Agribusiness & Applied Economics Report No. 626 April 2008

An Economic Analysis of Corn-based Ethanol Production

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Acknowledgments

The authors extend appreciation to David Saxowsky, Cole Gustafson and Bruce Dahl for reviewing this manuscript, and to Edie Watts who helped prepare the manuscript.

Copies of this publication are available electronically at the following website: http://ageconsearch.umn.edu/. Please address your inquiries regarding this publication to the Department of Agribusiness and Applied Economics, North Dakota State University, P.O. Box 5636, Fargo, ND 58105-5636, phone 701-231-7441, fax 701-231-7400 or email ndsu.agribusiness@ndsu.edu.

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Abstract

A global multi-commodity simulation model was developed to estimate the impact of changes in ethanol production on the U.S. corn industry. Increased ethanol production under the Energy Acts of 2005 and 2007 resulted in a significant increase in the price of corn. However, for corn-based ethanol production, the break-even price of corn is approximately $4.52 per bushel with a federal subsidy of $0.51 per gallon of pure ethanol and $2.50 gasoline. With a corn price of $4.52, the economically desirable ethanol production is approximately 11 billion gallons. In order to produce 15 billion gallons of corn-based ethanol and to maintain the price of corn at $4.52 per bushel, supply of corn in the U.S. should be increased substantially through increases in corn yield rather than increases in corn acres.

The increased price of corn leads to major structural changes in the corn industry in the United States as well as other corn producing and consuming countries. Corn production would increase in response to higher price levels, corn used for livestock feed may decrease, and U.S. exports decrease due mainly to a surge in corn used for ethanol production. This decrease in U.S. exports should be met by additional production in other countries.

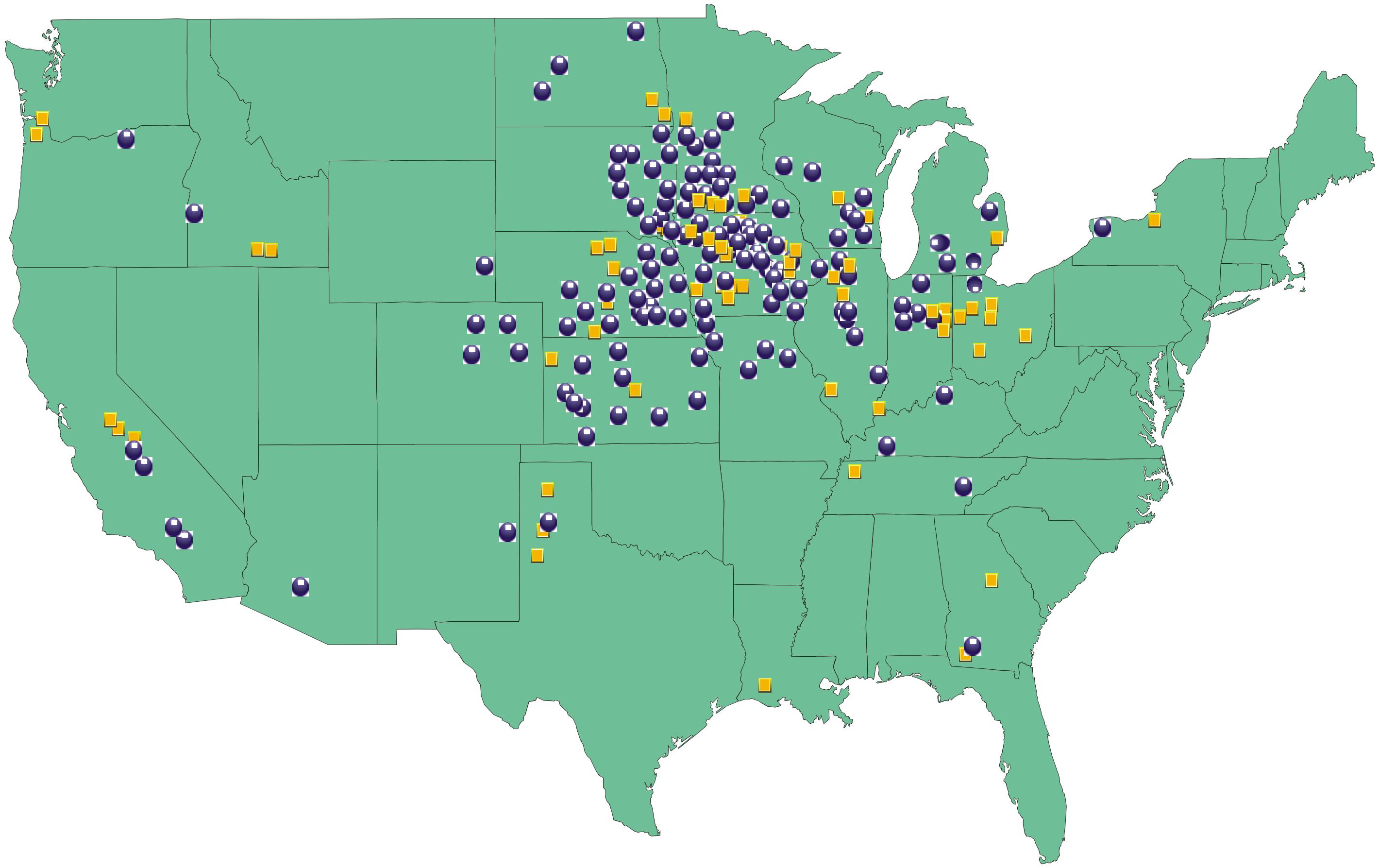
The increased price of corn also leads to increases in the prices of soybeans, wheat, high fructose corn syrup (HFCS), and agricultural inputs, such as land value and cash rent, fertilizer and chemicals, and farm equipment. In addition, the current price of corn has resulted in an increase in the production cost of livestock. The increase in prices of agricultural commodities and inputs would cause increases in retail prices of food in the U.S.

