An Analysis of the Link between Ethanol, Energy, and Crop Markets

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Abstract

This study analyzes the impact of price shocks in three input and output markets critical to ethanol: gasoline, corn, and sugar. We investigate the impact of these shocks on ethanol and related agricultural markets in the United States and Brazil. We find that the composition of a country's vehicle fleet determines the direction of the response of ethanol consumption to changes in the gasoline price. We also find that a change in feedstock costs affects the profitability of ethanol producers and the domestic ethanol price. In Brazil, where two commodities compete for sugarcane, changes in the sugar market affect the competing ethanol market.

Keywords: agricultural markets, energy, ethanol, renewable fuels.

JEL codes: Q11, Q18, Q42

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1. Introduction

Biofuels, particularly ethanol, are gaining ground in many countries. The high crude oil prices of recent months have created an interest among many groups in finding alternative energy sources. This energy-based interest in ethanol and biodiesel has changed the fundamentals of the ethanol market. High oil prices have made ethanol production more profitable, and many countries are taking advantage of this opportunity. Environmental concerns combined with the desire to find alternative markets for agricultural commodities have further fueled this interest. When analyzing the future of ethanol markets, most of the emphasis has been on energy, i.e., crude oil markets. However, agricultural commodity markets are also an important determinant of the dynamics of ethanol markets.

A number of new studies have examined the role of biofuels as part of a solution to high crude oil prices, dependence on crude oil imports and the volatility of its supply, as well as environmental concerns (Eidman 2005, USDA 2006). Von Lampe (2006) examines the impact of a number of scenarios on the biofuels market, including the impact of higher crude oil prices. He finds that higher crude oil prices lead to higher agricultural commodity prices through higher cost of production and higher incentives to produce biofuels, which increase the demand for feedstocks. Thus, it is important to understand the link between ethanol, corn, and sugarcane markets, as corn and sugarcane are the most widely used crops for producing ethanol. The extent of agriculture's role in providing a reliable and long-term source of energy depends on many factors but more critically on the price of a feedstock such as corn, which constitutes the major cost for an ethanol plant. Hence, the cost of the feedstock is an important determinant of the profit margin for ethanol plants and determines the expansion of plant capacity. The competition between the ethanol sector and the other sectors using the same feedstock is also critical, as the relative profitability of these sectors will determine the long-term changes in the agricultural sector. For example, the relative prices of ethanol and sugar, both by-products of sugarcane production, are critical in understanding how these industries will evolve over time.

Within this framework, the objective of this study is to provide an analysis of ethanol markets conditioned on the underlying fundamentals. Here, we discuss the emergence of ethanol markets in the United States and Brazil, which are the major producers and consumers of ethanol as an alternative fuel, in response to the recent rise in world crude oil prices. Although ethanol is used mainly as an additive in the United States, it is seen as a future alternative to gasoline in the United States and other countries and a way to reduce dependence on crude oil imports. Brazil has accomplished this shift by providing initially ethanol vehicles that run solely on ethanol, and more recently flex-fuel vehicles (FFVs), which run on gasoline, ethanol, or any combination of the two.

We first look at the link between energy and ethanol markets. The impact of a change in the gasoline price on international ethanol markets is analyzed, with an emphasis on the United States and Brazil. The analysis also addresses the impact of the commodity prices that affect the ethanol sector, namely, the price of corn in the U.S. and the price of sugar in Brazil. The second part of the analysis examines the impact of an exogenous corn price shock in the U.S. on international ethanol markets. Finally, the analysis investigates the impact of a shock to the raw sugar price on ethanol markets.

This study offers a number of contributions to the literature on ethanol. One contribution is that the price of a crop used in ethanol production, i.e., corn, and the price of a competing commodity, i.e., sugar, are solved endogenously. The corn and sugar prices are computed through an equilibrium mechanism that equates excess supply to excess demand. Previous studies, with the exception of Ferris and Joshi (2005), have tended to hold these prices constant (Gallagher et al. 2006, Koizumi and Yanagishima 2005). We set up linkages between an international ethanol model, an international sugar model, and a U.S. crops model. The U.S. crops model incorporates reduced-form equations for U.S. crop exports that capture the responses of international crop markets to changes in U.S. crop prices. Thus, the analysis moves beyond a correlation between markets to providing a liaison between energy and agricultural markets and modeling ethanol market equilibrium with links to its fundamental determinants. Contrary to Ferris and Joshi's (2005) work, which takes ethanol projections provided by the U.S. Department of Energy as given, this study models and provides projections for ethanol production and consumption in the U.S. based on the latest market conditions and policy settings.

Furthermore, the analysis addresses the complicated relationship of ethanol as both a substitute for and a complement to gasoline. This relationship affects the direction of the impact of the gasoline price shock. The different characteristics of the vehicle fleets in the U.S. and Brazil determine the final results from a gasoline price shock. Therefore, the model provides an insight into what might happen in the U.S. if FFVs dominate the market, as is projected to happen in Brazil.

In the following paragraphs, we provide a brief discussion on legislation and the type of demand for ethanol in both the U.S. and Brazil. Then, we discuss the link between ethanol and related markets, namely, gasoline, corn in the U.S., and sugar in Brazil. Next, 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. A concise description of the data also is given. After having introduced the price shock scenarios, we present the key results of our simulations and our concluding remarks.

The study finds that the composition of the vehicle fleet determines the direction of the response of ethanol consumption to a change in the gasoline price. Thus, an increase in the price of gasoline decreases ethanol consumption in the U.S. whereas it increases total consumption of ethanol in Brazil. This is attributed to the fact that the U.S. vehicle fleet is made up primarily of vehicles that run on gasoline only or gasoline blended at 10% ethanol while the Brazilian vehicle fleet is comprised of both gasohol vehicles, which run on gasoline blended with a mandated percentage of ethanol (between 20% and 25%), and FFVs. The study also finds that a change in feedstock costs affects the profitability of ethanol producers and impacts the domestic price of ethanol. In the U.S., an increase in corn price leads to lower production of ethanol. This in turn increases the U.S. domestic price, allowing Brazil, a low-cost ethanol producer, to capture a higher share of the U.S. ethanol market. In countries where two commodities compete for one feedstock, the changes in one market bring about changes in the competing market. Thus, an increase in the price of sugar, which competes with ethanol for sugarcane in Brazil, leads to lower ethanol production, as more sugarcane is diverted to sugar production, and increases the price of ethanol in world markets.

2. U.S. and Brazilian Ethanol Markets

2.1. United States

In the U.S., ethanol is currently used as an additive for gasoline. Other additives include alkylates, polymers, normal butane, and the recently obsolete MTBE (methyl tertiary butyl ether). Gallagher et al. (2003) give the various performances and environmental attributes for gasoline combined with these different additives. An advantage of ethanol is that it burns clean with a low carbon dioxide content. An important attribute of ethanol is that it acts as an octane booster, enhancing engine performance. Another feature is that its use provides oxygen to the atmosphere, preventing air pollution from carbon monoxide and ozone, thus contributing to environmental goals. These characteristics have made ethanol a competitive additive in the gasoline market.

2.1.1. Legislation in the United States

The Clean Air Act Amendments of 1990 in the United States established the Oxygenated Fuels Program and the Reformulated Gasoline (RFG) Program, both of which created a new demand for ethanol blended with gasoline. RFG was used to reduce vehicle emissions in areas that were in severe or extreme non-attainment of the National Ambient Air Quality Standards for ground-level ozone. Multiple metropolitan areas, including New York, Los Angeles, Chicago, Philadelphia, and Houston, are covered by this requirement. Evidence that the most widely used oxygenate, MTBE, contaminates groundwater led to pressure to eliminate the oxygen requirement in RFG (Yacobucci 2006). Thus, the Energy Policy Act of 2005 eliminated the oxygenate requirement for federal RFG as of May 2006. However, there are other oxygenate requirements that remain effective (such as state winter oxygenated programs) and that create a market for ethanol.

The Energy Policy Act of 2005 also introduced the Renewable Fuel Standard (RFS), which requires U.S. fuel production to include a minimum amount of renewable fuels each year, starting at 4 billion gallons in 2006 and reaching 7.5 billion gallons by 2012. For calendar year 2013 and each year thereafter, the minimum required volume of renewable fuels would be equal to the same percentage of the amount of renewable fuels in 2012 (7.5 billion gallons) in the total gasoline sold in the U.S. in that year. In addition, starting in 2013, the required amount of renewable fuels must include a minimum 250 million gallons derived from cellulosic biomass (EIA 2006a). The law directs the Environmental Protection Agency (EPA) to establish a credit trading system to provide flexibility to fuel producers. Under this program, ethanol produced from cellulosic feedstocks is granted extra credit: a gallon of cellulosic ethanol counts as 2.5 gallons of renewable fuel (Yacobucci 2006).

2.1.2. Ethanol Production

The ethanol industry consists of both wet and dry mills. Wet mills produce ethanol and its by-products corn gluten meal, corn gluten feed, corn oil, and carbon dioxide (CO_2). Dry mills, which are the predominant mill type, produce ethanol with dried distillers grains with solubles (DDGS) and CO_2 as by-products (Coltrain 2001, Tiffany 2002). In 2002, dry milling facilities represented approximately 60% of U.S. ethanol production, while wet mills accounted for 40%. In 2005, dry mill ethanol refineries accounted for 79% of production capacity and wet mills, 21%. There are 101 plants currently operating, with a production capacity of 4.8 billion gallons per year. Thirty-four new ethanol plants are under construction and seven expansion projects are underway, which will generate an additional capacity of 2.2 billion gallons (RFA 2006).

Shapouri and Gallagher (2005) report the results of a USDA survey of ethanol production costs that focused on dry mill plants for the year 2002. The net feedstock costs for the plants ranged from 39¢ to 68¢ per gallon in 2002, which make up the major portion of the cost for ethanol plants. Thus, feedstock costs are the major determinants of an ethanol plant's profitability and capacity expansion in the industry. Comparatively, the cost of energy averaged 17.3¢ per gallon of ethanol. Labor costs ranged from 3¢ to 11¢ per gallon, maintenance costs, from 1¢ to 7¢, and administrative costs, from 1¢ to 18¢ per gallon. Shapouri and Gallagher (2005) report that new plant construction costs between $1.05 and $3.00 per gallon.

2.1.3. Ethanol Blends and Vehicle Types

In the United States, ethanol is mostly blended at 10% with gasoline (E-10) and is available only in certain states. Ethanol is also available as E-85, a blend of 85% ethanol and 15% unleaded gasoline that can be used in FFVs.

In 1997, some vehicle manufacturers began including E-85 fueling capability in certain model lines of vehicles. For 2002, the Energy Information Administration (EIA) estimated that the number of E-85 vehicles that are capable of operating on E-85, gasoline, or both was around 4.1 million. Many of these alternative-fueled vehicles are sold and used as traditional gasoline-powered vehicles. The National Ethanol Vehicle Coalition (NEVC) estimates that approximately 6 million FFVs have been sold in the U.S. to date, although many buyers are unaware that they have purchased this type of vehicle. This number is estimated to increase to about 9 million by 2008, which is a dramatic increase from less than 1 million in 2000 (Lampert 2006).

If E-10 or E-85 is used, there is a drop in fuel economy. Therefore, when discussing the ethanol and gasoline relationship, it is necessary to look at the energy content of each fuel. According to NEVC, a gallon of ethanol has 66.58% of the energy content of a gallon of unleaded gasoline. Thus, E-85 has 72.95% of the energy content of unleaded gasoline and E-10 has 96.81% of the energy content of unleaded gasoline (NEVC 2006). Consequently, the two blends need to be priced competitively with respect to other fuels.

