evolving policies being implemented by a number of countries, this study provides analysis using recent policy settings and provides insight into how these policies will affect the future of ethanol markets. An original approach in this study is the explicit modeling of the linkage between the agricultural commodity markets and the energy markets. Furthermore, we address the issue of ethanol acting as both a substitute and a complement to gasoline and how that affects the direction of the impact from the policy change. Since data on ethanol is currently very limited and sparse, this study further contributes to the existing literature by utilizing a multitude of data from different sources, which have been extensively scrutinized to provide the most cohesive data for analysis.

In the following paragraphs, we describe the U.S. and Brazilian ethanol markets and provide a brief discussion on the relative competitiveness between the two countries' ethanol sectors. Then, we briefly explain the structure of the international ethanol model used for the simulations as well as the country-specific models for the U.S. and Brazil. After having introduced the policy reform scenario, we present the key results of our simulations.

The study finds that the removal of trade distortions induces an increase in the world price of ethanol and a decrease in the U.S. domestic ethanol price, which results in a decline in U.S. ethanol production and an increase in consumption. Consequently, U.S. net ethanol imports increase significantly. The higher world ethanol price results in an increase in Brazilian ethanol production and a decrease in total ethanol consumption, causing net exports to increase relative to the baseline. In the second scenario, the removal of trade distortions and the 51¢-per-gallon tax credit to refiners blending ethanol induces a lower increase in the world ethanol price relative to the first scenario.

## **Overview of U.S. and Brazilian Ethanol Markets**

### ***The U.S. Ethanol Market***

In the U.S., ethanol is produced primarily from corn, and the industry consists of both wet and dry mills. Wet mills produce ethanol and the by-products corn gluten meal, corn gluten feed, corn oil, and CO<sub>2</sub>. Dry mills, which are the predominant mill-type, produce ethanol with dried distillers grains (DDG) and solubles and CO<sub>2</sub> as by-products (Coltrain, 2001; Tiffany, 2002). The recent boost in ethanol demand is largely the result of several states banning the use of a gasoline additive called MTBE, as it is suspected of contaminating drinking water. Another boost to ethanol demand comes from the U.S. Energy Bill of 2005 in general and RFS in particular. The recent increase in crude oil and gasoline prices has also opened a new market for ethanol as a fuel extender (Eidman, 2006).

There are numerous state and federal legislations that affect the U.S. ethanol market. One of the earliest is the Energy Tax Act of 1978, which introduced the motor fuel excise tax exemption that gives ethanol blends of at least 10 percent by volume a 40¢ per gallon exemption on the federal motor fuels tax. Since then, various tax laws have been adopted to change the level of tax credit, which currently stands at 51¢ per gallon through 2010. The Energy Policy Act of 1992 extended the fuel tax exemption to two additional blend rates containing less than 10 percent ethanol; i.e., 5.7 percent and 7.7 percent. It also created a number of alternative-fueled vehicle requirements for government and state motor fleets to encourage biofuel use. The Clean Air Act Amendments of 1990 established the Oxygenated Fuels Program and the Reformulated Gasoline Program, which in turn increased ethanol demand as an additive. The Energy Policy Act of 2005 introduced RFS, which requires U.S. fuel production to include a minimum amount of renewable fuel each year, starting at 4 billion gallons in 2006 and reaching 7.5 billion gallons

in 2012. After 2012, renewable fuel production must grow by at least the same rate as gasoline production. The Energy Policy Act also eliminated the oxygenate requirement for reformulated gasoline (Duffield and Collins, 2006; Yacobucci, 2006a).

The U.S. trade policy on ethanol includes an ad valorem tariff of 2.5 percent as well as an import duty of 54¢ per gallon. One of the objectives of the tariff is to ensure that the benefits of the domestic U.S. ethanol tax credit do not accrue to foreign producers. The other important trade policy that affects ethanol imports is the Caribbean Basin Economic Recovery Act (CBERA) that groups Central American countries with Caribbean countries. This Act created the current import rules for ethanol under the Caribbean Basin Initiative (CBI). Under this agreement, if ethanol is produced from at least 50 percent agricultural feedstock grown in a CBERA country, it is admitted into the U.S. free of duty. If the local feedstock content is lower, limitations apply on the quantity of duty-free ethanol. The amount of ethanol that can be imported duty-free that is produced from non-CBERA agricultural feedstock is restricted to 60 million gallons or 7 percent of the U.S. domestic ethanol market, whichever is greater. To comply with this requirement, hydrous ethanol is imported to a CBI country and is dehydrated before it can be exported to the U.S. Dehydration plants are currently operating in CBI countries like Jamaica, Costa Rica, and El Salvador, where hydrous ethanol produced in other countries, historically Brazil and Europe, can be dehydrated before it is exported to the U.S. (Yacobucci, 2006b).

In 2005, U.S. ethanol production capacity was 4.3 billion gallons from 95 ethanol refineries. Capacity expansion totaled 0.2 billion gallons, while capacity under construction was 1.8 billion gallons. Ethanol production consumed 1.4 billion bushels of corn (about 12.6 percent of U.S. corn production) in 2005; 3.3 billion bushels of corn are expected to be utilized by 2015

(about 24.9 percent of a 13 billion bushel crop). Thus, ethanol production has already exceeded the 2006 target of the renewable fuels mandate. Despite the rapid increase in production, consumption of ethanol has been outpacing production for the past few years, which has led to increased imports into the U.S.

### ***The Brazilian Ethanol Market***

Brazil is currently the world's largest producer of ethanol, deriving its supply from sugarcane. Brazil is one of the first countries to promote ethanol widely through its National Alcohol Program, which was launched in late 1975 in response to high oil prices and declining sugar prices (Bolling and Suarez, 2001). The program was intended to reduce Brazil's dependence on foreign oil and to find alternative markets for Brazilian sugar. The government promoted the production of ethanol by offering credit guarantees and low-interest loans for construction of new plants and by setting ethanol prices at favorable levels relative to gasoline. This resulted in a dramatic increase in ethanol production by the end of the 1970s. The ethanol sector was further boosted by the introduction of ethanol cars that ran on hydrous ethanol in 1979. The government also imposed mandates on blending ratios of ethanol with gasoline and provided incentives to citizens to drive ethanol cars.

The Brazilian ethanol program flourished during the early 1980s. By the mid-1980s, however, world oil prices fell and Brazil faced severe economic difficulties. Support for the ethanol program was drastically cut and ethanol production began to decline. By the late 1980s, sugar prices began to recover and sugar became more profitable. As a result of the decline in ethanol production, along with the significant number of ethanol cars in use, Brazil experienced a serious shortage of ethanol in 1990 and the country was compelled to import ethanol to meet demand. Consumers lost confidence in ethanol and the sale of ethanol cars declined significantly.

The setting of ethanol prices was eliminated and the industry was deregulated by 1999 (Brilhante, 1997; Moreira and Goldemberg, 1999).

The Brazilian government currently provides support to ethanol production through both market regulations and tax incentives. In terms of market regulations, a blending ratio of anhydrous ethanol with gasoline of between 20 and 25 percent in transport fuel is imposed. There are also credit provisions for ethanol storage, in the form of a lower excise tax for ethanol than for gasoline and through the use of strategic reserves. Imports of ethanol to Brazil are subject to an ad valorem duty of 20 percent. Ethanol in Brazil is produced from low-cost sugarcane and therefore can compete with gasoline on a production-cost basis without any subsidies.

Recently, increased demand for ethanol in Brazil has been driven by the popularity of flex-fuel cars that can run on gasoline, ethanol, or a combination of the two. Flex-fuel vehicles and ethanol vehicles, which run only on hydrous ethanol, both enjoy some tax incentives not offered to gasohol cars that run only on gasoline blended with ethanol at the mandate set by legislation. The sale of flex-fuel cars has increased dramatically (by 585 percent in 2004) since their introduction in 2003. The share of flex-fuel cars in total vehicle sales reached 22 percent in 2004, 40 percent in 2005, and is expected to rise to 60 percent in 2006. Flex-fuel vehicles are expected to be the predominant vehicle type in Brazil while ethanol vehicles are expected to diminish to insignificant numbers within the next decade (F.O. Lichts, 2006b).