An Economic Analysis of Corn-based Ethanol Production

Introduction

Industrial use of corn has increased dramatically during the past two decades. The most recent increases are due to increasing ethanol production during 2006 and 2007. High fructose corn syrup (HFCS) production, used as a substitute for sugar in the soft drink industry, caused a major increase in demand for corn during the 1980s, utilizing 500 million bushels of corn per year. During the late 1990s and early in the 2000s, the amount of corn required for ethanol production increased by approximately 1 billion bushels. These two non-traditional uses of corn consume almost 40% of the current U.S. corn crop.

Significant growth in ethanol production is likely to continue given recent federal legislation mandating increased ethanol use. The Energy Security Act of 2005 includes a renewable fuels standard that requires annual U.S. ethanol and biodiesel consumption to total 7.5 billion gallons by 2012. Ethanol production has more than doubled since 2004 to meet this goal. Further, the Energy Independence and Security Act (EISA) of 2007 sets a high renewable fuel standard (RFS) requiring fuel producers to use at least 36 billion gallons of bio-fuels by 2022. The Act requires 9 billion gallons of bio-fuels to meet the standard in 2008, 13.2 billion gallons of ethanol and bio-fuel by 2012, and 15 billion gallons by 2016. As a result of this increased demand, a number of plants are being completed. The current ethanol production capacity is 7.9 billion gallons and additional capacity of 5.5 billion gallons is under construction in the United States. Figure 1 shows existing plants and those under construction.



Bio-refineries in Production (139)

Bio-refineries under Construction (62)

Source: Renewable Fuels Association

Figure 1. Location of U.S. Bio-refineries

Our study examines the impact of alternative levels of corn-based ethanol production on the U.S. and world corn industry. This study develops a global multi-commodity model focusing on the corn-based ethanol industry. Various scenarios with different ethanol production levels are evaluated in order to estimate the impact on the U.S. and world corn industries. The effects of the new RFS under the Energy Acts of 2005 and 2007 are analyzed.