2.2 Brazil

Brazil has been a pioneer in ethanol production, well before 1975 when the national fuel alcohol program (Proálcool) was established and ethanol began to be produced from sugarcane. Brazil is the lowest-cost producer of ethanol. Von Lampe (2006) suggests that Brazil is the only country that would be able to produce ethanol economically even if crude oil prices fell to $39 per barrel. Currently, ethanol makes up more than 40% of the fuel demand in Brazil. There are two types of ethanol produced in Brazil: anhydrous and hydrous ethanol. Anhydrous ethanol is used as an additive to gasoline based on the mandated blend. Hydrous ethanol, which contains water, is used in its pure state in ethanol and FFVs. Although the demand for hydrous ethanol had been declining in past years because of a drop in the sale of ethanol vehicles, it has regained ground with the introduction of FFVs.

2.2.1. Legislation in Brazil

With the fall in international sugar prices and the increased burden of the petroleum bill after the first oil crisis in 1973, the Brazilian government decided to launch the Proálcool Program in 1975. The government mandated a blending ratio of ethanol for all gasoline sold in Brazil depending on market conditions. It promoted the production of ethanol by offering subsidies to ethanol producers, credit guarantees, low-interest loans for construction of new plants, and storage credit to millers (Schmitz, Schmitz, and Seale 2003). Ethanol prices were set at favorable levels relative to gasoline. This dramatically increased the country's production and consumption of ethanol. After the second oil crisis in 1979, tax reductions for ethanol vehicles, which were introduced in the same year and ran only on 100% hydrous ethanol, made ethanol very attractive to consumers. Because of the subsidies, by 1986, 76% of all new vehicles built ran on hydrous ethanol (Brilhante 1997).

By the mid-1980s, the sharp decrease in international crude oil prices seriously affected the cost-effectiveness of the ethanol program. Production capacity stopped growing, the government reduced soft loans to the industry, and consumption growth slowed down. By the late 1980s and early 1990s, there was a sharp shortage in ethanol, and consumers lost confidence in the commodity as a fuel. The sale of ethanol vehicles fell to nearly zero. Government oversight of ethanol prices was eliminated and the industry was deregulated by 1999. In 2003, the introduction of FFVs contributed to the revival of the ethanol industry in Brazil (La Rovere and Simões 2004).

The Brazilian government continues to mandate a blending ratio of anhydrous ethanol with gasoline of between 20% and 25% in transport fuel. A lower excise tax is imposed on ethanol relative to gasoline. Anhydrous ethanol is not taxed while the tax rate for gasoline was 52.12% in January 2006, 58% higher than the tax on hydrous ethanol. Furthermore, ethanol and FFVs are granted federal tax incentives. Ethanol imports to Brazil are subject to a 20% ad valorem duty. The government role has changed dramatically, from directly supporting the industry to ensuring the industry's smooth transformation to a market-driven sector and regulating its environmental impact (Martines-Filho, Brunquist, and Vian 2006).

2.2.2. Ethanol Production

Ethanol in Brazil is produced primarily from sugarcane. Since both sugar and ethanol are produced from sugarcane, a large number of the existing plants in Brazil are dual plants, producing both commodities. Depending on the relative prices, these plants can switch between the production of sugar and ethanol. Most of these mills are able to produce both commodities at a maximum ratio of 55 to 45.

Eighty-five percent of Brazil's total sugarcane production is grown in the Center/South region. In 2005, the region had 233 operating mills and distilleries. The North/Northeast region had about 90 mills. With the increased demand for both sugar and ethanol, the industry has seen a significant expansion, with an additional 19 sugar and ethanol mills opening in 2006, adding a cane-crushing capacity of 13.3 million tons. However with the increased demand for ethanol both domestically and internationally, 12 out of the 19 mills will produce only ethanol. There are

14 mills currently under construction and 5 mills undergoing expansion. The government anticipates that 89 new mills will have to be built in the next few years to meet the rising demand for ethanol (F.O.Lichts 2006b, Martines-Filho, Burnquist and Vian 2006).

Fixed and variable production costs for Brazilian ethanol production from sugarcane for 2005 were calculated to be around 21¢ and 89¢ per gallon of fuel, respectively, the lowest cost among the major ethanol-producing countries (Martines-Filho, Burnquist, and Vian 2006; von Lampe 2006). Given Brazil's long history in producing ethanol, costs have declined steadily because of technological advancements and increases in yield, economies of scale, and organizational learning. Costs are also kept low by using the by-product *bagasse*, a fibrous residue remaining after the cane is crushed, to generate electricity for the plant (Goldemberg et al. 2004, Moreira and Goldemberg 1999).

2.2.3. Ethanol Blends and Vehicle Types

Prior to the introduction of FFVs in 2003, the Brazilian vehicle fleet was comprised of primarily gasohol and ethanol vehicles. However, since 2003, FFVs have been increasing at a dramatic pace. The sale of FFVs increased by 585% between 2003 and 2004. The share of FFVs in the total vehicle market reached 22% in 2004, 40% in 2005, and is expected to rise to 60% in 2006. About 1.5 million FFVs were on the road at the beginning of 2006, with nearly 2 million more expected to be added by the end of the year. The share of FFVs in new car sales amounted to almost 80% in April 2006, while the sales of ethanol vehicles plummeted (ANFAVEA 2006). This share is expected to increase to 90%, and FFVs will likely be the predominant vehicle type in Brazil within the next decade (F.O. Lichts 2006c).

3. The Relationship between Ethanol and Related Markets

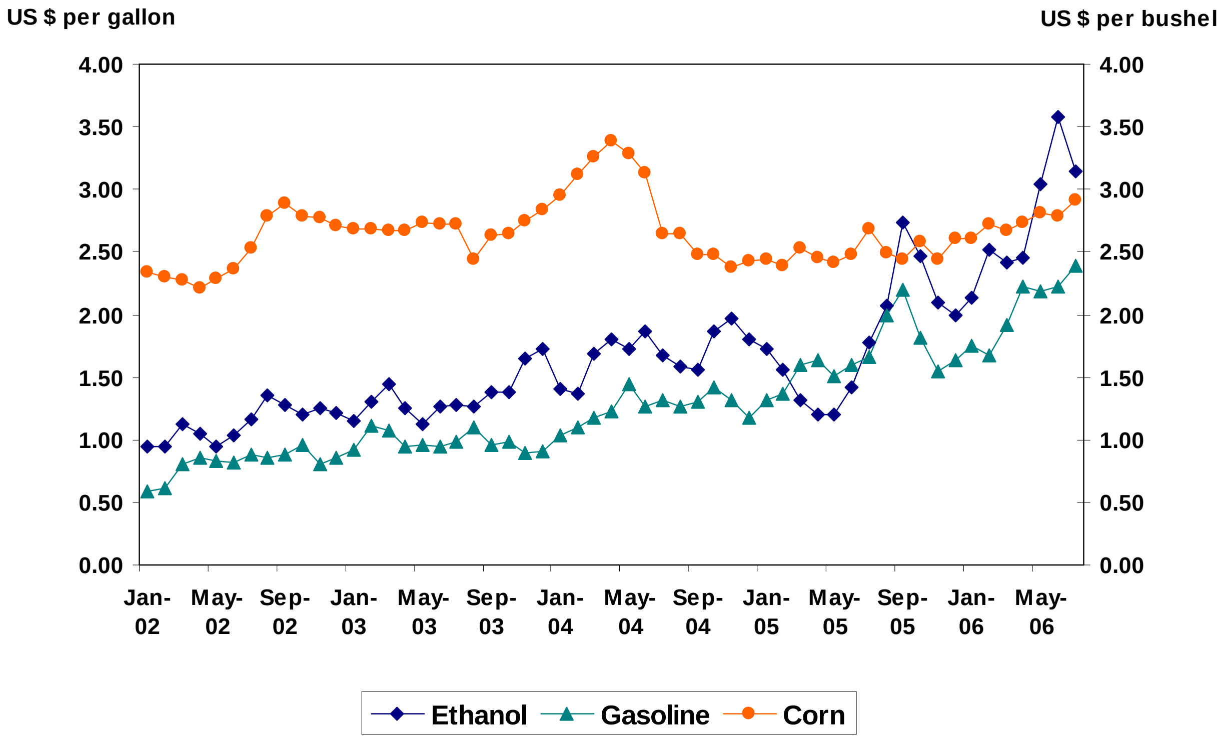
3.1 United States

The relationship between ethanol and gasoline prices in the United States has been strong. Eidman (2005) notes that as wholesale gasoline prices have increased over the past years, ethanol prices have moved with them. He attributes this link to the value of ethanol as a fuel extender, whereby the market price of ethanol depends on the wholesale price of gasoline.

In past years, the ethanol price generally was around 50¢ above the gasoline price because of the tax exemption given to ethanol, which varied between 51¢ and 54¢ per gallon. However, more recent events have altered this general trend. The rise in crude oil prices increased the gasoline price above the ethanol price in the U.S. for a short period between March 2005 and June 2005. Then, the RFS and the replacement of MTBE in the U.S. with ethanol increased the demand and therefore the domestic price of ethanol above that of gasoline starting in July 2005. Although production and capacity growth have been high, demand outpaced production. This can be seen in Figure 1, which shows that the gap between ethanol and gasoline prices has widened in the past few months. Generally, the positive correlation between gasoline and ethanol prices in the U.S. is mainly driven by policies and legislation such as RFS and the replacement of MTBE by ethanol.

The recent expansion of the ethanol industry in the U.S. has dramatically increased domestic demand for corn. Therefore, the corn farm price on average has increased in recent months (see Figure 1), as the ethanol industry is competing with the livestock industry, which uses corn as a major feed source.

Figure 1. U.S. Ethanol, Gasoline, and Corn Prices

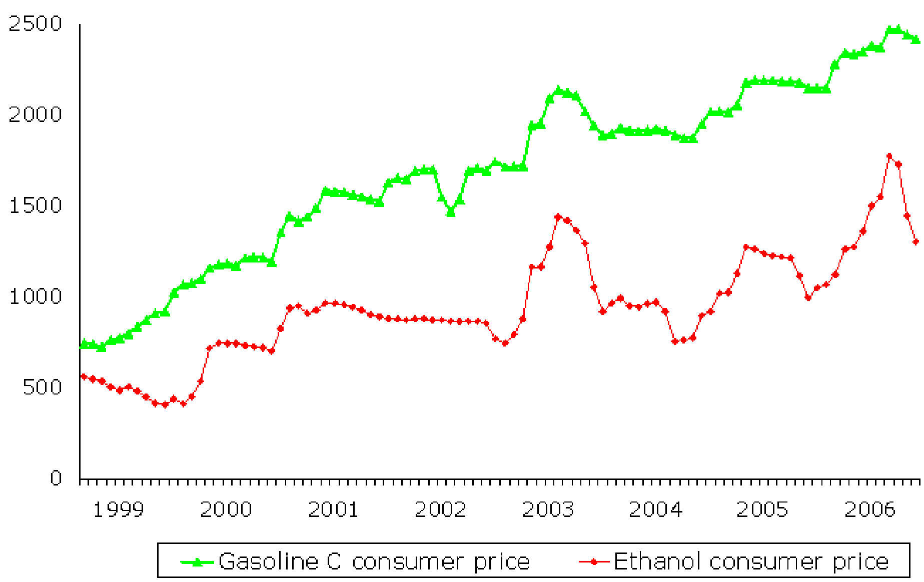


Source: Nebraska Ethanol Board and USDA NASS 2006

3.2 Brazil

The link between ethanol and gasoline was weak in Brazil prior to 2003 and their respective prices did not tend to move together. The increase in global interest in ethanol as a fuel alternative as well as the introduction of FFVs in 2003 in Brazil has changed this relationship. Figure 2 illustrates that the two prices show a strong positive correlation after 2003, although the price of ethanol tends to exhibit more volatility than the price of gasoline. Before 2003, Brazil's vehicle fleet was comprised mainly of ethanol and gasohol vehicles. These vehicles are not very responsive to gasoline price changes, as ethanol vehicles rely on only hydrous ethanol for fuel while gasohol vehicles use anhydrous ethanol at mandated blending ratios. An increase in the price of gasoline would not affect hydrous ethanol consumers and would affect gasohol consumers only to a certain extent. On the other hand, FFVs are more responsive to ethanol and gasoline price changes. An increase in the gasoline price would result in a decline in the demand for gasohol since FFVs can lower their consumption of gasohol (and therefore anhydrous ethanol) and increase their consumption of hydrous ethanol. Thus, the higher demand for hydrous ethanol pushes up the price of ethanol. As the number of FFVs increases in Brazil, the price responsiveness to ethanol and gasoline will become more pronounced.