In Brazil, a large number of plants are dual plants producing both sugar and ethanol, and they can switch easily between the production of sugar and ethanol based on relative prices.<sup>1</sup> Thus, sugar and ethanol prices have tended to move closely together, whereas in the U.S.,

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<sup>1</sup> The switch between ethanol and sugar in these dual plants is restricted to a maximum of 60 percent in either direction.

movement in ethanol prices is affected primarily by the gasoline market and by government regulations. In the past few years, the relative price of sugar and ethanol has favored more sugarcane diverted to ethanol production rather than to sugar production. With the increased demand in ethanol both domestically and internationally, the share of sugarcane used in ethanol production is expected to rise steadily.

In 2005, production of sugar and ethanol in Brazil totaled 28.2 million metric tons and 4.8 billion gallons, respectively, continuing a record trend for the past few years. The record production has resulted in the export of 18 million metric tons of sugar and 0.6 billion gallons of ethanol in 2005. Ethanol production is expected to increase by 48.5 percent while ethanol exports are expected to nearly double by 2015. If both sugar and ethanol prices remain competitive in the near future, Brazil is expected to continue to increase sugarcane production for both sugar and ethanol. The country has enough land to significantly increase sugarcane area harvested.

### ***Competitiveness of U.S. versus Brazilian Ethanol Sectors***

The cost of ethanol per gallon of fuel from sugarcane in Brazil, at 83¢ per gallon of fuel, is lower than the cost from corn in the U.S., at \$1.09 per gallon (von Lampe, 2006). In addition to the higher cost of production, there are additional costs in the U.S. associated with transporting ethanol from the production locations in the Midwest to major population areas, particularly in the coastal regions. This has led to an increase in the competitiveness of Brazilian ethanol imports despite steep tariffs in the U.S. Furthermore, volatility in U.S. domestic ethanol prices, which sometimes leads to spikes, provides Brazil with the opportunity to export ethanol to the U.S. For example, in October 2005 the Brazilian anhydrous ethanol price was \$1.38 per gallon. Adding freight and the import tariff, the price for ethanol would reach \$2.07 per gallon (including the 11¢-per-gallon transportation cost), which was below the \$2.47-per-gallon U.S.

domestic price for the same month. Consequently, Brazil was able to export 5.2 million gallons to the U.S. in October, up from zero exports in August and 2.7 million gallons in September 2005. In total, Brazil exported 86.5 million gallons of ethanol in 2004 and 65.9 million gallons in 2005, becoming the major source of U.S. ethanol imports (Renewable Fuels Association, 2006).

### **Structure of the International Ethanol Model**

The international ethanol model is a non-spatial, multi-market world model consisting of a number of countries/regions, including a Rest-of-World aggregate to close the model. The model specifies ethanol production, use, and trade between countries/regions. Country coverage consists of the United States, Brazil, European Union-15, China, Japan, and a Rest-of-World aggregate. The model incorporates linkages to the agriculture and energy markets, namely U.S. crops, world sugar, and gasoline markets.

The general structure of the country model is made up of behavioral equations for production, consumption, ending stocks, and net trade.<sup>2</sup> The model solves for a representative world ethanol price (Brazilian anhydrous ethanol price) by equating excess supply and excess demand across countries. Using price transmission equations, the domestic price of ethanol for each country is linked with the representative world price through exchange rates and other price policy wedges. All prices in the model are expressed in real terms. Through linkages to the U.S. crops and world sugar models, we also endogenously solve for all the U.S. crops prices including the U.S. corn farm price and its by-products (High Fructose Corn Syrup, DDG, etc.).

Furthermore, the world raw sugar price is solved endogenously by equating excess supply to

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<sup>2</sup> Complete country models are established for the U.S., Brazil, and the EU-15, while only net trade equations are set up for China, Japan, and the Rest-of-World because of limited data availability.

excess demand in the world sugar market. It is important to note that since this is a new area of investigation, the limited data availability dictates the modeling approach.

### ***U.S. Ethanol Model***

#### *Ethanol Demand*

Total U.S. ethanol demand is divided into fuel ethanol demand and a residual demand that consists of non-fuel alcohol use (industrial and beverage). Fuel ethanol demand is a derived demand from the cost function for refiners blending gasoline with additives, including ethanol. Given that only aggregate data is available on U.S. motor gasoline consumption, we are constrained to model an aggregate composite gasoline production representing all types of gasoline available on the U.S. market. Let  $C$  denote the cost function for the refiners supplying all types of gasoline blended with additives, including gasoline blended with ethanol. The cost function is written as  $C = C(P_E^{US}, P_O^{US}, Policy, Q_{GS}^{US})$ , where  $Q_{GS}^{US}$  is the refiners' output, which is the gasoline supply,  $P_E^{US}$  is the domestic price of ethanol,  $P_O^{US}$  is the U.S. price of crude oil, and  $Policy$  is federal and state legislations that affect refiners' ethanol demand.<sup>3</sup> Under a constant-returns-to-scale assumption, the cost function can be written as  $C = \tilde{C}(P_E^{US}, P_O^{US}, Policy) \cdot Q_{GS}^{US}$ . The marginal cost ( $MC_G$ ) of gasoline is constant as long as input prices are constant. Gasoline output  $Q_{GS}^{US}$  is eventually determined by the intersection of gasoline demand and the marginal cost of gasoline ( $MC_G$ ) at the equilibrium in the gasoline market. By Shephard's lemma, the intermediate demand for fuel ethanol,  $(\partial C / \partial P_E^{US})$ , is derived as

$$E_F^{US} = \frac{\partial C}{\partial P_E^{US}} = Q_{GS}^{US} \cdot \left( \frac{\partial \tilde{C}}{\partial P_E^{US}} \right), \quad (1)$$

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<sup>3</sup> We abstract from the time dimension when this detail is not necessary.

where  $E_F^{US}$  is the fuel ethanol demand in million gallons and  $\partial\tilde{C}/\partial P_E^{US}$  is the derived demand for ethanol per unit of gasoline. Accounting for the specific policy interventions affecting refiners, we obtain the following equation:

$$\frac{\partial\tilde{C}}{\partial P_E^{US}} = f(P_E^{US} - TR^{US}, P_o^{US}, Mandate, RFS), \quad (2)$$

where  $TR^{US}$  stands for the tax rebate of 51¢ per gallon that refiners get when they blend 10 percent ethanol with gasoline,  $Mandate$  is the requirement of ethanol blend in percentage in certain states, and  $RFS$  denotes the Renewable Fuels Standard created by the Energy Bill of 2005 in million gallons.

$Q_{GD}^{US}$  denotes the Marshallian demand for gasoline in the U.S. market, that is, the amount of gasoline consumption used in transportation in million gallons. It is expressed as

$$Q_{GD}^{US} = g(P_G^{US}, P_E^{US} - TR^{US}, GDP^{US}, Pop^{US}), \quad (3)$$

where  $P_G^{US}$  is the price of unleaded gasoline in dollars per gallon and is a function of  $P_o^{US}$ .  $P_G^{US}$  is included in equation (3), as final consumers see the unleaded gasoline price.<sup>4</sup>  $GDP^{US}$  is real gross domestic product (GDP) in 1995 U.S. dollars, and  $Pop^{US}$  is population. Consumers respond positively to a decrease in the price of the composite fuel, which is a function of the prices of gasoline and ethanol. The ethanol component of the composite aggregate fuel consumption increases as the ethanol price falls relative to the price of gasoline to capture the substitution between the types of gasoline at the gas station pump.

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<sup>4</sup> Although there exist several types of gasoline available to consumers, we use the price of unleaded gasoline as a proxy for a composite gasoline price since all types of gasoline prices are highly correlated.