Several studies have indicated that increased ethanol production has a positive impact on corn prices. U.S. Department of Agriculture (USDA) Chief Economist Keith Collins testified in 2000 that a phase-out of methlyl tertiay butyl ether (MTBE) would result in an increase of 500 million bushels of corn used for ethanol per year, and the USDA analysis found that this increase in corn demand would raise the average price of corn by $0.14 per bushel.

Otto and Gallagher (2001) analyzed the impact in Iowa from a West Coast MTBE ban and a nation-wide MTBE ban. Under the West Coast ban, they found that annual ethanol production increased in Iowa by 193 million gallons, using 77.2 million bushels of corn. The statewide corn price increased $0.043 per bushel, resulting in a $74.8 million income gain to corn farmers. This price benefit is expected to be concentrated in the 50-mile radius surrounding a new ethanol facility. Their analysis indicates that producers near the facility could expect a $0.20 per bushel premium that diminishes as distance and transportation costs to the facility increase. With an extended MTBE ban, Otto and Gallagher estimated that ethanol production in Iowa increases by 505.9 million gallons, using 202.4 million bushels of corn. The increased production causes the statewide corn price to increase $0.109 per bushel, resulting in a $189.7 million income gain to corn farmers.

In a 2004 study, Ferris and Joshi estimated the impact that a MTBE ban, a proposed renewable fuels standard, potential rising petroleum prices, and the proposed revision of the eight-hour ozone air quality standards could have on ethanol production and key agricultural variables. They estimated that by 2010, ethanol production would increase from 2.5 billion gallons in 2003 to a range from 3.3 to 4.7 billion gallons. Under a scenario in which ethanol production increases to 4.7 billion gallons in 2010, they found that corn prices received by farmers would increase by 18% (in comparison to the base case) in 2007 and by 7% in 2010. They estimated that corn acreage would increase by 4%, and that higher corn prices would encourage more feeding of wheat, causing a 4% increase in wheat acreage. They also found that soybean meal used for feed would decrease 3.6%, soybean acreage would decrease 3%, livestock production would decrease because of higher feed costs, livestock prices would increase, and soybean oil price would decrease 5% because of increased corn oil production. The estimate by Ferris and Joshi of 4.7 billion gallons of ethanol produced in 2010 is likely to be on the conservative side. Bothast (2005) expects ethanol demand to more than double in the next decade from the 3.4 billion gallons produced in 2004.

The Food and Agricultural Policy Research Institute (FAPRI) (2005) conducted a study following the passage of the 2005 energy bill to estimate the impact of the new renewable fuels standard. Under FAPRI's baseline scenario, before the new energy bill, corn use for ethanol was projected to increase from the 2004 level of 1.4 billion bushels to an average of 1.93 billion bushels for the 2010/11 to 2014/15 time period. With the addition of the renewable fuels standard, the FAPRI estimate of corn use for ethanol increases an additional 632 million bushels per year, to 2.57 billion bushels. FAPRI estimated that the additional 632 million bushels of corn used for ethanol would increase the price received by farmers by 12.5 cents per bushel, or 5.41%. They found that as a result of the energy bill, corn production would increase 0.92%, and total use would increase 0.94%. Corn use for ethanol would increase 32.6%, but feed use and exports would decrease 3.3% and 11.4%, respectively, due to higher prices.

McNew and Griffith (2005) examined the impact of ethanol plants on local grain prices, using data for a number of local cash markets near newly opened ethanol plants. They found that, on average across plants, corn prices increased 12.5 cents per bushel at the plant site, and some positive impact on price was felt up to 68 miles from the plant.

Unlike these studies, the model developed for this study includes corn as well as other commodities competing with corn for crop land to examine supply responses to price by allowing interactions among the crops. The model also includes major corn producing and consuming countries to evaluate the impact of corn-based ethanol production not only on the U.S. corn industry but also on the world corn industry.