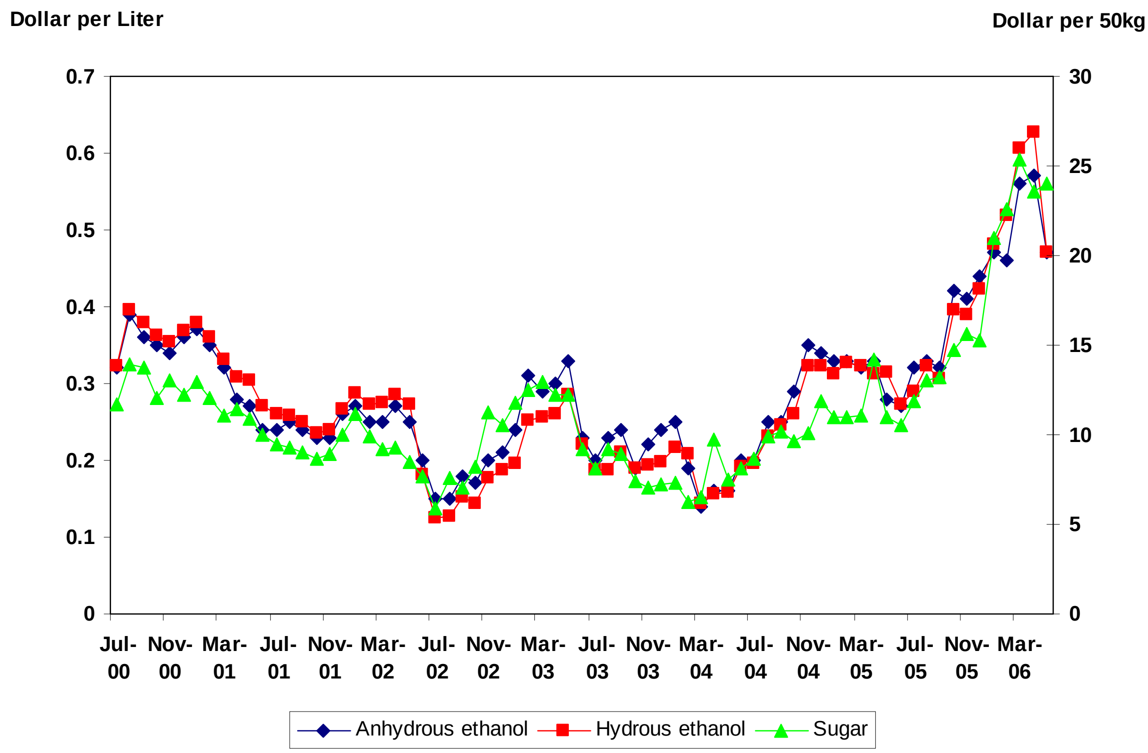
Figure 2. Brazilian Ethanol and Gasoline Prices



Source: ANP 2006

Historically, sugar and ethanol prices have tended to move together (Figure 3). With the recent dramatic rise in energy prices, the fundamentals of the relationship between sugar and ethanol in Brazil have changed. The competition between the two commodities, which both compete for sugarcane, has increased substantially, consequently changing the dynamics of the global sugar market. The increased demand for ethanol, coming from high crude oil prices, shifts sugarcane from the production of sugar to ethanol, thus tightening sugar supplies and increasing sugar prices. The competition between sugar and ethanol has also been exacerbated by the 2003 introduction of FFVs in Brazil. Therefore, there is evidence that strong oil prices are associated with high sugar prices. A market analysis by the FAO concluded that sugar prices generally tend to follow oil prices, as signals from the oil market are transmitted much faster to the sugar market than from sugar to oil markets (FAO 2006).

Figure 3. Brazilian Ethanol and Sugar Prices



Source: CEPEA 2006

The decision by producers as to whether to produce sugar or ethanol depends on the relative prices of the two commodities. Given current capacity, the industry could process a maximum of 55% of sugarcane to produce either sugar or ethanol depending on relative prices.

However, this maximum swing capacity is changing over time. With the recent increased demand for ethanol, Brazilian mills are increasing their ethanol capacity relative to sugar, therefore reducing their flexibility. Furthermore, new mills are first built as ethanol only, since sugar mills are more expensive to build and can be added in the future (F.O. Lichts 2006a). If this trend continues, it may suggest relatively limited increases in sugar production despite strong signals from the markets.

4. International Ethanol Model

The international ethanol model is a non-spatial, multi-market world model linking ethanol to its input and output markets. The general model structure specifies behavioral equations for ethanol production, consumption, ending stocks, and net trade for the United States, Brazil, and European Union-15. Net trade equations are constructed for China, Japan, and a Rest-of-World aggregate because of limited data availability for complete model development. The model incorporates linkages to the U.S. crops, which include models for most of the agricultural commodities in the U.S., as well as reduced-form equations that capture the responses of the international crop markets to changes in the U.S. crop prices. Through these linkages, all U.S. crop prices are solved endogenously. The ethanol model is also linked to world sugar through an international sugar model, which includes the major sugar producing and consuming countries. The world raw sugar price is solved endogenously by equating excess supply to excess demand in the world sugar market. Linkage to the energy market is provided via modeling the demand for energy for transportation, i.e., modeling fuel consumption in the U.S.

The ethanol model solves for a representative world ethanol price (Brazilian anhydrous ethanol price) by equating excess supply and excess demand across countries. Price transmission equations link the domestic price of ethanol for each country with the representative world price through exchange rates and other price policy wedges.

4.1 U.S. Ethanol Model

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. A detailed description of the U.S. ethanol model is presented in Appendix I.

The demand structure is comprised of equations for composite gasoline consumption (all vehicle fuel consumption for transportation purposes including unleaded gasoline and gasoline blended with ethanol) and share of ethanol in gasoline consumption. The model includes the following major policy parameters: the 51¢-per-gallon volumetric ethanol excise tax credit that refiners receive for blending 10% ethanol with gasoline; the mandated requirement of ethanol blend in certain states; and the RFS of the Energy Bill of 2005. In the U.S. demand model, consumers respond positively to a decrease in the price of the composite gasoline, which is a function of the prices of gasoline and ethanol. The ethanol component of the composite gasoline consumption increases as the ethanol price falls relative the price of gasoline to capture the substitution between the types of gasoline at the gas station pump.

Since in the U.S. fuel ethanol is currently used as an additive to gasoline, ethanol acts as a complementary good to pure gasoline. However, with the introduction of FFVs and the recent use of ethanol as a fuel enhancer induced by high gasoline prices, ethanol can also act as a substitute for gasoline. In this analysis, the complementary relationship is more dominant than the substitute relationship for two reasons. First, ethanol is currently blended at 10% in most cases, and the blend is not available in all states.[1] Second, FFVs represent a negligible portion of the U.S. vehicle fleet. The analysis assumes substitution effects will continue to be limited although the effects may get larger in the future if FFVs become more prevalent.

To model domestic ethanol production in the U.S., we use a restricted profit function for both wet and dry mill ethanol plants. Profit maximization under capacity constraint yields a profit function, which can be expressed as a function of a 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 are weighted by the share of production by each mill type. Ethanol production is a function of the net return and a production capacity, which is computed using an endogenous growth rate of capacity based on the expected future profits by investors.

The U.S. ethanol model structure also incorporates an equation for ending stocks and equations for imports. Imports are split into those from Caribbean Basin Initiative (CBI) countries and those from other countries, as there are differing trade policy regimes for the two groups. We construct a price-switching regime depending on whether the import tariff is prohibitive or not. When the tariff is not prohibitive, the domestic U.S. price is determined by the world price through a price transmission equation. When the tariff is prohibitive, the domestic price is solved endogenously within the model. Since U.S. ethanol exports are small, they are held constant.

4.2 Brazilian Ethanol Model

The Brazilian ethanol model is described in detail in Appendix I. Brazilian ethanol demand is divided into anhydrous and hydrous ethanol demand, as they respond to different

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[1] In some states, ethanol blending rates of less than 10% are used to provide an oxygenate in the reformulated gasoline blends.

economic incentives depending on the three types of vehicles (alcohol, flex-fuel, and gasohol vehicles). The behavioral equation for anhydrous ethanol consumption includes the mandated blend of 20%-25%, as anhydrous ethanol is used only with gasoline blend at mandated levels. The equation for hydrous ethanol includes the number of FFVs in the vehicle fleet since hydrous ethanol is used in FFVs at any level.

In both the anhydrous and hydrous ethanol consumption equations, there is an interaction term that is used to capture the higher demand responsiveness of FFVs to changes in the price of gasoline. The number of FFVs is projected to increase significantly, which will make the demand for both anhydrous and hydrous ethanol become increasingly responsive to the change in the price of gasoline. As the price of gasoline rises, the demand for anhydrous ethanol declines, since FFVs substitute hydrous ethanol for gasoline blended with anhydrous ethanol. Conversely, if the price of gasoline increases, the demand for hydrous ethanol increases, as FFVs increase their use of hydrous ethanol relative to anhydrous ethanol blended in gasoline.

In modeling the supply of ethanol in Brazil, the derived demand for sugarcane that goes into ethanol production comes from the profit-maximization problem of sugarcane producers. In this case, the competition between ethanol and sugar for sugarcane is critical. In the ethanol model, there is a behavioral equation for the share of sugarcane in ethanol production, which is a function of the relative price of ethanol to sugar. The model also includes an equation for inventory demand. Net exports are derived as a residual.

5. Data and Scenario Results

5.1 Data

All the models used in this study are calibrated on 2005 data. A 10-year baseline is generated for the period between 2006 and 2015. Elasticity values for supply and demand responses are based on econometric analysis and on consensus estimates.[2] In general, data for ethanol supply and utilization were obtained from the F.O. Lichts online database, the Food and Agriculture Organization (FAO) of the United Nations (FAOSTAT Online 2006), 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 the International Monetary Fund and Global Insight.