In equilibrium in the gasoline market, quantity of gasoline supplied by refiners is equal to the quantity of gasoline demanded by final consumers ( $Q_{GD}^{US}$ ), i.e.,  $Q_{GS}^{US} = Q_{GD}^{US} = Q_G^{US}$ . Substituting equations (2) and (3) into equation (1) yields the derived demand of ethanol evaluated at the equilibrium of the gasoline market,  $E_{F^*}^{US}$ :

$$E_{F^*}^{US} = \frac{\partial C}{\partial P_E^{US}} = f(P_E^{US} - TR^{US}, P_o^{US}, Mandate, RFS) \cdot g(P_G^{US}, P_E^{US} - TR^{US}, GDP^{US}, Pop^{US}) \quad (4)$$

At the equilibrium of the gasoline market,  $\partial \tilde{C} / \partial P_E^{US}$  can be interpreted as the share of fuel ethanol in total gasoline consumption ( $E_{F^*}^{US} / Q_{GD}^{US}$ ).

In U.S. gasoline production, fuel ethanol is mainly used as an additive to gasoline.<sup>5</sup> In this regard, ethanol acts as a complementary good to pure gasoline. However, in demand ethanol is a substitute to gasoline, through the introduction of E85 cars, which run on gasoline blended with up to 85 percent ethanol, and because of the recent use of ethanol as a fuel enhancer induced by high gasoline prices. In this study, through the parameterization of equation (4), it is assumed that the complementary relationship is more dominant than the substitute relationship because currently ethanol is blended only at 10 percent and is not available in all states. Furthermore, E85 cars represent a negligible portion of the U.S. vehicle fleet. Substitution effects are currently limited but may get larger in the future if E85 cars become popular. To reflect the complementarity, an increase in the price of gasoline translates into a net decrease in demand for ethanol  $E_{F^*}^{US}$ . The coefficient estimate for  $P_o^{US}$  in equation (2) is positive compared to the coefficient estimate of  $P_G^{US}$  in equation (3), which is negative. The former effect is smaller than the latter in absolute value.

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<sup>5</sup> For more detailed discussion on various additives in gasoline markets, including ethanol, see Gallagher et al., 2003.

The magnitude of the complementary and substitute relationships also depends on the assumptions made about the composition of the U.S. vehicle fleet in the future. As long as the number of flex-fuel (E85) vehicles in the U.S. remains relatively small, there is only limited substitution for regular cars in terms of substituting gasoline for ethanol. Finally, to complete the specification of total ethanol demand, the residual ethanol demand is simply set up as a function of the U.S. domestic ethanol price.

### *Ethanol Supply*

To model the domestic ethanol production in the U.S., we use a restricted profit function for the ethanol plants. Both wet and dry mill plants use mainly natural gas as an input in the process. Profit maximization under capacity constraint yields a profit function, which can be expressed as a function of the return per bushel of corn net of energy cost. To account for the different processes of ethanol production, the relative marginal revenues from the by-products from each process is weighted by the share of production by each mill type;  $s_{DM}$  is the share of dry mill production in total ethanol production, and  $s_{WM}$  is the share of wet mill production.

Thus, the net return per bushel of corn for ethanol plants in the U.S.,  $\pi^{NET}$ , is expressed as

$$\begin{aligned} \pi^{NET} = & \gamma_E \cdot P_E^{US} + (s_{WM} \cdot ((\gamma_{GF} \cdot P_{GF}^{US}) + (\gamma_{GM} \cdot P_{GM}^{US}) + (\gamma_{CO} \cdot P_{CO}^{US}))) \\ & + (s_{DM} \cdot (\gamma_{DDG} \cdot P_{DDG}^{US})) - P_C^{US} - m \cdot P_{NG}^{US}. \end{aligned} \quad (5)$$

In equation (5),  $P_{GF}^{US}$  is the price of gluten feed in dollars per ton,  $P_{GM}^{US}$  is the price of gluten meal in dollars per ton,  $P_{CO}^{US}$  is the price of corn oil in dollars per gallon,  $P_{DDG}^{US}$  is the price of DDG in dollars per ton, and  $P_C^{US}$  is the price of corn in dollars per bushel.  $P_{NG,t}^{US}$  is an index of the price of natural gas, which is multiplied by  $m=0.0038$  to scale the index to dollars per bushel

of corn. The conversion rates ( $\gamma_i$ ) are used to convert each price to dollars per bushel of corn.<sup>6</sup>

This allows us to construct the ethanol supply function ( $Y^{US}$ ) as

$$Y^{US} = h(\pi^{NET}, PC), \quad (6)$$

where  $PC$  denotes the production capacity in million gallons.<sup>7</sup> The equation for the production capacity is  $PC_t = PC_{t-1} \cdot (1 + g_t)$ , where  $g_t$  is the endogenous growth rate of this capacity and  $t$

denotes the time period. We model the growth rate as

$$g_t = \begin{cases} k(\pi_{t-1}^{NET}, E(D_E)) & \text{if } \pi_{t-1}^{NET} > 35\text{¢ per bushel} \\ 0 & \text{Otherwise} \end{cases}, \quad (7)$$

where  $E(D_E)$  is defined as the expected future demand that investors project for ethanol and 35¢ per bushel is the trigger fixed cost of building a new ethanol plant expressed per bushel of corn.

This cost estimate is obtained from industry sources. In the U.S., production capacity has been increasing at an unprecedented pace, which prompted us to set up the above capacity equation and to incorporate the expectations of investors on future profits.

### *Inventory Demand*

Next, the ending stock ( $ES_t^{US}$ ) equation is expressed as follows:

$$ES_t^{US} = m(ES_{t-1}^{US}, P_{E,t}^{US}) \quad (8)$$

where the coefficient estimate for  $P_{E,t}^{US}$  is negative.

### *Ethanol Trade*

The trade equations consist of export and import equations. Because U.S. ethanol exports

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<sup>6</sup> The conversion rates for each by-product are tons per bushel, whereas the conversion rate for ethanol is gallons per bushel. One bushel of corn creates 2.8 gallons of ethanol, 0.0057 ton of gluten feed, 0.0015 ton of gluten meal and 0.0008 ton of corn oil through the wet mill process, or it generates 2.8 gallons of ethanol and 0.0087 ton of DDG through the dry mill process on average.

<sup>7</sup> The exit decisions by firms are not modeled.

are small, they are kept constant. U.S. ethanol imports are the sum of imports from CBI countries ( $M_{CBI}$ ) and imports from other countries ( $M_{Other}$ ).<sup>8</sup> For the CBI countries, there is a tariff rate quota (TRQ) rule. The in-quota tariff rate is  $\tau^i$ , which is zero. The out-of-quota tariff rate is  $\tau^o$ , which is 2.5 percent plus 54¢ per gallon. The TRQ is set at 60 million gallons or 7 percent of U.S. consumption, whichever is greater. We set up the CBI import equation based on the relative world ethanol price to the domestic U.S. price as follows:

$$M_{CBI} = \begin{cases} Capacity & \text{if } P_E^{US} > \theta \cdot (P_E^W \cdot (1 + \tau^A) + tc) \\ \alpha + \beta \cdot \left( \frac{P_E^{US}}{P_E^W \cdot (1 + \tau^A) + tc} \right) & \text{if } P_E^{US} > \phi \cdot (P_E^W \cdot (1 + \tau^A) + tc) \\ M_{CBI} = 0 & \text{Otherwise} \end{cases} \quad (9)$$

where *Capacity* is the CBI countries' maximum capacity of their dehydration plants, and *tc* is the transportation cost.  $\theta$  and  $\phi$  are transmission coefficients that are both less than one, and  $\phi < \theta$ . They are included to account for the transaction costs between firms, the time lag between contracts and delivery, and the daily volatility in ethanol prices, which are not captured in the annual price data. Transportation cost (*tc*) is 11¢ per gallon.<sup>9</sup> For CBI, *tc* also includes the transformation (dehydration) costs. In the above equations,  $\tau^A = \tau^i$  if  $M_{CBI} \leq TRQ$ , and  $\tau^A = \tau^o$  if  $M_{CBI} > TRQ$ .

Imports from other countries are subject to the out-of-quota tariff rate of 2.5 percent plus 54¢ per gallon. The import equations for other countries are as follows:

<sup>8</sup> The CBI countries in this study include only Costa Rica, El Salvador, and Jamaica. U.S. imports anhydrous ethanol from CBI countries, as these countries import hydrous ethanol and dehydrate it prior to exporting because of CBERA requirements.