Trends in corn supply and use over the last several years are identified in the next section. A description of the government support which has encouraged the rapid expansion of ethanol production is included in this section. The next section presents a global multi-commodity partial equilibrium econometric model for the U.S. and world corn industries developed for this study. The results under alternative levels of corn-based ethanol production are presented in the third section. The last section presents the conclusions of this study.

The Energy Acts of 2005 and 2007 and the U.S. Corn Industry

U.S. corn production has followed a long-term upward trend, due mostly to yield increases (Figure 2). Annual U.S. corn production averaged 4.1 billion bushels in the 1960s, 6.0 billion bushels in the 1970s, 7.2 billion bushels in the 1980s, 8.6 billion bushels in the 1990s, and 10.1 billion bushels from 2000-2004. Production reached a high of 12.8 billion bushels in 2007. The area harvested has not increased significantly over time, except for 2007, but yields have consistently risen, doubling since the 1960s. Also, the corn production regions have shifted to the west and north. The United States imports a minimal amount of corn, usually about 10-15 million bushels per year, which is well below 1% of domestic production.

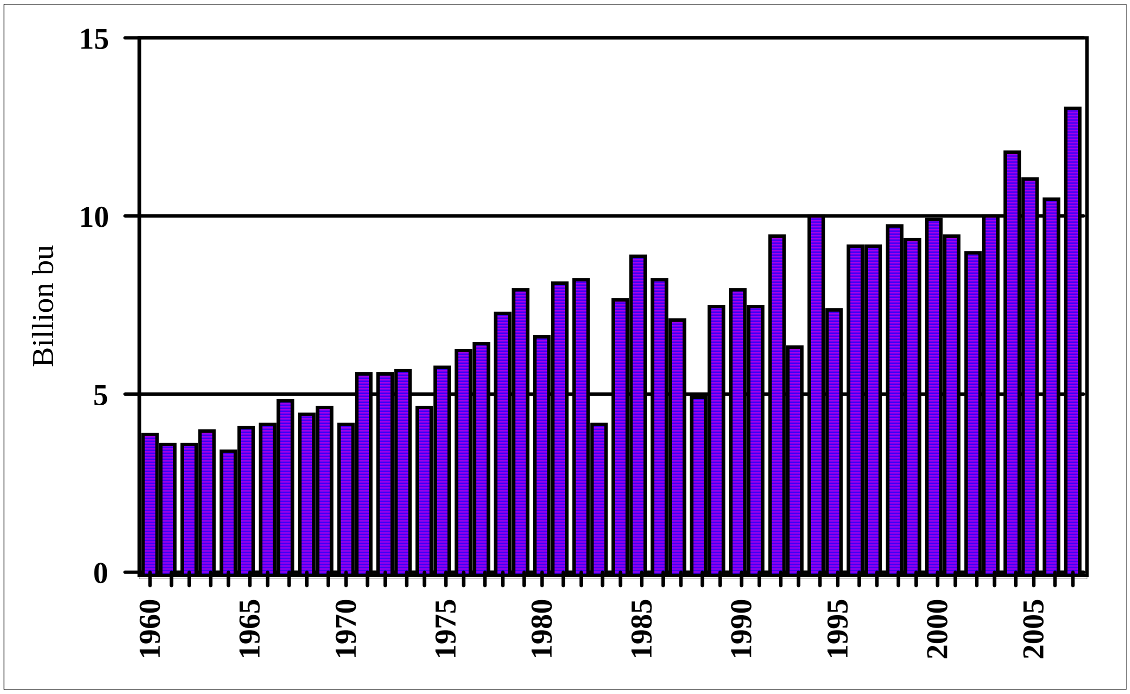


Figure 2. U.S. Corn Production

The majority of U.S. corn production has been used domestically for livestock feed. Domestic feed use has increased over time, reaching 6.2 billion bushels in 2004 before falling to about 6.0 billion bushels in 2006 and 2007 (Figure 3). The other uses of corn include food, seed, industrial uses, and exports. U.S. corn exports have been stagnant over the last 25 years, averaging approximately 1.8 billion bushels per year. Food and industrial uses, on the other hand, have risen steadily, reaching 4.5 billion bushels in 2007. Feed use has averaged about 60% of production, though it declined to 52% in 2004. The percentage of production exported averaged 27% in the 1980s, but has since declined to approximately 15-20%. Food, seed, and industrial use has increased to about 40% of production.