The U.S. ethanol price is the FOB average rack price for Omaha, Nebraska, and the unleaded gasoline price is the FOB average rack price for Omaha, Nebraska, provided by the Nebraska Ethanol Board. The crude oil price is the refiners' acquisition cost of imported crude oil obtained from the Energy Information Administration (EIA). The corn price is the farm price from the USDA National Agricultural Statistics Service online database. The natural gas utility price index is from Global Insight. The DDGS, gluten meal, gluten feed and corn oil prices were obtained from the USDA Economic Research Service (ERS). U.S. gasoline consumption is the finished motor gasoline demand from EIA.

Data for Brazilian ethanol supply and utilization, 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. Flex-fuel and other vehicle data were obtained from the ANFAVEA (2005) and vehicle projections were obtained from UNICA (2006).

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[2] Details on elasticity values are available from the authors upon request.

5.2 Scenarios

The study analyzes three scenarios in which shocks to gasoline, corn, and sugar prices are introduced exogenously to the baseline. Furthermore, the shocks are given at 20% for each commodity starting in 2006 and covering the period to 2015. The scenario results are given in terms of averages for the period 2006 to 2015. Tables 1, 2, and 3 present the summary results in average terms for the 20% shock for gasoline, corn, and sugar, respectively. Detailed results for all scenarios are provided in Appendix II.[3]

5.2.1 Gasoline Price Shock

A 20% shock in gasoline price in the U.S. results in an almost 4% decline in composite gasoline consumption (Table 1). The share of fuel ethanol in composite gasoline consumption increases by 2.5% because of the substitution of gasoline blended with ethanol for gasoline blended with other additives. However, total ethanol consumption declines by 1.5% because the complementarity relationship overrides the substitution effect. Composite gasoline consumption overall declines as consumers drive less and consume less of all fuels, including blends. The fall in total ethanol consumption leads to a reduction in the U.S. domestic ethanol price and therefore profitability of ethanol plants. This results in a 0.7% reduction in ethanol production. Because of the lower demand for ethanol, the demand for feedstock declines. However, higher fuel prices result in higher cost of production for all crops. Therefore, the net effect on the price of corn is an increase of 0.6%. The price of DDGS, which is the by-product of predominant (dry-mill) processing, increases by 0.3% since less ethanol, and therefore less DDGS, is being produced.

The world ethanol price declines by about 1.9% because of the lower U.S. demand, since net U.S. imports decline by 16.7%. Brazil responds by reducing ethanol production by nearly

[3] The shocks on gasoline, corn, and sugar prices were also applied at 10% and 50%. Results are available from the authors upon request.

0.7% and increasing total ethanol consumption by 0.3% on average. In Brazil, the price of gasoline blended with ethanol goes up as the price of gasoline goes up. Therefore, the demand for gasohol falls and consequently the demand for anhydrous ethanol declines by 5.2%. However, hydrous ethanol consumption goes up by 2.6% because of the substitution effect overriding the complementary effect as FFVs switch from gasohol to hydrous ethanol. This is in contrast to the historical trends in Brazil (see Figure 2), which show positive correlation between gasoline and ethanol prices. This is due to the decline in Brazilian net exports by 5.3% as U.S. ethanol demand falls. The lower U.S. demand translates into a lower ethanol price. In Brazil alone, the positive correlation between gasoline and ethanol price can be maintained if export demand is held constant. With the decline in Brazilian ethanol production more sugarcane is diverted to sugar production. The increased supply of sugar leads to a reduction in sugar prices by 0.2%.

It is important to note that these results reflect the short run in which the number of FFVs in the U.S. is limited, which in turn restricts the substitution possibilities between gasoline and ethanol. In the long run, with the increase in FFVs in the U.S., substitution between gasoline and ethanol increases, and higher gasoline price would lead to higher ethanol consumption. Table D in Appendix II shows the results of a gasoline price shock scenario given an increase in FFVs in the U.S. We assume that FFVs will increase by 20% per year to 32 million units by 2015 from 4 million in 2004. Given this assumption, a 20% increase in gasoline price increases the share of fuel ethanol in composite gasoline consumption by 23.2% between 2006 and 2015. This results from a shift in consumption from gasoline to ethanol primarily by FFVs. Thus, total ethanol consumption in the U.S. increases by 17.4%. The higher demand for ethanol leads to an increase in the domestic ethanol price by 8.3%. U.S. net imports increase by 278.2% and consequently, the world ethanol price increases by 34.9%. This shows that our results are critically dependent on the vehicle fleet composition.

5.2.2 Corn Price Shock

The 20% exogenous increase in the U.S. corn price reduces U.S. ethanol production by 3.7%, as net profit margins decline for ethanol plants (Table 2). Thus, the U.S. domestic ethanol price increases by 2.3%. The share of fuel ethanol in composite gasoline consumption decreases by 0.6% and total ethanol consumption declines by 0.6%. U.S. net imports increase by 56.5%, as the reduction in production exceeds the reduction in consumption.

The world ethanol price increases by 6.6% in response to higher U.S. imports. Brazilian production increases by 2.4% in response to the higher world price. Total ethanol consumption declines by 0.9%, with anhydrous ethanol consumption declining by 0.6% and hydrous ethanol, by 1%. Hydrous ethanol consumption responds more to a change in ethanol price than does anhydrous consumption, as the existence of FFVs increases the elasticity of demand with respect to price since consumers can switch easily between alternative fuels. The higher ethanol production means that more sugarcane is diverted to ethanol production, thus reducing the supply of sugar in the world market. The price of raw sugar increases by nearly 0.6%. Brazilian ethanol net exports increase by 17.4% to meet the higher world ethanol demand.

5.2.3 Sugar Price Shock

The share of sugarcane going into ethanol production declines by 2.6% in Brazil when the raw sugar price is exogenously increased by 20% (Table 3). The resulting reduction in ethanol production increases the world ethanol price by 6.1%, as net exports of Brazil decline by nearly 10%. The higher ethanol price results in a 0.8% reduction in total ethanol consumption in Brazil.

The higher world ethanol price reduces U.S. net imports by 24.9%, which results in a tighter U.S. ethanol market and a 1.8% increase in the U.S. domestic ethanol price. Ethanol production increases by nearly 1%, as profit margins increase. Total ethanol consumption declines by 0.5%, as the share of fuel ethanol in composite gasoline consumption decreases by 0.5%. The increased demand for corn going into ethanol production in the U.S. increases the corn price by about 0.2%.

6. Conclusions

Given the rising interest in ethanol as a renewable fuel and the changing landscape of the fuel markets brought about by soaring crude oil prices, this study attempts to contribute to the literature by examining the underlying fundamentals of the ethanol market. Within this context, it is crucial to model the liaison between energy and agricultural markets, as the agricultural sector is increasingly becoming a source of energy through biofuel production. Already an established source of fuel in Brazil, ethanol is well on its way to becoming a mainstream fuel in the U.S.

Although the literature so far has centered on energy markets and the crude oil price, it is critical to understand the dynamics of the relationship between ethanol and corn markets in the U.S. and ethanol and sugar markets in Brazil. In the U.S., corn is the primary feedstock for the production of ethanol. Furthermore, corn is an important feed component in the U.S. livestock sector. U.S. corn net exports made up nearly 62% of world net trade of corn in 2005. Thus, any change in the U.S. corn market brought about by the emerging ethanol market will have a significant impact on the world corn market and on the U.S. livestock sector. On the other hand, in Brazil ethanol competes with sugar for sugarcane, and the expansion of ethanol production and use not only in Brazil but worldwide will have major ramifications for the Brazilian and world sugar markets. To this end, we utilize a multi-market international ethanol model to analyze the impact of the gasoline price, the U.S. corn price, and the world sugar prices on both ethanol and commodity markets.

Given the emerging nature of ethanol markets, our analysis comes with some caveats. Data availability and consistency is limited, which has led to the combination of different data sources. In this study, the complementarity relationship is considered to be more dominant than the substitution relationship between ethanol and gasoline in the U.S. However, this relationship is expected to change if the share of FFVs in the U.S. total vehicle fleet significantly increases as it has in Brazil. This may change the dynamics of how ethanol markets respond to a gasoline price change. Currently, corn serves as the major feedstock for ethanol production in the U.S. However, if a long-term goal of energy independence is to be met, new sources of feedstock for ethanol need to be found. The addition of cellulosic and other biomass feedstock in the production of ethanol may yet again change the structure of the market. The importance of corn as a feedstock may steadily decline. Although sugarcane is a lower-cost feedstock, the use of biomass may also change the relationship between ethanol and sugar markets.

The study finds that an increase in gasoline prices affects the U.S. and Brazilian ethanol markets differently because of the characteristic of their respective vehicle fleets. In the U.S. where vehicles run either on gasoline or gasoline blended with 10% ethanol, the share of fuel ethanol in composite gasoline consumption increases. However, the total consumption of ethanol declines as total composite gasoline consumption decreases. In Brazil, where vehicles run on up to 25% blended gasoline and where the share of FFVs is increasing dramatically, the increase in gasoline prices leads to an increase in total ethanol consumption. Specifically, the consumption of anhydrous ethanol used in gasohol vehicles declines while the consumption of hydrous ethanol used primarily in FFVs increases. The net effect is an increase in total ethanol consumption. This result illustrates the importance of the composition of the vehicle fleet on the relative magnitudes of the complementarity and substitution relationships between ethanol and gasoline. Thus, the evolution of the vehicle fleet in the U.S. is critical in driving the direction of both ethanol price and consumption in the gasoline price shock scenario.

An increase in the U.S. corn price decreases the profit margin for ethanol plants and leads to a reduction in ethanol production. Consequently, the U.S. domestic ethanol price increases, making ethanol imports from Brazil relatively more attractive. The higher demand for ethanol imports in the U.S. increases the world ethanol price. Since Brazil is a low-cost producer of ethanol, it captures most of the increase in U.S. imports despite high import tariffs.

An increase in the world price of raw sugar diverts more sugarcane into the production of sugar relative to ethanol in Brazil. This results in lower production of ethanol and lower net exports from Brazil. The lower supply of ethanol in the world market leads to an increase in the world ethanol price. The results of the scenarios show that ethanol and sugar prices tend to move together in Brazil.

This study illustrates that the discussions about the role of ethanol as a fuel source need to take into consideration the response of world agricultural markets. The price of corn in the U.S. is impacted by and impacts not only ethanol production, but also the prices of other crops in the U.S., area allocation, and the world corn market and how other countries respond to the price change. The impact also extends to the U.S. livestock sector through feed prices. This study is an attempt to show that special attention needs to be given to modeling the linkages between energy, ethanol, and agricultural markets to understand the overall impact of a change in one market and the resulting spillover effects.

Table 1. Impact of 20 Percent Gasoline Price Shock on U.S. and Brazilian Ethanol Markets

Average 2006-2015	(US$/gallon)		(US$/cwt)	(US$/bushel)		
World	Ethanol Price	Gasoline Price	Raw Sugar Price	Corn Price		
Baseline	1.27	1.92	14.34	2.38		
Scenario	1.25	2.30	14.31	2.39		
% chg from baseline	-1.91%	20.00%	-0.17%	0.59%		
		(Million Gallons)			(Ratio)	(US$/gallon)
United States	Production	Total Ethanol Consumption	Net Imports	Gasoline Consumption	Share of Fuel Ethanol in Gasoline Consumption	Domestic Ethanol Price
Baseline	7,064	7,459	396	152,797	0.046	1.95
Scenario	7,016	7,347	332	146,766	0.048	1.93
% chg from baseline	-0.67%	-1.49%	-16.69%	-3.97%	2.50%	-1.03%
			(Million Gallons)			(Ratio)
Brazil	Production	Anhydrous Consumption	Hydrous Consumption	Total Ethanol Consumption	Net Exports	Share of Sugarcane in Ethanol Production
Baseline	6,165	1,444	3,574	5,018	1,147	0.534
Scenario	6,121	1,369	3,665	5,034	1,087	0.532
% chg from baseline	-0.69%	-5.18%	2.60%	0.34%	-5.28%	-0.40%

Note: Gasoline consumption refers to total composite gasoline consumption, including unleaded gasoline and gasoline blended with ethanol.