<sup>9</sup> The transportation cost estimate is calculated based on industry sources and various market reports (EIA, 2004; F.O. Lichts, 2006a; USDA AMS, 2006).

$$M_{Other} = \begin{cases} 0 & \text{if } P_E^{US} < \phi \cdot (P_E^W \cdot (I + \tau^o) + tc) \\ (Demand - Supply) & \text{Otherwise} \end{cases}, \quad (10)$$

where supply is the sum of production, beginning stocks, and imports from CBI countries, and demand is the sum of consumption, ending stocks, and exports.

Through equations (9) and (10), we see that when the tariff is not prohibitive, import demand is positive, making the domestic U.S. price dictated by the world ethanol price through a price transmission equation. When the tariff is prohibitive and there are no imports from other countries, the domestic U.S. price is solved endogenously within the model, equating excess supply to excess demand. Hence, to account for this, we construct a price switching regime. The domestic price of ethanol can be solved endogenously ( $P_E^{Endogenous}$ ) or it can be a price transmission from the world price of ethanol. If  $P_E^{Endogenous} > P_E^W \cdot (I + \tau^o) + tc$ , then the domestic ethanol price equals  $P_E^W \cdot (I + \tau^o) + tc$ . If  $P_E^{Endogenous} < P_E^W \cdot (I + \tau^o) + tc$ , then the domestic ethanol price is  $P_E^{Endogenous}$ .

### ***Brazil Ethanol Model***

#### *Ethanol Demand*

In Brazil, the ethanol demand is divided into anhydrous and hydrous ethanol demand, as they respond to different economic incentives depending on the three types of vehicles (alcohol, flex-fuel, and gasohol cars). The alcohol vehicles use only hydrous ethanol, the gasohol vehicles use only anhydrous ethanol, while the flex-fuel vehicles can use both hydrous ethanol and anhydrous ethanol (blended in gasoline). Therefore, we model anhydrous ethanol demand ( $E_A^B$ ) and hydrous ethanol demand separately ( $E_H^B$ ), where total ethanol demand in Brazil  $E_{Total}^B$  equals  $(E_H^B + E_A^B)$ .

The behavioral equations for anhydrous and hydrous ethanol consumption are given as follows:

$$E_A^B = n(P_E^W, P_G^B, I, GDP^B, Pop^B, Blend) \quad (11)$$

$$E_H^B = p(P_E^W, P_G^B, I, GDP^B, Pop^B, F^B) \quad (12)$$

where  $P_E^W$  represents the price of Brazilian anhydrous ethanol in reals per gallon, which is also the world ethanol price. Although there is a price for hydrous ethanol, only one price for ethanol, namely anhydrous, is used in both demand equations. The two prices are highly correlated as, in general, the price of anhydrous ethanol is the price of hydrous ethanol plus the cost of dehydration, which is assumed constant.  $P_G^B$  is the price of gasoline in reals per gallon, and  $I$  is an interaction term that is equal to  $P_G^B$  times the ratio of flex-fuel cars in the total vehicle fleet.  $F^B$  denotes the number of flex-fuel cars in the vehicle fleet in units.  $GDP^B$  and  $Pop^B$  are the GDP in 1995 reals and population for Brazil, respectively.  $Blend$  is the mandate of 20–25 percent. The interaction term  $I$  is used to capture the higher demand responsiveness of flex-fuel cars to changes in the price of gasoline. As the number of flex-fuel cars increases in the projection period, the demand for both anhydrous and hydrous ethanol becomes increasingly responsive to the change in the price of gasoline. In the case of anhydrous demand, as the price of gasoline rises, the demand for ethanol declines as flex-fuel cars substitute hydrous ethanol for gasoline blended with anhydrous ethanol. So the coefficients for  $P_G^B$  and  $I$  in equation (11) are negative. Conversely, for the demand for hydrous ethanol, if the price of gasoline increases, the demand increases, as flex-fuel cars increase their use of hydrous ethanol relative to anhydrous ethanol blended in gasoline. Hence, the coefficients for  $P_G^B$  and  $I$  in equation (12) are positive.

### *Ethanol Supply*

In modeling the supply of ethanol in Brazil, the link between sugar and ethanol markets is critical, as ethanol is produced from sugarcane in Brazil, so ethanol and sugar compete for sugarcane. Therefore, the derived demand for sugarcane that goes into ethanol production comes from the profit-maximization problem of sugarcane producers.

In the Brazilian sugar model, we obtain the area harvested for sugarcane in Brazil ( $AHA_t^C$ ) from the cane producers' profit maximization, which is given as

$$AHA_t^C = q(AHA_{t-1}^C, P_{S,t}^B, P_{E,t}^B, P_{AC,t}^B), \quad (13)$$

where  $P_{S,t}^B$  is the price of sugar in reals per ton and  $P_{AC,t}^B$  is the price of competing crops (namely, soybeans) in reals per ton.<sup>10</sup> Sugarcane production is area harvested for sugarcane multiplied by the yield. In the ethanol model, the behavioral equation for the share of sugarcane in ethanol production ( $S_E^C$ ) is given by

$$S_E^C = r \left( \frac{P_E^B}{P_S^B} \right), \quad (14)$$

where the coefficient estimate for the ratio of prices is positive. Sugarcane used in ethanol production equals  $S_E^C$  multiplied by total sugarcane production. Ethanol production equals sugarcane used in ethanol production times the conversion rate of 22.98 gallons per metric ton of sugarcane.

### *Inventory Demand*

The ethanol ending stock ( $ES_t^B$ ) equation is constructed as

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<sup>10</sup> The  $P_{S,t}^B$  is the world price (Caribbean FOB) of raw sugar times the exchange rate.

$$ES_t^B = v(ES_{t-1}^B, P_{E,t}^B), \quad (15)$$

where the coefficient estimate for  $P_{E,t}^B$  is negative.

### *Ethanol Trade*

Net exports are derived as a residual, i.e., equal to production plus beginning stocks minus consumption minus ending stocks. Although there is an ethanol import tariff in Brazil, it is not incorporated into the model, as Brazil is a net exporter of ethanol.

### **Model Calibration, Data Source, and Variables**

The model is calibrated on the most recent available data (2005) and then generates a 10-year baseline to 2015. The model combines econometric and consensus estimates of supply and demand responses to their respective arguments (prices, price of related products, income, etc.).<sup>11</sup> In general, data for ethanol supply and utilization were obtained from the F.O. Lichts Online Database, the Food and Agricultural Organization (FAO) of the United Nations (FAOSTAT Online), the Production, Supply and Distribution View (PS&D) of the U.S. Department of Agriculture (USDA), and the European Commission Directorate General for Energy and Transport. Macroeconomic data such as real GDP, GDP deflator, population, and exchange rate were gathered from various sources, including the International Monetary Fund and Global Insight (formerly WEFA-DRI).

Production, consumption, export, import, and stock data for the U.S. were taken from F.O. Lichts. To split the total ethanol demand into its two components, we use data on U.S. total ethanol consumption from F.O. Lichts, and data on the share of corn going into fuel alcohol use and into other fuel alcohol use from the U.S. Department of Agriculture's Economic Research

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<sup>11</sup> Details on the model, including elasticity values, are available from the authors upon request.

Service. U.S. ethanol import data are divided into imports from different countries according to the U.S. International Trade Council data set. U.S. production capacity was obtained from the Renewable Fuels Association's Annual Industry Outlook publications. The U.S. ethanol price is the FOB average rack price for Omaha, Nebraska, provided by the Nebraska Ethanol Board. The unleaded gasoline price is the FOB average rack price for Omaha, Nebraska, provided at the same website. The crude oil price is the refiners' acquisition cost of imported crude oil obtained from the Energy Information Administration's (EIA) *Short-Term Energy Outlook May 2006*, and *Annual Energy Outlook 2006* publications. U.S. gasoline consumption is the finished motor gasoline demand (that includes ethanol and ethers blended into gasoline) from EIA's *Short-Term Energy Outlook May 2006* and *Annual Energy Outlook 2006* publications. As a proxy for expected future demand projected by ethanol investors, we used a five-year average of ethanol demand projected five years into the future provided by EIA's *Annual Energy Outlook 2006*. The corn price is the farm price from the USDA National Agricultural Statistics Service online database. The natural gas utility price index was from Global Insight. The DDG price (Lawrenceburg), gluten meal price (60 percent, IL Pts), and gluten feed price (21 percent, IL Pts) were from the USDA Economic Research Service *Feed Situation and Outlook Yearbook*. The corn oil price (Chicago) was from USDA Economic Research Service *Oil Crop Yearbook* and *Oilseed Outlook*.