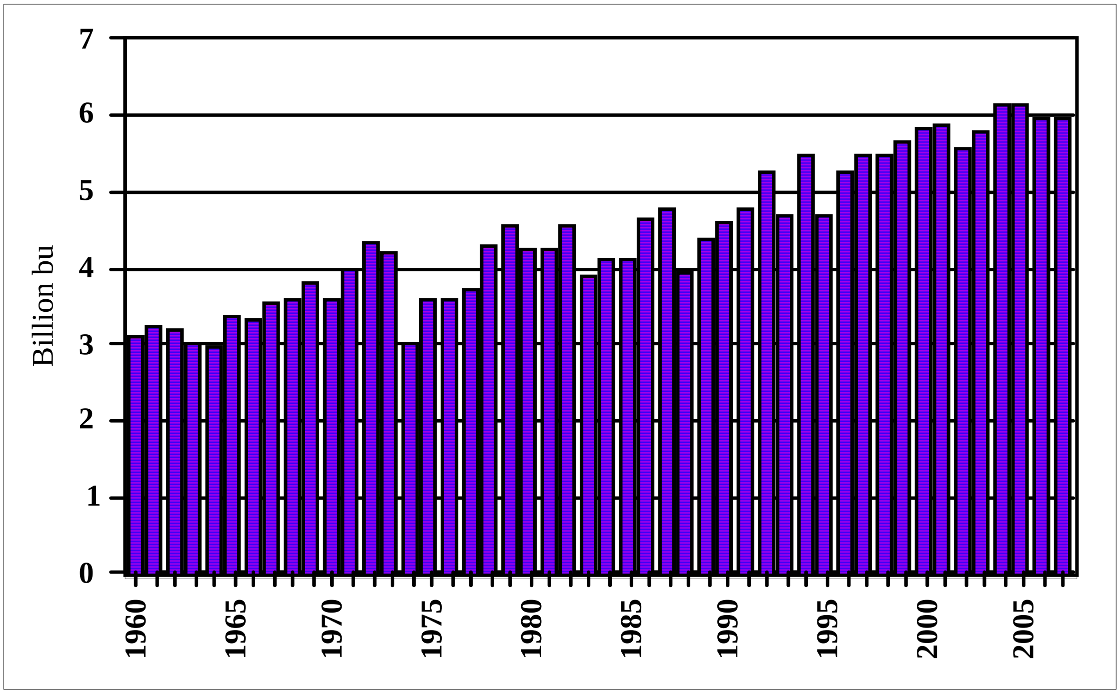


Figure 3. U.S. Consumption of Corn for Livestock Feed

The food and industrial uses of corn include ethanol, HFCS, glucose and dextrose, starch, cereals and other food products, and alcohol for beverage and industrial use (Figure 4). Seed use is a very small component of total use, averaging 21 million bushels per year. Ethanol accounted for the largest percentage of food and industrial use, followed by HFCS, starch, glucose, and dextrose in 2007.