Table 2. Impact of 20 Percent Corn Price Shock on U.S. and Brazilian Ethanol Markets

Average 2006-2015	(US$/gallon)		(US$/cwt)	(US$/bushel)		
World	Ethanol Price	Gasoline Price	Raw Sugar Price	Corn Price		
Baseline	1.27	1.92	14.34	2.38		
Scenario	1.35	1.92	14.42	2.86		
% chg from baseline	6.57%	0.00%	0.55%	20.00%		
		(Million Gallons)			(Ratio)	(US$/gallon)
United States	Production	Total Ethanol Consumption	Net Imports	Gasoline Consumption	Share of Fuel Ethanol in Gasoline Consumption	Domestic Ethanol Price
Baseline	7,064	7,459	396	152,797	0.046	1.95
Scenario	6,811	7,414	604	152,768	0.046	1.99
% chg from baseline	-3.67%	-0.62%	56.52%	-0.02%	-0.62%	2.25%
			(Million Gallons)			(Ratio)
Brazil	Production	Anhydrous Consumption	Hydrous Consumption	Total Ethanol Consumption	Net Exports	Share of Sugarcane in Ethanol Production
Baseline	6,165	1,444	3,574	5,018	1,147	0.534
Scenario	6,315	1,434	3,538	4,973	1,343	0.541
% chg from baseline	2.41%	-0.64%	-1.02%	-0.91%	17.44%	1.35%

Note: Gasoline consumption refers to total composite gasoline consumption, including unleaded gasoline and gasoline blended with ethanol.

Table 3. Impact of 20 Percent Raw Sugar Price Shock on U.S. and Brazilian Ethanol Markets

Average 2006-2015 World	(US$/gallon) Ethanol Price	Gasoline Price	(US$/cwt) Raw Sugar Price	(US$/bushel) Corn Price
Baseline	1.27	1.92	14.34	2.38
Scenario	1.35	1.92	17.21	2.38
% chg from baseline	6.13%	0.00%	20.00%	0.19%

United States	(Million Gallons) Production	Total Ethanol Consumption	Net Imports	Gasoline Consumption	(Ratio) Share of Fuel Ethanol in Gasoline Consumption	(US$/gallon) Domestic Ethanol Price
Baseline	7,064	7,459	396	152,797	0.046	1.95
Scenario	7,132	7,423	292	152,774	0.046	1.98
% chg from baseline	0.99%	-0.50%	-24.90%	-0.01%	-0.50%	1.82%

Brazil	(Million Gallons) Production	Anhydrous Consumption	Hydrous Consumption	Total Ethanol Consumption	Net Exports	(Ratio) Share of Sugarcane in Ethanol Production
Baseline	6,165	1,444	3,574	5,018	1,147	0.534
Scenario	6,006	1,435	3,541	4,976	1,031	0.520
% chg from baseline	-2.57%	-0.60%	-0.93%	-0.83%	-9.99%	-2.57%

Note: Gasoline consumption refers to total composite gasoline consumption, including unleaded gasoline and gasoline blended with ethanol.

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Appendix I

International Ethanol Model

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

Behavioral equations for production, consumption, ending stocks, and net trade make up the general structure of the model. 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. 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, all the U.S. crop prices are solved endogenously, including the U.S. corn farm price and its by-products such as high-fructose corn syrup, distiller’s dried grains and solubles, etc. Furthermore, the world raw sugar price is solved endogenously by equating excess supply to excess demand in the world sugar market.

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 $C = C(G_1^S, P_1^{ET}, P_1^{CR}, Policy,)$, where G_1^S is the refiners' output, which is the composite gasoline supply; P_1^{ET} is the domestic price of ethanol; P_1^{CR} is the U.S. price of crude oil; and $Policy$ is federal and state legislations that impact refiners' ethanol demand. The subscript 1 denotes the United States. We abstract from the time dimension unless necessary. Under the constant-returns-to-scale assumption, the cost function can be written as $C = \tilde{C}(P_1^{ET}, P_1^{CR}, Policy) \cdot G_1^S$. The marginal cost of composite gasoline is constant as long as input prices are constant. Composite gasoline output G_1^S is eventually determined by the intersection of composite gasoline demand and the marginal cost of composite gasoline at the equilibrium in the composite gasoline market. By Shephard's lemma, the intermediate demand for fuel ethanol, ($\partial C / \partial P_1^{ET}$), is derived as

$$D_1^{ET} = \frac{\partial C}{\partial P_1^{ET}} = G_1^S \cdot \left(\frac{\partial \tilde{C}}{\partial P_1^{ET}} \right), \quad (1)$$

where D_1^{ET} is the fuel ethanol demand in million gallons and $\partial \tilde{C} / \partial P_1^{ET}$ is the derived demand for ethanol per unit of composite gasoline. Accounting for the specific policy interventions affecting refiners, we obtain the following equation:

$$\frac{\partial \tilde{C}}{\partial P_1^{ET}} = f(P_1^{ET} - VEETC, P_1^{CR}, Mandate, RFS), \quad (2)$$

where $VEETC$ stands for volumetric ethanol excise tax credit, which is the tax rebate of 51¢ per gallon that refiners get when they blend 10% ethanol with gasoline. $Mandate$ is the percentage requirement for blending ethanol in certain states, and RFS denotes the Renewable Fuels Standard created by the Energy Bill of 2005 in million gallons.

G_1^D denotes the Marshallian demand for composite gasoline in the U.S. market, that is, the amount of composite gasoline consumption used in transportation in million gallons. It is expressed as

$$G_1^D = g(P_1^{GAS}, P_1^{ET} - VEETC, GDP_1, Pop_1), \qquad (3)$$

where P_1^{GAS} is the price of unleaded gasoline in dollars per gallon and is a function of P_1^{CR}. P_1^{GAS} is included in equation (3), as final consumers see the unleaded gasoline price.[4] GDP_1 is real gross domestic product (GDP) in 1995 U.S. dollars, and Pop_1 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.

In equilibrium in the composite gasoline market, the quantity of composite gasoline supplied by refiners is equal to the quantity of composite gasoline demanded by final consumers (G_1^D), i.e., $G_1^S = G_1^D = G_1^*$. Substituting equations (2) and (3) into equation (1) yields the derived demand of ethanol evaluated at the equilibrium of the composite gasoline market, D_1^{ET*}:

$$D_1^{ET*} = \frac{\partial C}{\partial P_1^{ET}} = f(P_1^{ET} - VEETC, P_1^{CR}, Mandate, RFS) \cdot g(P_1^{GAS}, P_1^{ET} - VEETC, GDP_1, Pop_1). \quad (4)$$

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[4] Although several types of gasoline are available to consumers, we use the price of unleaded gasoline as a proxy for a composite gasoline price since prices for all types of gasoline are highly correlated.

At the equilibrium of the composite gasoline market, $\partial\tilde{C} / \partial P_1^{ET}$ can be interpreted as the share of fuel ethanol in total gasoline consumption (D_1^{ET*} / G_1^D).

In U.S. composite gasoline production, fuel ethanol is mainly used as an additive to gasoline. In this regard, ethanol acts as a complementary good to pure gasoline. However, in demand, ethanol is a substitute for gasoline, through the introduction of E-85 vehicles or FFVs, which run on gasoline blended with up to 85% ethanol, and because of the recent use of ethanol as a fuel enhancer induced by high gasoline prices. In this analysis, through the parameterization of equation (4), the complementary relationship is considered to be more dominant than the substitute relationship because ethanol is currently blended at 10% in most cases and is not available in all states. Furthermore, E-85 vehicles represent a negligible portion of the U.S. vehicle fleet. Substitution effects are currently limited but may get larger in the future if E-85 vehicles become popular. To reflect the complementarity, an increase in the price of gasoline translates into a net decrease in demand for ethanol D_1^{ET*}. The coefficient estimate for P_1^{ET} in equation (2) is positive compared to the coefficient estimate of P_1^{GAS} in equation (3), which is negative. The former effect is smaller than the latter in absolute value.

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 FFVs in the U.S. remains relatively small, there is only limited substitution for regular vehicles 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 function of a 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_D is the share of dry mill production in total ethanol production, and s_W is the share of wet mill production. Thus, the net return per bushel of corn for ethanol plants in the U.S., R_1^{NET}, is expressed as

$$R_1^{NET} = \gamma_{ET} \cdot P_1^{ET} + (s_W \cdot ((\gamma_{GF} \cdot P_1^{GF}) + (\gamma_{GM} \cdot P_1^{GM}) + (\gamma_{CO} \cdot P_1^{CO})))$$

$$+(s_D \cdot (\gamma_{DDG} \cdot P_1^{DDG})) - P_1^C - \mu \cdot P_1^{NG} . \quad (5)$$

In equation (5), P_1^{GF} is the price of gluten feed in dollars per ton, P_1^{GM} is the price of gluten meal in dollars per ton, P_1^{CO} is the price of corn oil in dollars per gallon, P_1^{DDG} is the price of DDGS in dollars per ton, and P_1^C is the price of corn in dollars per bushel. P_1^{NG} is an index of the price of natural gas, which is multiplied by $\mu=0.0038$ to scale the index to dollars per bushel of corn. The conversion rates (γ_i) are used to convert each price to dollars per bushel of corn.[5] This allows us to construct the ethanol production function (Q_1) as

$$Q_1 = h(R_1^{NET}, Y_1^{ET}), \quad (6)$$

where Y_1^{ET} denotes the production capacity in million gallons.[6] The equation for the production

[5] 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 DDGS through the dry mill process on average.

[6] The exit decisions by firms are not modeled.

capacity is $Y_{1,t}^{ET} = Y_{1,t-1}^{ET} \cdot (1 + g_t)$, where g_t is the endogenous growth rate of this capacity and t denotes the time period. We model the growth rate as

$$g_t = \begin{cases} k(R_{1,t-1}^{NET}, E(FD_1^{ET})) & if \quad R_{1,t-1}^{NET} > 35¢ \; per\ bushel \\ 0 & Otherwise \end{cases}, \tag{7}$$

where $E(FD_1^{ET})$ is defined as the expected future demand that investors project for ethanol, which is the five-year average of ethanol demand projected five years into the future (provided by EIA's Annual Energy Outlook 2006). We incorporate a 35¢ per bushel cost of building a new ethanol plant. This cost estimate is obtained from industry sources. When the net return falls below 35¢ per bushel, the capacity growth rate is zero and no new ethanol plant is built. 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 demand.

Inventory Demand

Next, the ending stock (S_1^{END}) equation is expressed as follows:

$$S_1^{END} = m(S_1^{BEG}, P_1^{ET}), \tag{8}$$

where S_1^{BEG} is the beginning stock for ethanol in the U.S., and the coefficient estimate for P_1^{ET} is negative.