Most of the data for Brazil, including ethanol supply and utilization data as well as ethanol and sugar prices, sugarcane data, and Brazilian gasoline consumption, were obtained from the Attaché Reports of USDA's Foreign Agriculture Service. Ethanol prices are for anhydrous ethanol provided on a monthly basis for the State of São Paulo, Brazil.<sup>12</sup> Sugar prices

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<sup>12</sup> For anhydrous ethanol prices, freight costs are not included and federal taxes are included only up to April 2002.

include tax in the domestic market. Data for anhydrous and hydrous ethanol consumption is not available separately, so anhydrous ethanol consumption data was computed using the formula

$$E_A^B = Q_G^B \cdot \left( \frac{Blend}{1 - Blend} \right),$$
 where *Blend* is the mandate of 20–25 percent,  $E_A^B$  denotes anhydrous

ethanol consumption in million gallons, and  $Q_G^B$  is gasoline consumption for Brazil in million gallons. Flex-fuel and other vehicle data were obtained from the *Brazilian Automotive Industry Yearbook* (ANFAVEA, 2005) and vehicle projections were obtained from UNICA, 2006. In the Brazilian ethanol model, the gasoline price is the U.S. gasoline price obtained from EIA's *Annual Energy Outlook 2006* publication converted to local currency per gallon.<sup>13</sup>

### **Reform Scenarios and Results**

We consider two scenarios as deviations from the baseline. The first scenario is the removal of the trade distortions in the U.S. The out-of-quota duties of 2.5 percent and 54¢ per gallon are removed for all U.S. ethanol imports. For CBI countries, the TRQ is also eliminated. The second scenario removes the trade barriers and the federal tax credit for the refiners that blend ethanol with gasoline. Although this credit is 51¢ per gallon, the effective tax credit of 5.1¢ per gallon is removed, as that is what the final consumer sees since the ethanol is blended mostly at 10 percent. In each scenario, the policy reforms are fully implemented in 2006 and their impact is measured in deviations for the years 2006 to 2015. We report the average of these annual changes as a summary indicator of the impacts. Table 1 summarizes the impacts on the world market and presents the detailed impacts on the U.S. and Brazilian ethanol markets for the

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<sup>13</sup> The U.S. crude oil and gasoline prices are assumed to be the world prices for crude oil and gasoline, respectively. These prices are used in the Brazilian model because of lack of access to Brazilian fuel price data.

first scenario; Table 2 presents the impacts for the second scenario. Appendix A contains the detailed results of the two scenarios.

### ***Scenario 1: Impact of Trade Liberalization***

With the removal of the duties, the U.S. domestic ethanol price decreases by 13.6 percent, which results in a 7.2 percent decline in ethanol production and a 3.6 percent increase in consumption. The lower domestic price leads to a rise in the share of fuel ethanol in gasoline consumption by 3.7 percent. Given the lower domestic ethanol price, consumers are substituting gasoline blended with ethanol for gasoline blended with other additives. The removal of trade distortions in the U.S. and the corresponding higher U.S. ethanol demand increases the world ethanol price by 23.9 percent on average over the simulation period (Table 1).

**Table 1: Impact of Removal of U.S. Trade Barriers on U.S. and Brazilian Ethanol Markets**

Average 2006-2015	(US\$/gallon)		(US\$/cwt)	(US\$/bushel)	(US\$/ton)	(US\$/ton)
World	Ethanol Price	Crude Oil Price	Raw Sugar Price	Corn Price	DDG Price	Gluten Feed Price
Baseline	1.27	1.39	14.34	2.38	78.47	58.80
Scenario 1	1.57	1.39	14.59	2.34	79.00	58.50
% chg from baseline	23.89%	0.00%	1.77%	-1.53%	0.68%	-0.50%
	(Million Gallons)					(US\$/gallon)
United States	Production	Consumption	Net Imports	Gasoline Consumption	Share of Fuel Ethanol in Gasoline Consumption	Domestic Ethanol Price
Baseline	7,063.80	7,458.87	396.04	152,796.54	0.046	1.95
Scenario 1	6,563.66	7,730.73	1,169.05	152,962.58	0.048	1.68
% chg from baseline	-7.23%	3.75%	199.04%	0.11%	3.74%	-13.57%
	(Million Gallons)					Share of Sugarcane in Ethanol Production
Brazil	Production	Anhydrous Consumption	Hydrous Consumption	Total Consumption	Net Exports	Share of Sugarcane in Ethanol Production
Baseline	6,164.54	1,443.50	3,574.47	5,017.97	1,146.92	0.534
Scenario 1	6,730.05	1,410.04	3,444.13	4,854.18	1,877.14	0.560
% chg from baseline	9.10%	-2.32%	-3.74%	-3.32%	63.96%	4.87%

Net imports of the U.S. increase by 199 percent. Given that net imports make up only 5.3 percent of domestic consumption in the baseline, the large increase in net imports in the first scenario

translates into a 15.1 percent share of net imports in total domestic consumption. Since the duties are removed, Brazil can now export ethanol to the U.S. directly without having to go through the CBI countries. Therefore, trade diversion occurs, with ethanol imports from CBI countries declining to zero and with Brazil making up for the decline with higher exports to the U.S.

The lower domestic production of ethanol translates into reduced demand for corn in the U.S. Thus, the corn price declines by 1.5 percent on average relative to the baseline. Given the decline in corn used in ethanol production, the production of by-products decreases, by 7.1 percent on average for DDG, and by 1.7 percent each for gluten feed, gluten meal, and corn oil. The reduction in the production of DDG increases the price of DDG by 0.7 percent. The price of gluten meal increases by 0.9 percent because of its production decline. However, the prices of gluten feed and corn oil fall by 0.5 percent and 0.2 percent, respectively, as the impact from the lower corn price, which decreases the cost of production, exceeds the impact from lower production.

Brazil responds to the higher world ethanol price by increasing its production by 9.1 percent on average relative to the baseline. Total ethanol consumption decreases by 3.3 percent and net exports increase by 64 percent. The higher ethanol price leads to a 4.9 percent increase in the share of sugarcane used in ethanol production. This results in less sugarcane used in sugar production, which decreases sugar production in Brazil. The lower supply of Brazilian sugar leads to an increase in the world raw sugar price of 1.8 percent on average.

### ***Scenario 2: Impact of Trade Liberalization and Tax Credit Removal***

In this scenario, in addition to the removal of the tariffs in the U.S., the 51¢-per-gallon federal tax credit is also removed. The simulation results are presented in Table 2. U.S. ethanol

consumption decreases by 2.1 percent as the tax credit benefit for refiners is removed.<sup>14</sup> The U.S. domestic ethanol price decreases by 18.4 percent, which is higher in this scenario relative to the first scenario, since U.S. ethanol consumption is lower. In response to the lower domestic price, production decreases by 9.9 percent. The world ethanol price increases by 16.5 percent on average compared to the baseline, which is also lower than in scenario 1. The impact on the corn by-products market is similar to that in the first scenario, particularly in direction.