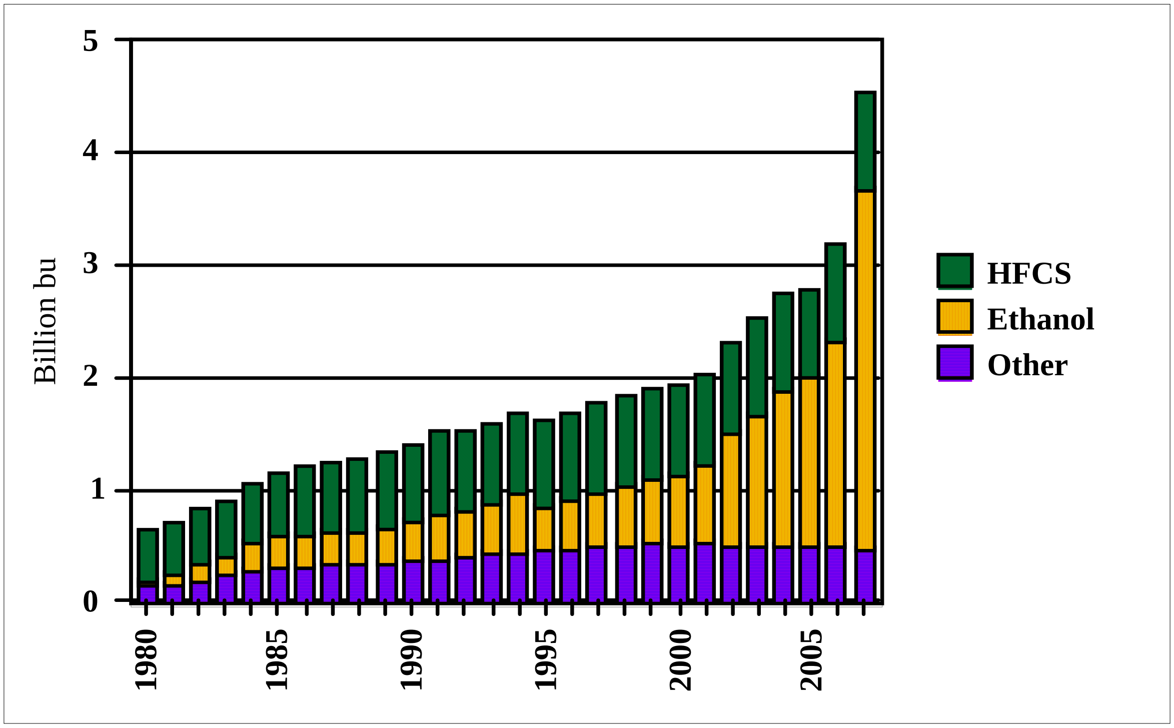


Figure 4. U.S. Industrial Uses of Corn

The recent increase in food and industrial use of corn is due largely to ethanol production. The amount of corn devoted to ethanol steadily increased from almost nothing prior to the 1980s to about 400 to 500 million bushels annually in the mid 1990s. Since then, ethanol production has increased sharply, consuming 1.4 billion bushels of corn in 2004 and 3.7 billion bushels in 2007. Figure 5 shows ethanol production in gallons since 1980. Ethanol production increased in every year but 1996. Production has more than doubled over the last five years, increasing from 2.9 billion gallons in 2003 to 7.9 billion gallons in 2007, and is expected to continue to rise.