Ethanol Trade

The trade equations consist of export and import equations. Because U.S. ethanol exports 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}). The CBI countries in this article include only Costa Rica, El Salvador, and Jamaica. For the CBI countries, there is a tariff rate quota (TRQ) rule. The in-quota tariff rate is τ^i, which is zero. The out-of-quota tariff rate is τ^o, which is 2.5% plus 54¢ per gallon. The TRQ is set at 60 million gallons or 7% 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:

$$M_{CBI} = \begin{cases} Capacity & if \quad P_1^E > \varphi \cdot (P_W^{ET} \cdot (1+\tau^A) + TC) \\ \alpha + \beta \cdot \left(\dfrac{P_1^{ET}}{P_W^{ET} \cdot \left(1+\tau^A\right) + TC} \right) & if \quad P_1^{ET} > \sigma \cdot (P_W^{ET} \cdot (1+\tau^A) + TC) \\ M_{CBI} = 0 & Otherwise \end{cases}, \qquad (9)$$

where $Capacity$ is the CBI countries' maximum capacity of their dehydration plants, and TC is the transportation cost. φ and σ are transmission coefficients that are both less than one, and $\sigma < \varphi$. 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.[7] 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% plus 54¢ per gallon. The import equations for other countries are as follows:

$$M_{OTHER} = \begin{cases} 0 & if \quad P_1^{ET} < \sigma \cdot (P_W^{ET} \cdot (1+\tau^o) + TC) \\ (Demand - Supply) & Otherwise \end{cases}, \qquad (10)$$

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.

[7] The transportation cost estimate is calculated based on industry sources and various market reports (EIA 2004; F.O. Lichts 2006a,b; USDA AMS 2006).

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 either be solved endogenously ($P_1^{ET,E}$) or it can be a price transmission from the world price of ethanol. If $P_1^{ET,E} > P_W^{ET} \cdot (1+\tau^o) + TC$, then the domestic ethanol price equals $P_W^{ET} \cdot (1+\tau^o) + TC$. If $P_1^{ET,E} < P_W^{ET} \cdot (1+\tau^o) + TC$, then the domestic ethanol price is $P_1^{ET,E}$.

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 vehicles). The alcohol vehicles use only hydrous ethanol, the gasohol vehicles use only anhydrous ethanol, while the FFVs can use both hydrous ethanol and anhydrous ethanol (blended in gasoline). Therefore, we model anhydrous ethanol demand (D_2^{AE}) and hydrous ethanol demand separately (D_2^{HE}), where total ethanol demand in Brazil D_2^{ET} equals $(D_2^{AE} + D_2^{HE})$ and the subscript denotes Brazil.

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

$$D_2^{AE} = n(P_W^{ET}, P_2^{GAS}, Interaction, Blend, GDP_2, Pop_2) \quad (11)$$

$$D_2^{HE} = p(P_W^{ET}, P_2^{GAS}, Interaction, Flex_2, GDP_2, Pop_2), \quad (12)$$

where P_W^{ET} 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_2^{GAS} is the price of gasoline in reals per gallon, and $Interaction$ is an interaction term that is equal to P_2^{GAS} times the ratio of FFVs in the total vehicle fleet. $Blend$ is the mandate of 20%–25% set by the government depending on market conditions. $Flex_2$ denotes the number of FFVs in the vehicle fleet in units. GDP_2 and Pop_2 are the GDP in 1995 reals and population for Brazil, respectively. The interaction term $Interaction$ is used to capture the higher demand responsiveness of FFVs to changes in the price of gasoline. As the number of FFVs 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 FFVs substitute hydrous ethanol for gasoline blended with anhydrous ethanol. So the coefficients for P_2^{GAS} and $Interaction$ in equation (11) are negative. Conversely, for the demand for hydrous ethanol, if the price of gasoline increases, the demand increases as FFVs increase their use of hydrous ethanol relative to anhydrous ethanol blended in gasoline. Hence, the coefficients for P_2^{GAS} and $Interaction$ 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 (AH^{CANE}) from the cane producers' profit maximization, which is given as

$$AH^{CANE} = q(AH^{CANE}_{lagged}, P_2^{SU}, P_2^{ET}, P_2^{OTHER}), \tag{13}$$

where P_2^{SU} is the price of sugar in reals per ton (the Caribbean FOB raw sugar price times the exchange rate), and P_2^{CC} is the price of competing crops (namely, soybeans) in reals per ton. 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 ($Share^{ET}_{CANE}$) is given by

$$Share^{ET}_{CANE} = r\left(\frac{P_2^{ET}}{P_2^{SU}}\right), \tag{14}$$

where the coefficient estimate for the ratio of prices is positive. Sugarcane used in ethanol production equals S^{ET}_{CANE} 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 (S_2^{END}) equation is constructed as

$$S_2^{END} = v(S_2^{BEG}, P_2^{ET}), \tag{15}$$

where S_2^{BEG} is the Brazilian beginning ethanol stocks, and the coefficient estimate for P_2^{ET} 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 natural net exporter of ethanol.

Appendix II

Table A: Impact of a 20 Percent Gasoline Price Shock on World Ethanol Markets

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
World						(U.S. Dollars per Gallon)					
Anhydrous ethanol price											
Baseline	1.29	1.34	1.24	1.21	1.19	1.22	1.25	1.28	1.30	1.32	1.35
Scenario A	1.29	1.31	1.23	1.20	1.17	1.20	1.23	1.25	1.27	1.30	1.31
Percentage Change	0.00%	-2.00%	-1.05%	-1.35%	-1.59%	-1.70%	-1.91%	-2.03%	-2.09%	-2.11%	-3.25%
Net Exports						(Million Gallons)					
Baseline	645	796	1006	1059	1102	1174	1229	1267	1287	1296	1299
Scenario A	645	740	963	1014	1052	1121	1170	1203	1220	1227	1201
Percentage Change	0.00%	-6.96%	-4.28%	-4.29%	-4.49%	-4.53%	-4.82%	-5.03%	-5.21%	-5.33%	-7.61%
Raw Sugar Price						(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 A	12.20	13.90	13.43	13.69	13.84	14.00	14.29	14.58	14.86	15.15	15.42
Percentage Change	0.00%	-0.30%	0.02%	-0.07%	-0.11%	-0.12%	-0.16%	-0.17%	-0.18%	-0.18%	-0.47%
Gasoline Price						(U.S. Dollars per Gallon)					
Baseline	1.66	1.96	1.97	1.92	1.87	1.82	1.85	1.89	1.92	1.96	2.00
Scenario A	1.66	2.36	2.37	2.31	2.25	2.18	2.22	2.26	2.31	2.36	2.40
Percentage Change	0.00%	20.09%	20.11%	20.01%	19.91%	19.79%	19.86%	19.94%	20.01%	20.09%	20.16%
United States											
Production						(Million Gallons)					
Baseline	3886	4729	5196	5786	6396	6948	7479	7917	8333	8732	9123
Scenario A	3886	4719	5159	5742	6348	6898	7424	7857	8270	8666	9073
Percentage Change	0.00%	-0.22%	-0.72%	-0.76%	-0.74%	-0.71%	-0.74%	-0.75%	-0.75%	-0.75%	-0.54%
Total Ethanol Consumption											
Baseline	4007	4950	5563	6168	6786	7381	7935	8375	8775	9147	9507
Scenario A	4007	4880	5481	6076	6687	7275	7817	8248	8642	9009	9354
Percentage Change	0.00%	-1.42%	-1.48%	-1.49%	-1.47%	-1.43%	-1.48%	-1.51%	-1.52%	-1.51%	-1.62%
Net Imports											
Baseline	127	217	370	385	393	434	456	459	443	417	386
Scenario A	127	157	325	338	341	378	394	392	372	344	282
Percentage Change	0.00%	-27.48%	-12.12%	-12.36%	-13.28%	-12.94%	-13.70%	-14.65%	-15.94%	-17.43%	-27.03%
Composite Gasoline Consumption											
Baseline	139894	140974	143476	146739	149905	152843	154767	156718	158738	160850	162955
Scenario A	139894	134141	136748	140344	143841	147111	149051	151004	153022	155142	157251
Percentage Change	0.00%	-4.85%	-4.69%	-4.36%	-4.05%	-3.75%	-3.69%	-3.65%	-3.60%	-3.55%	-3.50%
Share of Fuel Ethanol in Composite Gasoline Consumption						(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 A	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%	3.50%	3.27%	2.91%	2.60%	2.33%	2.22%	2.15%	2.10%	2.05%	1.89%
Domestic Ethanol Price						(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 A	1.80	1.99	1.91	1.88	1.85	1.88	1.91	1.93	1.95	1.98	1.99
Percentage Change	0.00%	-0.23%	-0.69%	-0.88%	-1.03%	-1.12%	-1.27%	-1.35%	-1.41%	-1.43%	-0.87%
Corn Farm Price						(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 A	1.86	2.05	2.17	2.29	2.37	2.43	2.47	2.50	2.53	2.55	2.57
Percentage Change	0.00%	0.12%	0.83%	0.85%	0.74%	0.62%	0.55%	0.55%	0.52%	0.54%	0.56%
DDG Price						(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 A	77.66	76.67	79.20	80.08	80.08	80.02	79.93	79.27	78.46	77.39	76.26
Percentage Change	0.00%	0.10%	0.27%	0.43%	0.41%	0.39%	0.36%	0.37%	0.37%	0.38%	0.35%
Gluten Feed Price											
Baseline	50.68	52.97	55.63	57.64	58.97	59.90	60.60	60.69	60.73	60.52	60.31
Scenario A	50.68	53.04	55.93	57.99	59.31	60.20	60.88	60.97	61.00	60.80	60.59
Percentage Change	0.00%	0.11%	0.53%	0.62%	0.58%	0.50%	0.46%	0.45%	0.45%	0.45%	0.47%
Gluten Meal Price											
Baseline	278.20	259.78	266.70	266.95	265.16	264.64	263.72	261.19	257.51	252.94	248.07
Scenario A	278.20	259.90	266.38	266.99	265.33	264.85	263.94	261.39	257.74	253.14	248.21
Percentage Change	0.00%	0.04%	-0.12%	0.02%	0.06%	0.08%	0.08%	0.08%	0.09%	0.08%	0.05%
Corn Oil Price						(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 A	25.46	24.25	25.53	26.49	27.02	27.48	28.02	28.51	28.96	29.46	30.02
Percentage Change	0.00%	0.02%	-0.35%	-0.25%	-0.21%	-0.18%	-0.19%	-0.20%	-0.19%	-0.19%	-0.18%

Table A: (continued)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Brazil											
Production	(Million Gallons)										
Baseline	4768	5087	5496	5700	5889	6092	6287	6479	6670	6867	7079
Scenario A	4768	5064	5472	5672	5856	6054	6242	6428	6614	6807	6995
Percentage Change	0.00%	-0.46%	-0.43%	-0.48%	-0.56%	-0.63%	-0.71%	-0.78%	-0.84%	-0.87%	-1.18%
Total Ethanol Consumption											
Baseline	4196	4326	4503	4643	4786	4918	5058	5212	5383	5571	5779
Scenario A	4196	4357	4522	4661	4803	4933	5072	5225	5394	5581	5794
Percentage Change	0.00%	0.72%	0.44%	0.39%	0.35%	0.30%	0.28%	0.25%	0.21%	0.17%	0.26%
Anhydrous Ethanol Consumption											
Baseline	1398	1376	1394	1414	1439	1461	1464	1467	1470	1474	1478
Scenario A	1398	1300	1315	1338	1365	1390	1393	1394	1395	1397	1401
Percentage Change	0.00%	-5.53%	-5.63%	-5.39%	-5.09%	-4.81%	-4.88%	-4.98%	-5.09%	-5.19%	-5.18%
Hydrous Ethanol Consumption											
Baseline	2798	2950	3109	3229	3348	3458	3594	3745	3913	4098	4302
Scenario A	2798	3057	3207	3323	3438	3543	3680	3831	3999	4184	4393
Percentage Change	0.00%	3.63%	3.16%	2.92%	2.68%	2.47%	2.39%	2.29%	2.20%	2.09%	2.13%
Net Exports											
Baseline	607	769	991	1056	1102	1174	1229	1267	1287	1296	1299
Scenario A	607	714	948	1011	1052	1121	1170	1203	1220	1227	1201
Percentage Change	0.00%	-7.16%	-4.33%	-4.29%	-4.49%	-4.53%	-4.82%	-5.03%	-5.21%	-5.33%	-7.61%
Share of Sugarcane in Ethanol Production						(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 A	0.51	0.51	0.52	0.52	0.52	0.53	0.53	0.54	0.54	0.55	0.55
Percentage Change	0.00%	-0.34%	-0.22%	-0.26%	-0.31%	-0.35%	-0.40%	-0.44%	-0.46%	-0.48%	-0.71%