**Table 2: Impact of Removal of U.S. Trade Barriers & Federal Tax Credit on U.S. and Brazilian Ethanol Markets**

Average 2006-2015	(US\$/gallon)		(US\$/cwt)	(US\$/bushel)	(US\$/ton)	(US\$/ton)
World	Ethanol Price	Crude Oil Price	Raw Sugar Price	Corn Price	DDG Price	Gluten Feed Price
Baseline	1.27	1.39	14.34	2.38	78.47	58.80
Scenario 2	1.48	1.39	14.51	2.33	79.20	58.39
% chg from baseline	16.51%	0.00%	1.22%	-2.10%	0.94%	-0.69%
	(Million Gallons)					(US\$/gallon)
United States	Production	Consumption	Net Imports	Gasoline Consumption	Share of Fuel Ethanol in Gasoline Consumption	Domestic Ethanol Price
Baseline	7,063.80	7,458.87	396.04	152,796.54	0.046	1.95
Scenario 2	6,384.51	7,310.96	928.74	152,699.71	0.045	1.59
% chg from baseline	-9.92%	-2.12%	136.97%	-0.06%	-2.26%	-18.38%
	(Million Gallons)					Share of Sugarcane in Ethanol Production
Brazil	Production	Anhydrous Consumption	Hydrous Consumption	Total Consumption	Net Exports	Share of Sugarcane in Ethanol Production
Baseline	6,164.54	1,443.50	3,574.47	5,017.97	1,146.92	0.534
Scenario 2	6,553.90	1,420.39	3,484.43	4,904.82	1,650.07	0.552
% chg from baseline	6.26%	-1.61%	-2.58%	-2.29%	44.01%	3.39%

## Conclusions

There has been a lot of interest in ethanol as a renewable fuel because of the surge in demand in the U.S., higher crude oil prices, and the U.S. Energy Bill of 2005, which introduced a renewable fuel standard. Given the importance of the impact of trade distortions on U.S. ethanol markets, this study attempts to contribute to this discussion by analyzing a trade liberalization

<sup>14</sup> Consumers see only a 5.1¢-per-gallon reduction from the removal of the 51¢-per-gallon tax credit.

scenario as well as the effect of removal of domestic distortions. This study also addresses the complex relationship between gasoline and ethanol, with ethanol acting as both a substitute and a complement to gasoline.

We use a multi-market international ethanol model that is calibrated on 2005 market data and policies to investigate the impact of the U.S. tariff removal on prices, production and consumption, and trade. Ethanol is an emerging market, currently driven primarily by regulations and mandates, with Brazil and the U.S. leading the way. Trade distortions are an important contributor to the distortions in commodity markets, with large price and consumption effects. The study finds that trade barriers in the U.S. have been effective in protecting the ethanol industry and keeping domestic prices strong. With the removal of trade distortions, the world ethanol price increases, as demand for ethanol, and therefore imports, increases in the U.S. Imports to the coastal regions in the U.S. would increase significantly with trade liberalization, as transportation costs of ethanol from the Midwest are high. Thus, Brazil, with its comparative advantage of low-cost ethanol production, would benefit from the removal of the U.S. duties. Given that the CBI countries are currently an indirect route for Brazilian ethanol exports to the U.S., these countries could see a significant reduction in their exports to the U.S. since Brazil would export ethanol directly without duties.

The effect of the removal of trade distortions extends beyond the ethanol market, affecting the corn market and its by-products, as well as the sugar market. The price of corn in the U.S. is impacted by the change in the demand for corn used in ethanol production. This affects the prices of other crops in the U.S. and the area allocation between them. This has implications for the U.S. livestock sector because the prices of feed by-products from ethanol production change as well as the prices of other feeds such as the price of soy meal.

Brazil is a major player in the world ethanol market where both gasoline and sugar prices play an important role in determining what happens. The tariff rate in the U.S. is approximately 45 percent in ad valorem terms, which means that if it were eliminated, the U.S. market would become very attractive to Brazil. Under this scenario, with the increase in the world ethanol price, more sugarcane is diverted toward the production of ethanol and thus, the price of raw sugar rises. Ethanol and sugar in Brazil compete for sugarcane. Depending on the prices of ethanol and sugar, Brazil may end up increasing both the production of ethanol and sugar by expanding sugarcane area. Brazil can produce and export more ethanol than is projected in this study given stronger assumption on its ability to increase sugarcane production through acreage expansion, its potential to increase ethanol production capacity, and future investments in infrastructure.

The second scenario adds the removal of the federal tax credit for refiners blending ethanol to the removal of the trade barriers in the U.S. The marginal impact of the tax credit removal is a reduction in the refiners' demand for ethanol, prompting a reduction in imports and a corresponding decline in the world ethanol price. Thus, the final effect of the removal of both the tariff and the tax credit is a lower increase in net imports of the U.S. relative to the first scenario and a lower increase in the world ethanol price.

Given the emerging nature of the ethanol markets, our analysis comes with some caveats. Data availability and consistency is limited, which has led to the combination of different data sets. Various data sources have different definitions for ethanol variables. In addition, the time series for ethanol data is very short, making econometric estimations difficult. Within the brief time series, there have been radical changes (e.g., policy changes, crude oil price hikes) in the ethanol sector that have inherently changed the relationship between the variables, such as the

link between the ethanol and gasoline markets and between the ethanol and crop markets. In terms of modeling, constructing the U.S. production function is complicated by the rapidly increasing production capacity of ethanol in the U.S. To accommodate for this, we used a proxy for investors' expectations of future ethanol demand, which is an ad hoc method of modeling forward-looking expectations. Although we remove the tax credit at the federal level, there are various state-level regulations targeting ethanol that are not incorporated into the aggregate U.S. model. It is also important to note that the increasing popularity of flex-fuel cars in Brazil, and to a lesser extent in the U.S., may change the dynamics of how ethanol markets respond to a price change. As the number of flex-fuel cars increases, the complementary relationship between gasoline and ethanol becomes less pronounced while the substitution effect becomes stronger. This in turn changes the demand response, which may change the results of our policy scenarios. Within this framework of a fast-changing ethanol market, we have attempted to model and analyze the underlying fundamentals of the ethanol market.