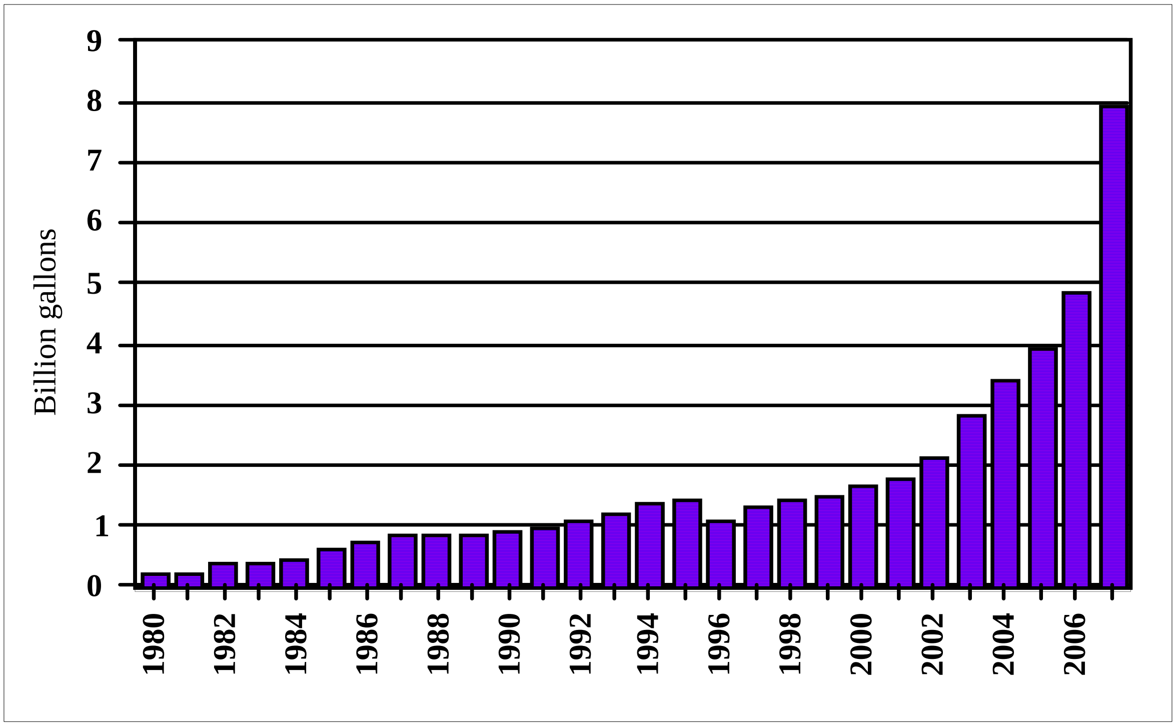


Figure 5. U.S. Ethanol Production

HFCS production increased significantly in the 1980s and the early-to-mid 1990s, but peaked in the late 1990s. The amount of corn consumed by HFCS production increased steadily from 165 million bushels in 1980 to 540 million bushels in 1999. Since then, HFCS production has stabilized, and declined slightly in 2004. HFCS price dropped sharply in the mid 1990s as production increased, and then rebounded slightly when production leveled off. Recently, HFCS price has increased due to higher corn prices. Other food and industrial uses of corn, such as starch, have been gradually increasing.

The rapid increase in ethanol production has been driven to a large extent by government policy. The RFS in the Energy Acts of 2005 and 2007 assures increased ethanol demand for several years in the future. The 2005 legislation requires that the combined use of ethanol and biodiesel must equal at least 4 billion gallons in 2006, and this requirement will increase each year to 7.5 billion gallons in 2012. The EISA of 2007 sets a much higher RFS of 36 billion gallons of bio-fuels by 2022. The RFS requires 9 billion gallons of conventional bio-fuels by 2008, 13.2 billion gallons by 2012, and 15 billion gallons by 2015. Since corn-based ethanol is considered to be a conventional bio-fuel in the Act, the mandated ethanol production under the Acts is mainly corn-based ethanol.

Ethanol has historically cost more per gallon than gasoline. Federal subsidies, import tariffs, and mandated use under the energy acts help the ethanol industry overcome its price disadvantage, encouraging production. The ethanol industry receives a production tax credit of $0.51 per gallon of pure (100%) ethanol. Small ethanol producers also receive an income tax credit of $0.10 per gallon for the first 15 million gallons. This credit is restricted to ethanol producers whose total plant output does not exceed 60 million gallons of ethanol annually.

In addition, the ethanol industry benefits from other government policies. Certain areas of the country are required by federal policy to blend an oxygenate into gasoline to help the fuel burn cleaner and reduce air pollution. Methyl tertiary butyl ether (MTBE) has been the primary oxygenate added to gasoline. Ethanol has been the second-most used oxygenate. A growing list of states has banned the use of MTBE after it was found to pollute ground water which provided a growing new market for ethanol.