Table B: Impact of a 20 Percent Corn Price Shock on World Ethanol Markets

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
World					(U.S. Dollars per Gallon)						
Anhydrous ethanol price											
Baseline	1.29	1.34	1.24	1.21	1.19	1.22	1.25	1.28	1.30	1.32	1.35
Scenario B	1.29	1.50	1.29	1.27	1.25	1.28	1.31	1.34	1.37	1.46	1.48
Percentage Change	0.00%	12.61%	4.01%	4.59%	4.87%	4.86%	4.82%	4.78%	5.31%	10.65%	9.23%
Net Exports					(Million Gallons)						
Baseline	645	796	1006	1059	1102	1174	1229	1267	1287	1296	1299
Scenario B	645	1043	1149	1200	1246	1324	1385	1427	1464	1610	1631
Percentage Change	0.00%	31.06%	14.22%	13.24%	13.16%	12.80%	12.66%	12.66%	13.82%	24.27%	25.49%
Raw Sugar Price					(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 B	12.20	14.20	13.35	13.70	13.88	14.05	14.35	14.65	14.96	15.43	15.63
Percentage Change	0.00%	1.84%	-0.56%	0.04%	0.21%	0.27%	0.30%	0.33%	0.49%	1.70%	0.90%
United States											
Production					(Million Gallons)						
Baseline	3886	4729	5196	5786	6396	6948	7479	7917	8333	8732	9123
Scenario B	3886	4450	4991	5578	6180	6726	7251	7684	8086	8393	8770
Percentage Change	0.00%	-5.92%	-3.94%	-3.59%	-3.37%	-3.20%	-3.05%	-2.94%	-2.96%	-3.88%	-3.86%
Total Ethanol Consumption											
Baseline	4007	4950	5563	6168	6786	7381	7935	8375	8775	9147	9507
Scenario B	4007	4945	5510	6108	6724	7317	7871	8311	8715	9139	9501
Percentage Change	0.00%	-0.12%	-0.95%	-0.97%	-0.92%	-0.86%	-0.81%	-0.77%	-0.68%	-0.09%	-0.06%
Net Imports											
Baseline	127	217	370	385	393	434	456	459	443	417	386
Scenario B	127	491	520	533	546	592	620	628	630	749	733
Percentage Change	0.00%	126.35%	40.55%	38.35%	38.99%	36.60%	35.93%	36.72%	42.16%	79.77%	89.79%
Composite Gasoline Consumption											
Baseline	139894	140974	143476	146739	149905	152843	154767	156718	158738	160850	162955
Scenario B	139894	140970	143441	146700	149865	152803	154728	156679	158702	160845	162951
Percentage Change	0.00%	0.00%	-0.02%	-0.03%	-0.03%	-0.03%	-0.03%	-0.02%	-0.02%	0.00%	0.00%
Share of Fuel Ethanol in Composite Gasoline Consumption						(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 B	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%	-0.12%	-0.97%	-0.97%	-0.92%	-0.86%	-0.80%	-0.76%	-0.67%	-0.09%	-0.06%
Domestic Ethanol Price					(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 B	1.80	2.00	1.97	1.95	1.93	1.96	1.99	2.02	2.04	2.02	2.02
Percentage Change	0.00%	0.27%	2.65%	3.01%	3.18%	3.20%	3.20%	3.20%	2.98%	0.43%	0.34%
Corn Farm Price					(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 B	1.86	2.46	2.58	2.72	2.83	2.89	2.95	2.98	3.02	3.04	3.07
Percentage Change	0.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%

Table B: (continued)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Brazil											
Production					(Million Gallons)						
Baseline	4768	5087	5496	5700	5889	6092	6287	6479	6670	6867	7079
Scenario B	4768	5233	5613	5808	6001	6210	6410	6607	6812	7108	7347
Percentage Change	0.00%	2.87%	2.14%	1.91%	1.91%	1.93%	1.96%	1.98%	2.12%	3.50%	3.80%
Total Ethanol Consumption											
Baseline	4196	4326	4503	4643	4786	4918	5058	5212	5383	5571	5779
Scenario B	4196	4231	4475	4612	4754	4886	5025	5180	5347	5500	5717
Percentage Change	0.00%	-2.18%	-0.62%	-0.67%	-0.68%	-0.66%	-0.65%	-0.62%	-0.67%	-1.29%	-1.08%
Anhydrous Ethanol Consumption											
Baseline	1398	1376	1394	1414	1439	1461	1464	1467	1470	1474	1478
Scenario B	1398	1357	1388	1408	1432	1454	1457	1460	1463	1459	1465
Percentage Change	0.00%	-1.40%	-0.41%	-0.45%	-0.46%	-0.46%	-0.46%	-0.45%	-0.50%	-1.00%	-0.87%
Hydrous Ethanol Consumption											
Baseline	2798	2950	3109	3229	3348	3458	3594	3745	3913	4098	4302
Scenario B	2798	2875	3087	3204	3322	3432	3568	3719	3885	4041	4252
Percentage Change	0.00%	-2.54%	-0.71%	-0.77%	-0.78%	-0.75%	-0.72%	-0.69%	-0.73%	-1.40%	-1.16%
Net Exports											
Baseline	607	769	991	1056	1102	1174	1229	1267	1287	1296	1299
Scenario B	607	1014	1134	1196	1246	1324	1385	1427	1464	1610	1631
Percentage Change	0.00%	31.93%	14.38%	13.24%	13.16%	12.80%	12.66%	12.66%	13.82%	24.27%	25.49%
Share of Sugarcane in Ethanol Production						(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 B	0.51	0.52	0.52	0.53	0.53	0.54	0.54	0.55	0.55	0.56	0.57
Percentage Change	0.00%	2.14%	0.93%	0.94%	0.99%	1.01%	1.03%	1.04%	1.16%	2.18%	2.10%

Table C: Impact of a 20 Percent Raw Sugar Price Shock on World Ethanol Markets

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
World					(U.S. Dollars per Gallon)						
Anhydrous ethanol price											
Baseline	1.29	1.34	1.24	1.21	1.19	1.22	1.25	1.28	1.30	1.32	1.35
Scenario C	1.29	1.46	1.28	1.26	1.24	1.27	1.30	1.33	1.37	1.48	1.52
Percentage Change	0.00%	9.16%	3.43%	3.64%	3.87%	4.03%	4.17%	4.31%	5.25%	11.48%	12.01%
Net Exports					(Million Gallons)						
Baseline	645	796	1006	1059	1102	1174	1229	1267	1287	1296	1299
Scenario C	645	776	874	924	960	1022	1068	1097	1125	1255	1261
Percentage Change	0.00%	-2.45%	-13.12%	-12.83%	-12.88%	-12.92%	-13.09%	-13.41%	-12.58%	-3.15%	-2.94%
Raw Sugar Price					(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 C	12.20	16.73	16.11	16.44	16.62	16.82	17.17	17.52	17.86	18.21	18.59
Percentage Change	0.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%
United States											
Production					(Million Gallons)						
Baseline	3886	4729	5196	5786	6396	6948	7479	7917	8333	8732	9123
Scenario C	3886	4729	5275	5868	6482	7040	7578	8021	8433	8754	9142
Percentage Change	0.00%	0.00%	1.52%	1.42%	1.34%	1.33%	1.31%	1.32%	1.20%	0.25%	0.22%
Total Ethanol Consumption											
Baseline	4007	4950	5563	6168	6786	7381	7935	8375	8775	9147	9507
Scenario C	4007	4950	5518	6121	6737	7328	7880	8317	8722	9147	9509
Percentage Change	0.00%	0.00%	-0.82%	-0.77%	-0.73%	-0.71%	-0.70%	-0.69%	-0.60%	-0.01%	0.01%
Net Imports											
Baseline	127	217	370	385	393	434	456	459	443	417	386
Scenario C	127	217	244	255	258	289	303	297	290	395	368
Percentage Change	0.00%	0.00%	-34.03%	-33.77%	-34.42%	-33.36%	-33.67%	-35.37%	-34.52%	-5.16%	-4.70%
Composite Gasoline Consumption											
Baseline	139894	140974	143476	146739	149905	152843	154767	156718	158738	160850	162955
Scenario C	139894	140974	143446	146708	149873	152810	154733	156683	158706	160849	162955
Percentage Change	0.00%	0.00%	-0.02%	-0.02%	-0.02%	-0.02%	-0.02%	-0.02%	-0.02%	0.00%	0.00%
Share of Fuel Ethanol in Composite Gasoline Consumption						(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 C	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%	0.00%	-0.83%	-0.77%	-0.73%	-0.71%	-0.69%	-0.68%	-0.60%	-0.01%	0.01%
Domestic Ethanol Price					(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 C	1.80	2.00	1.96	1.94	1.92	1.95	1.98	2.02	2.03	2.01	2.01
Percentage Change	0.00%	0.00%	2.27%	2.39%	2.52%	2.65%	2.77%	2.88%	2.64%	0.08%	-0.02%
Corn Farm Price					(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 C	1.86	2.05	2.16	2.27	2.36	2.42	2.47	2.49	2.52	2.54	2.56
Percentage Change	0.00%	0.00%	0.31%	0.28%	0.27%	0.25%	0.26%	0.27%	0.24%	-0.02%	0.07%
DDG Price					(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 C	77.66	76.59	78.88	79.65	79.66	79.61	79.54	78.88	78.09	77.07	75.97
Percentage Change	0.00%	0.00%	-0.14%	-0.12%	-0.12%	-0.12%	-0.12%	-0.13%	-0.12%	-0.04%	-0.03%
Gluten Feed Price											
Baseline	50.68	52.97	55.63	57.64	58.97	59.90	60.60	60.69	60.73	60.52	60.31
Scenario C	50.68	52.97	55.68	57.69	59.02	59.95	60.65	60.74	60.77	60.51	60.32
Percentage Change	0.00%	0.00%	0.09%	0.09%	0.09%	0.08%	0.08%	0.08%	0.08%	-0.02%	0.02%
Gluten Meal Price											
Baseline	278.20	259.78	266.70	266.95	265.16	264.64	263.72	261.19	257.51	252.94	248.07
Scenario C	278.20	259.78	266.24	266.55	264.74	264.23	263.26	260.71	257.06	252.90	247.94
Percentage Change	0.00%	0.00%	-0.17%	-0.15%	-0.16%	-0.16%	-0.17%	-0.18%	-0.17%	-0.01%	-0.05%
Corn Oil Price					(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 C	25.46	24.25	25.61	26.57	27.08	27.54	28.09	28.58	29.03	29.53	30.07
Percentage Change	0.00%	0.00%	-0.01%	0.03%	0.03%	0.05%	0.05%	0.06%	0.06%	0.05%	0.00%