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## Appendix A

**Table A.1: Removal of U.S. Trade Barriers on U.S and Brazilian Ethanol Markets**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
<b>World</b>											
	(U.S. Dollars per Gallon)										
<b>Anhydrous ethanol price</b>											
Baseline	1.29	1.34	1.24	1.21	1.19	1.22	1.25	1.28	1.30	1.32	1.35
Scenario 1	1.29	1.69	1.57	1.52	1.49	1.51	1.54	1.57	1.59	1.61	1.63
Percentage Change	0.00%	26.54%	26.43%	25.49%	25.19%	24.28%	23.48%	22.86%	22.41%	21.96%	20.30%
<b>Net Exports</b>											
	(Million Gallons)										
Baseline	645.11	795.71	1006.10	1059.49	1101.50	1174.01	1229.27	1267.01	1286.57	1295.64	1299.49
Scenario 1	645.11	1313.45	1662.02	1769.31	1840.46	1931.26	1999.23	2047.61	2078.07	2098.55	2086.33
Percentage Change	0.00%	65.07%	65.20%	67.00%	67.09%	64.50%	62.64%	61.61%	61.52%	61.97%	60.55%
<b>Raw Sugar Price</b>											
	(U.S. Cents per Pound)										
Baseline	12.20	13.94	13.43	13.70	13.85	14.02	14.31	14.60	14.89	15.18	15.49
Scenario 1	12.20	14.47	13.69	13.87	14.02	14.20	14.51	14.83	15.14	15.45	15.75
Percentage Change	0.00%	3.83%	1.94%	1.24%	1.23%	1.33%	1.43%	1.56%	1.69%	1.82%	1.67%
<b>Crude Oil Price</b>											
	(U.S. Dollars per Gallon)										
Baseline	1.17	1.43	1.44	1.40	1.35	1.31	1.33	1.37	1.40	1.43	1.46
Scenario 1	1.17	1.43	1.44	1.40	1.35	1.31	1.33	1.37	1.40	1.43	1.46
Percentage Change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
<b>United States</b>											
<b>Production</b>											
	(Million Gallons)										
Baseline	3886	4729	5196	5786	6396	6948	7479	7917	8333	8732	9123
Scenario 1	3886	4367	4751	5309	5898	6437	6956	7384	7789	8176	8571
Percentage Change	0.00%	-7.67%	-8.57%	-8.24%	-7.79%	-7.36%	-6.99%	-6.73%	-6.53%	-6.37%	-6.05%
<b>Consumption</b>											
Baseline	4007	4950	5563	6168	6786	7381	7935	8375	8775	9147	9507
Scenario 1	4007	5155	5818	6441	7069	7669	8223	8663	9061	9432	9777
Percentage Change	0.00%	4.14%	4.57%	4.43%	4.17%	3.90%	3.63%	3.43%	3.26%	3.11%	2.84%
<b>Net Imports</b>											
Baseline	127	217	370	385	393	434	456	459	443	417	386
Scenario 1	127	791	1073	1136	1175	1233	1267	1279	1273	1256	1207
Percentage Change	0.00%	264.84%	189.77%	194.98%	198.87%	184.35%	177.66%	178.59%	187.25%	201.55%	212.55%
<b>Gasoline Consumption</b>											
Baseline	139894	140974	143476	146739	149905	152843	154767	156718	158738	160850	162955
Scenario 1	139894	141111	143642	146913	150081	153019	154941	156889	158906	161015	163110
Percentage Change	0.00%	0.10%	0.12%	0.12%	0.12%	0.12%	0.11%	0.11%	0.11%	0.10%	0.09%
<b>Share of Fuel Ethanol in Gasoline Consumption</b>											
	(Ratio)										
Baseline	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.06
Scenario 1	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.06	0.06
Percentage Change	0.00%	4.24%	4.63%	4.46%	4.18%	3.89%	3.60%	3.39%	3.22%	3.06%	2.79%
<b>Domestic Ethanol Price</b>											
	(U.S. Dollars per Gallon)										
Baseline	1.80	2.00	1.92	1.89	1.87	1.90	1.93	1.96	1.98	2.01	2.01
Scenario 1	1.80	1.80	1.68	1.63	1.60	1.62	1.65	1.68	1.70	1.72	1.74
Percentage Change	0.00%	-9.84%	-12.70%	-13.79%	-14.45%	-14.50%	-14.38%	-14.28%	-14.19%	-14.08%	-13.51%
<b>Corn Farm Price</b>											
	(U.S. Dollars per Bushel)										
Baseline	1.86	2.05	2.15	2.27	2.36	2.41	2.46	2.49	2.51	2.54	2.56
Scenario 1	1.86	2.02	2.11	2.22	2.32	2.38	2.43	2.45	2.48	2.50	2.53
Percentage Change	0.00%	-1.53%	-1.94%	-1.92%	-1.63%	-1.52%	-1.33%	-1.36%	-1.36%	-1.39%	-1.34%
<b>DDG Price</b>											
	(U.S. Dollars per Ton)										
Baseline	77.66	76.59	78.98	79.74	79.75	79.70	79.64	78.98	78.18	77.10	75.99
Scenario 1	77.66	77.17	79.55	80.27	80.25	80.24	80.18	79.52	78.70	77.60	76.47
Percentage Change	0.00%	0.76%	0.72%	0.66%	0.63%	0.68%	0.67%	0.68%	0.66%	0.66%	0.64%
<b>Gluten Feed Price</b>											
Baseline	50.68	52.97	55.63	57.64	58.97	59.90	60.60	60.69	60.73	60.52	60.31
Scenario 1	50.68	52.75	55.26	57.24	58.62	59.60	60.35	60.44	60.47	60.26	60.05
Percentage Change	0.00%	-0.43%	-0.66%	-0.69%	-0.59%	-0.50%	-0.41%	-0.41%	-0.43%	-0.44%	-0.43%
<b>Gluten Meal Price</b>											
Baseline	278.20	259.78	266.70	266.95	265.16	264.64	263.72	261.19	257.51	252.94	248.07
Scenario 1	278.20	262.00	269.24	269.52	267.47	267.10	266.04	263.68	259.99	255.50	250.57
Percentage Change	0.00%	0.85%	0.95%	0.96%	0.87%	0.93%	0.88%	0.95%	0.96%	1.01%	1.01%
<b>Corn Oil Price</b>											
	(U.S. Cents per Pound)										
Baseline	25.46	24.25	25.62	26.56	27.07	27.53	28.07	28.56	29.01	29.51	30.07
Scenario 1	25.46	24.27	25.62	26.54	27.01	27.46	27.98	28.48	28.92	29.42	29.97
Percentage Change	0.00%	0.10%	0.00%	-0.09%	-0.25%	-0.25%	-0.33%	-0.29%	-0.32%	-0.31%	-0.32%

**Table A.1: (continued)**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
<b>Brazil</b>											
<b>Production</b>	(Million Gallons)										
Baseline	4768	5087	5496	5700	5889	6092	6287	6479	6670	6867	7079
Scenario 1	4768	5392	5964	6233	6460	6687	6898	7105	7310	7522	7728
Percentage Change	0.00%	5.99%	8.53%	9.37%	9.69%	9.76%	9.73%	9.66%	9.60%	9.54%	9.18%
<b>Total Consumption</b>											
Baseline	4196	4326	4503	4643	4786	4918	5058	5212	5383	5571	5779
Scenario 1	4196	4127	4319	4469	4618	4755	4899	5057	5232	5423	5642
Percentage Change	0.00%	-4.58%	-4.07%	-3.74%	-3.52%	-3.31%	-3.14%	-2.97%	-2.81%	-2.66%	-2.38%
<b>Anhydrous Ethanol Consumption</b>											
Baseline	1398	1376	1394	1414	1439	1461	1464	1467	1470	1474	1478
Scenario 1	1398	1335	1356	1379	1404	1427	1432	1435	1439	1443	1450
Percentage Change	0.00%	-2.94%	-2.69%	-2.51%	-2.39%	-2.28%	-2.22%	-2.16%	-2.10%	-2.06%	-1.90%
<b>Hydrous Ethanol Consumption</b>											
Baseline	2798	2950	3109	3229	3348	3458	3594	3745	3913	4098	4302
Scenario 1	2798	2792	2963	3090	3214	3328	3468	3622	3793	3980	4192
Percentage Change	0.00%	-5.35%	-4.69%	-4.28%	-4.01%	-3.75%	-3.52%	-3.29%	-3.08%	-2.88%	-2.55%
<b>Net Exports</b>											
Baseline	607	769	991	1056	1102	1174	1229	1267	1287	1296	1299
Scenario 1	607	1283	1644	1763	1840	1931	1999	2048	2078	2099	2086
Percentage Change	0.00%	66.89%	65.87%	66.98%	67.09%	64.50%	62.64%	61.61%	61.52%	61.97%	60.55%
<b>Share of Sugarcane in Ethanol Production</b>	(Ratio)										
Baseline	0.51	0.51	0.52	0.52	0.53	0.53	0.54	0.54	0.55	0.55	0.56
Scenario 1	0.51	0.53	0.55	0.55	0.55	0.56	0.56	0.57	0.57	0.58	0.58
Percentage Change	0.00%	4.42%	4.89%	4.96%	5.02%	4.99%	4.96%	4.93%	4.92%	4.90%	4.67%