Table C: (continued)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Brazil											
Production						(Million Gallons)					
Baseline	4768	5087	5496	5700	5889	6092	6287	6479	6670	6867	7079
Scenario C	4768	4994	5341	5539	5721	5914	6098	6280	6472	6746	6958
Percentage Change	0.00%	-1.83%	-2.81%	-2.82%	-2.85%	-2.93%	-3.01%	-3.07%	-2.97%	-1.76%	-1.70%
Total Ethanol Consumption											
Baseline	4196	4326	4503	4643	4786	4918	5058	5212	5383	5571	5779
Scenario C	4196	4257	4479	4618	4761	4891	5030	5183	5348	5494	5698
Percentage Change	0.00%	-1.58%	-0.53%	-0.53%	-0.54%	-0.55%	-0.56%	-0.56%	-0.66%	-1.39%	-1.41%
Anhydrous Ethanol Consumption											
Baseline	1398	1376	1394	1414	1439	1461	1464	1467	1470	1474	1478
Scenario C	1398	1362	1389	1409	1433	1455	1458	1461	1463	1458	1461
Percentage Change	0.00%	-1.02%	-0.35%	-0.36%	-0.37%	-0.38%	-0.39%	-0.41%	-0.49%	-1.08%	-1.13%
Hydrous Ethanol Consumption											
Baseline	2798	2950	3109	3229	3348	3458	3594	3745	3913	4098	4302
Scenario C	2798	2895	3090	3209	3327	3436	3571	3722	3885	4036	4237
Percentage Change	0.00%	-1.85%	-0.61%	-0.61%	-0.61%	-0.62%	-0.62%	-0.62%	-0.72%	-1.51%	-1.51%
Net Exports											
Baseline	607	769	991	1056	1102	1174	1229	1267	1287	1296	1299
Scenario C	607	748	859	919	960	1022	1068	1097	1125	1255	1261
Percentage Change	0.00%	-2.70%	-13.36%	-12.91%	-12.88%	-12.92%	-13.09%	-13.41%	-12.58%	-3.15%	-2.94%
Share of Sugarcane in Ethanol Production						(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 C	0.51	0.50	0.51	0.51	0.51	0.52	0.52	0.52	0.53	0.54	0.55
Percentage Change	0.00%	-1.83%	-2.81%	-2.82%	-2.85%	-2.93%	-3.01%	-3.07%	-2.97%	-1.76%	-1.70%

Table D: Impact of a 20 Percent Gasoline Price Shock on Ethanol Markets Given Increase in U.S. FFVs

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
World						(U.S. Dollars per Gallon)						
Anhydrous ethanol price												
Baseline	1.29	1.34	1.24	1.21	1.19	1.22	1.25	1.28	1.30	1.32	1.35	1.27
Scenario D	1.29	1.63	1.42	1.36	1.37	1.45	1.62	1.87	2.05	2.17	2.28	1.72
Percentage Change	0.00%	22.15%	15.03%	11.80%	15.37%	18.88%	29.50%	46.71%	57.52%	64.31%	68.18%	34.94%
Net Exports						(Million Gallons)						
Baseline	645	796	1006	1059	1102	1174	1229	1267	1287	1296	1299	1151
Scenario D	645	1212	1403	1415	1527	1708	2045	2578	3046	3429	3734	2210
Percentage Change	0.00%	52.36%	39.47%	33.55%	38.66%	45.52%	66.40%	103.46%	136.79%	164.69%	187.32%	86.82%
Raw Sugar Price						(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	14.34
Scenario D	12.20	14.39	13.48	13.70	14.00	14.25	14.82	15.51	15.94	16.32	16.71	14.91
Percentage Change	0.00%	3.21%	0.42%	-0.01%	1.05%	1.68%	3.58%	6.25%	7.06%	7.52%	7.90%	3.87%
Gasoline Price						(U.S. Dollars per Gallon)						
Baseline	1.66	1.96	1.97	1.92	1.87	1.82	1.85	1.89	1.92	1.96	2.00	1.92
Scenario D	1.66	2.36	2.37	2.31	2.25	2.18	2.22	2.26	2.31	2.36	2.40	2.30
Percentage Change	0.00%	20.09%	20.11%	20.01%	19.91%	19.79%	19.86%	19.94%	20.01%	20.09%	20.16%	20.00%
United States												
Production						(Million Gallons)						
Baseline	3886	4729	5196	5786	6396	6948	7479	7917	8333	8732	9123	7064
Scenario D	3886	4745	5288	6036	6721	7352	7870	8196	8584	9066	9657	7351
Percentage Change	0.00%	0.32%	1.76%	4.33%	5.08%	5.82%	5.22%	3.53%	3.02%	3.83%	5.86%	3.88%
Total Ethanol Consumption												
Baseline	4007	4950	5563	6168	6786	7381	7935	8375	8775	9147	9507	7459
Scenario D	4007	5429	6080	6796	7565	8354	9193	10044	10883	11724	12593	8866
Percentage Change	0.00%	9.68%	9.29%	10.18%	11.47%	13.19%	15.86%	19.93%	24.03%	28.17%	32.46%	17.43%
Net Imports												
Baseline	127	217	370	385	393	434	456	459	443	417	386	396
Scenario D	127	681	794	760	845	1001	1324	1851	2301	2659	2934	1515
Percentage Change	0.00%	213.88%	114.41%	97.24%	114.98%	130.79%	190.10%	303.03%	419.30%	538.05%	659.87%	278.17%
Composite Gasoline Consumption												
Baseline	139894	140974	143476	146739	149905	152843	154767	156718	158738	160850	162955	152797
Scenario D	139894	134131	136699	140232	143703	146946	148895	150893	152925	155019	157067	146651
Percentage Change	0.00%	-4.85%	-4.72%	-4.43%	-4.14%	-3.86%	-3.79%	-3.72%	-3.66%	-3.63%	-3.61%	-4.04%
Share of Fuel Ethanol in Composite Gasoline Consumption						(Ratio)						
Baseline	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.06	0.05
Scenario D	0.03	0.04	0.04	0.05	0.05	0.05	0.06	0.06	0.07	0.07	0.08	0.06
Percentage Change	0.00%	15.97%	15.31%	15.92%	16.93%	18.41%	21.17%	25.40%	29.71%	34.08%	38.65%	23.15%
Domestic Ethanol Price						(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	1.95
Scenario D	1.80	2.01	1.98	2.04	2.06	2.13	2.15	2.11	2.11	2.19	2.31	2.11
Percentage Change	0.00%	0.46%	3.00%	7.75%	10.03%	12.17%	11.42%	7.70%	6.61%	8.89%	14.92%	8.30%
Corn Farm Price						(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	2.38
Scenario D	1.86	2.05	2.18	2.31	2.40	2.46	2.50	2.52	2.55	2.58	2.62	2.42
Percentage Change	0.00%	0.23%	1.35%	1.93%	1.93%	1.87%	1.67%	1.31%	1.31%	1.60%	2.14%	1.54%
DDG Price						(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	78.47
Scenario D	77.66	76.63	79.02	79.75	79.69	79.56	79.49	78.93	78.17	77.05	75.81	78.41
Percentage Change	0.00%	0.05%	0.05%	0.01%	-0.07%	-0.18%	-0.20%	-0.06%	-0.01%	-0.05%	-0.24%	-0.07%
Gluten Feed Price												
Baseline	50.68	52.97	55.63	57.64	58.97	59.90	60.60	60.69	60.73	60.52	60.31	58.80
Scenario D	50.68	53.05	56.02	58.20	59.55	60.44	61.08	61.09	61.15	61.02	60.93	59.25
Percentage Change	0.00%	0.15%	0.69%	0.97%	0.98%	0.90%	0.80%	0.66%	0.69%	0.82%	1.03%	0.77%
Gluten Meal Price												
Baseline	278.20	259.78	266.70	266.95	265.16	264.64	263.72	261.19	257.51	252.94	248.07	260.67
Scenario D	278.20	259.74	265.64	265.41	263.50	262.76	261.92	259.92	256.26	251.25	245.44	259.18
Percentage Change	0.00%	-0.02%	-0.40%	-0.58%	-0.63%	-0.71%	-0.68%	-0.49%	-0.49%	-0.67%	-1.06%	-0.57%
Corn Oil Price						(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	27.63
Scenario D	25.46	24.25	25.52	26.50	27.05	27.54	28.10	28.58	29.01	29.51	30.09	27.62
Percentage Change	0.00%	0.01%	-0.36%	-0.21%	-0.07%	0.05%	0.08%	0.05%	-0.01%	0.01%	0.08%	-0.04%

Table D: (continued)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Brazil												
Production						(Million Gallons)						
Baseline	4768	5087	5496	5700	5889	6092	6287	6479	6670	6867	7079	6165
Scenario D	4768	5342	5801	5984	6217	6502	6901	7465	8033	8558	9041	6984
Percentage Change	0.00%	5.01%	5.56%	4.99%	5.57%	6.72%	9.76%	15.22%	20.44%	24.62%	27.73%	12.56%
Total Ethanol Consumption												
Baseline	4196	4326	4503	4643	4786	4918	5058	5212	5383	5571	5779	5018
Scenario D	4196	4176	4411	4571	4690	4795	4860	4895	4991	5132	5310	4783
Percentage Change	0.00%	-3.45%	-2.04%	-1.54%	-2.02%	-2.51%	-3.92%	-6.09%	-7.28%	-7.89%	-8.12%	-4.49%
Anhydrous Ethanol Consumption												
Baseline	1398	1376	1394	1414	1439	1461	1464	1467	1470	1474	1478	1444
Scenario D	1398	1263	1292	1320	1342	1362	1349	1326	1313	1305	1302	1318
Percentage Change	0.00%	-8.21%	-7.27%	-6.69%	-6.70%	-6.74%	-7.84%	-9.58%	-10.69%	-11.41%	-11.88%	-8.70%
Hydrous Ethanol Consumption												
Baseline	2798	2950	3109	3229	3348	3458	3594	3745	3913	4098	4302	3574
Scenario D	2798	2913	3118	3252	3347	3433	3511	3568	3679	3827	4008	3466
Percentage Change	0.00%	-1.23%	0.30%	0.71%	-0.01%	-0.71%	-2.32%	-4.72%	-6.00%	-6.62%	-6.83%	-2.74%
Net Exports												
Baseline	607	769	991	1056	1102	1174	1229	1267	1287	1296	1299	1147
Scenario D	607	1182	1387	1410	1527	1708	2045	2578	3046	3429	3734	2205
Percentage Change	0.00%	53.81%	39.88%	33.55%	38.66%	45.52%	66.40%	103.46%	136.79%	164.69%	187.32%	87.01%
Share of Sugarcane in Ethanol Production						(Ratio)						
Baseline	0.51	0.51	0.52	0.52	0.53	0.53	0.54	0.54	0.55	0.55	0.56	0.53
Scenario D	0.51	0.53	0.54	0.54	0.54	0.55	0.57	0.59	0.61	0.62	0.64	0.57
Percentage Change	0.00%	3.71%	2.96%	2.45%	3.00%	3.73%	5.71%	8.95%	11.37%	13.09%	14.25%	6.92%