**Table A.2: Removal of U.S. Trade Barriers and Federal Tax Credit on U.S and Brazilian Ethanol Markets**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
<b>World</b>	(U.S. Dollars per Gallon)										
<b>Anhydrous ethanol price</b>											
Baseline	1.29	1.34	1.24	1.21	1.19	1.22	1.25	1.28	1.30	1.32	1.35
Scenario 2	1.29	1.57	1.46	1.42	1.39	1.42	1.45	1.48	1.50	1.53	1.55
Percentage Change	0.00%	17.92%	18.08%	17.40%	17.26%	16.70%	16.28%	15.95%	15.75%	15.56%	14.19%
<b>Net Exports</b>	(Million Gallons)										
Baseline	645.11	795.71	1006.10	1059.49	1101.50	1174.01	1229.27	1267.01	1286.57	1295.64	1299.49
Scenario 2	645.11	1146.25	1452.96	1542.19	1605.06	1691.69	1759.13	1807.59	1838.65	1860.05	1849.08
Percentage Change	0.00%	44.05%	44.42%	45.56%	45.72%	44.10%	43.10%	42.67%	42.91%	43.56%	42.29%
<b>Raw Sugar Price</b>	(U.S. Cents per Pound)										
Baseline	12.20	13.94	13.43	13.70	13.85	14.02	14.31	14.60	14.89	15.18	15.49
Scenario 2	12.20	14.30	13.60	13.81	13.97	14.14	14.45	14.76	15.06	15.37	15.66
Percentage Change	0.00%	2.60%	1.33%	0.82%	0.82%	0.90%	1.00%	1.09%	1.19%	1.30%	1.12%
<b>Crude Oil Price</b>	(U.S. Dollars per Gallon)										
Baseline	1.17	1.43	1.44	1.40	1.35	1.31	1.33	1.37	1.40	1.43	1.46
Scenario 2	1.17	1.43	1.44	1.40	1.35	1.31	1.33	1.37	1.40	1.43	1.46
Percentage Change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
<b>United States</b>	(Million Gallons)										
<b>Production</b>											
Baseline	3886	4729	5196	5786	6396	6948	7479	7917	8333	8732	9123
Scenario 2	3886	4154	4561	5128	5720	6261	6782	7212	7618	8006	8402
Percentage Change	0.00%	-12.16%	-12.22%	-11.36%	-10.56%	-9.88%	-9.32%	-8.91%	-8.58%	-8.31%	-7.90%
<b>Consumption</b>											
Baseline	4007	4950	5563	6168	6786	7381	7935	8375	8775	9147	9507
Scenario 2	4007	4753	5404	6020	6644	7241	7797	8239	8639	9012	9361
Percentage Change	0.00%	-3.98%	-2.87%	-2.40%	-2.10%	-1.89%	-1.74%	-1.63%	-1.55%	-1.48%	-1.54%
<b>Net Imports</b>											
Baseline	127	217	370	385	393	434	456	459	443	417	386
Scenario 2	127	605	849	896	926	980	1015	1027	1022	1007	959
Percentage Change	0.00%	179.26%	129.32%	132.62%	135.56%	126.07%	122.31%	123.72%	130.66%	141.74%	148.47%
<b>Gasoline Consumption</b>											
Baseline	139894	140974	143476	146739	149905	152843	154767	156718	158738	160850	162955
Scenario 2	139894	140836	143365	146638	149810	152752	154679	156632	158653	160767	162867
Percentage Change	0.00%	-0.10%	-0.08%	-0.07%	-0.06%	-0.06%	-0.06%	-0.06%	-0.05%	-0.05%	-0.05%
<b>Share of Fuel Ethanol in Gasoline Consumption</b>	(Ratio)										
Baseline	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.06
Scenario 2	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.06
Percentage Change	0.00%	-4.28%	-3.10%	-2.57%	-2.25%	-2.02%	-1.84%	-1.72%	-1.63%	-1.55%	-1.60%
<b>Domestic Ethanol Price</b>	(U.S. Dollars per Gallon)										
Baseline	1.80	2.00	1.92	1.89	1.87	1.90	1.93	1.96	1.98	2.01	2.01
Scenario 2	1.80	1.68	1.57	1.53	1.50	1.53	1.56	1.59	1.61	1.64	1.66
Percentage Change	0.00%	-15.61%	-18.08%	-18.98%	-19.50%	-19.36%	-19.04%	-18.79%	-18.55%	-18.29%	-17.62%
<b>Corn Farm Price</b>	(U.S. Dollars per Bushel)										
Baseline	1.86	2.05	2.15	2.27	2.36	2.41	2.46	2.49	2.51	2.54	2.56
Scenario 2	1.86	2.00	2.09	2.21	2.30	2.36	2.42	2.44	2.47	2.49	2.52
Percentage Change	0.00%	-2.42%	-2.78%	-2.67%	-2.22%	-2.05%	-1.77%	-1.80%	-1.79%	-1.81%	-1.75%
<b>DDG Price</b>	(U.S. Dollars per Ton)										
Baseline	77.66	76.59	78.98	79.74	79.75	79.70	79.64	78.98	78.18	77.10	75.99
Scenario 2	77.66	77.54	79.81	80.48	80.44	80.44	80.36	79.70	78.87	77.77	76.63
Percentage Change	0.00%	1.24%	1.05%	0.93%	0.86%	0.92%	0.90%	0.92%	0.88%	0.87%	0.84%
<b>Gluten Feed Price</b>											
Baseline	50.68	52.97	55.63	57.64	58.97	59.90	60.60	60.69	60.73	60.52	60.31
Scenario 2	50.68	52.62	55.10	57.08	58.50	59.49	60.26	60.36	60.39	60.18	59.96
Percentage Change	0.00%	-0.67%	-0.95%	-0.97%	-0.80%	-0.68%	-0.55%	-0.55%	-0.56%	-0.58%	-0.57%
<b>Gluten Meal Price</b>											
Baseline	278.20	259.78	266.70	266.95	265.16	264.64	263.72	261.19	257.51	252.94	248.07
Scenario 2	278.20	263.30	270.32	270.51	268.27	267.95	266.81	264.48	260.77	256.28	251.34
Percentage Change	0.00%	1.35%	1.36%	1.33%	1.17%	1.25%	1.17%	1.26%	1.27%	1.32%	1.32%
<b>Corn Oil Price</b>	(U.S. Cents per Pound)										
Baseline	25.46	24.25	25.62	26.56	27.07	27.53	28.07	28.56	29.01	29.51	30.07
Scenario 2	25.46	24.29	25.61	26.53	26.98	27.44	27.95	28.45	28.89	29.39	29.94
Percentage Change	0.00%	0.16%	-0.01%	-0.12%	-0.35%	-0.33%	-0.44%	-0.39%	-0.42%	-0.41%	-0.42%

**Table A.2: (continued)**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
<b>Brazil</b>											
<b>Production</b>	(Million Gallons)										
Baseline	4768	5087	5496	5700	5889	6092	6287	6479	6670	6867	7079
Scenario 2	4768	5294	5814	6062	6277	6498	6707	6912	7116	7327	7532
Percentage Change	0.00%	4.07%	5.80%	6.36%	6.59%	6.66%	6.68%	6.68%	6.68%	6.69%	6.41%
<b>Total Consumption</b>											
Baseline	4196	4326	4503	4643	4786	4918	5058	5212	5383	5571	5779
Scenario 2	4196	4192	4377	4524	4671	4806	4948	5104	5277	5466	5683
Percentage Change	0.00%	-3.09%	-2.79%	-2.55%	-2.41%	-2.28%	-2.18%	-2.07%	-1.98%	-1.89%	-1.67%
<b>Anhydrous Ethanol Consumption</b>											
Baseline	1398	1376	1394	1414	1439	1461	1464	1467	1470	1474	1478
Scenario 2	1398	1349	1368	1390	1415	1438	1442	1445	1448	1452	1458
Percentage Change	0.00%	-1.99%	-1.84%	-1.71%	-1.64%	-1.57%	-1.54%	-1.51%	-1.48%	-1.46%	-1.33%
<b>Hydrous Ethanol Consumption</b>											
Baseline	2798	2950	3109	3229	3348	3458	3594	3745	3913	4098	4302
Scenario 2	2798	2843	3009	3134	3256	3369	3506	3659	3829	4014	4225
Percentage Change	0.00%	-3.61%	-3.21%	-2.92%	-2.74%	-2.58%	-2.44%	-2.30%	-2.17%	-2.04%	-1.78%
<b>Net Exports</b>											
Baseline	607	769	991	1056	1102	1174	1229	1267	1287	1296	1299
Scenario 2	607	1117	1436	1537	1605	1692	1759	1808	1839	1860	1849
Percentage Change	0.00%	45.29%	44.87%	45.55%	45.72%	44.10%	43.10%	42.67%	42.91%	43.56%	42.29%
<b>Share of Sugarcane in Ethanol Production</b>	(Ratio)										
Baseline	0.51	0.51	0.52	0.52	0.53	0.53	0.54	0.54	0.55	0.55	0.56
Scenario 2	0.51	0.52	0.54	0.54	0.54	0.55	0.56	0.56	0.56	0.57	0.57
Percentage Change	0.00%	3.02%	3.36%	3.41%	3.45%	3.45%	3.45%	3.46%	3.47%	3.49%	3.29%