Several states also have policies promoting ethanol use, besides their MTBE bans. Minnesota, for example, requires all gasoline in the state to consist of 10% ethanol. Recent legislation requires this to increase to 20% by 2013. In 2005, North Dakota temporarily reduced the state tax on ethanol-blended gasoline fuel containing 85% ethanol (E85), from $0.21 to $0.01 per gallon.

The Federal government has imposed a $0.54 per gallon import tariff on foreign ethanol. The tariff increases the cost of imported ethanol supporting domestic production.

Federal and state governments have supported ethanol production for economic, environmental, and national security reasons. Another reason for the support is that it is believed that ethanol production helps farmers by increasing demand for corn and, therefore, raising its price. Ethanol production adds value to corn and could be beneficial to rural economies by creating jobs. Ethanol production also is supported for environmental reasons because it is cleaner than gasoline and for national security reasons because it could help lessen U.S. dependence on foreign oil, although corn-based ethanol could replace only a small percentage of U.S. gasoline consumption.

An Econometric Simulation Model for the U.S. and World Corn Industries

The empirical model for this study is a global multi-commodity partial equilibrium econometric simulation model, focusing on the world corn industry. The world is divided into six regions in the model, the United States, Argentina, Brazil, China, the European Union (EU) and the rest of the world (ROW). Commodities considered in this study are corn and soybeans, which compete with each other for crop-land. Wheat also competes with corn for crop-land. However, wheat is not included in the model since the competition is limited to a small area of the plains states in the U.S. Supply, demand, and carry-over stock equations are estimated for corn and soybeans in all the countries/regions and included in the model. Excess supply equation for each crop and country are derived from the corresponding behavioral equations in the model. The market clearing equilibrium for each crop is obtained by setting the sum of excess supply equations for all the countries/region equal to zero. Since there are two equilibrium conditions (for corn and soybeans) and two prices (for corn and soybeans), the equilibrium conditions are solved simultaneously for the prices of corn and soybeans, which satisfy market equilibrium in the world corn and soybeans industries. The model also provides equilibrium demands and supplies of corn and soybeans. The model is used to forecast production, consumption, exports, and price of each crop for the 2008-2016 period. It is assumed that U.S. and world agricultural policy remains unchanged, normal weather patterns continue, and there are no dramatic macroeconomic or political changes for the period.

The behavioral equations of corn and soybeans are estimated for the countries/regions and included in the model. Since the behavioral equations are similar between the two crops, those for the corn industry are presented in the following section.

Corn Supply

Harvested area is affected by the lagged real prices of corn, soybeans, and wheat. Real corn price is expected to have a positive impact on harvested area, and the lagged prices of soybean and wheat are expected to have a negative impact on harvested area, since soybeans and wheat are competing crops. In addition, lagged harvest area (HA_{t-1}) is included as an independent variable to capture dynamics in a producer's response (Nerlove). The harvested area equation is specified as:

$$HA_t = \mathrm{f}(HA_{t-1}, P^c_{t-1}, P^{sb}_{t-1}, P^w_{t-1}) \tag{1}$$

where HA_t = harvested area in time t, P^c_{t-1} = corn price in time t-1, P^{sb}_{t-1} = soybean price in time t-1, and P^w_{t-1} = wheat price in time t-1.

The yield equation includes the real corn price and a trend variable to account for advance in farming technology. The yield equation is specified as:

$$Y_t = \mathrm{f}(P^c_t, T_t) \tag{2}$$

where Y_t = yield in time t, P^c_t = corn price in time t, and T_t = trend.

Total U.S. corn production is harvested area times yield, as follows:

$$Pd_t = HA_t, *Y_t \tag{3}$$

where Pd_t = U.S. production in time t.

Corn Demand

Domestic demand for corn is comprised of domestic consumption and carry-over. Domestic consumption consists of feed demand, demand for ethanol production, and other industrial uses.

<u>Feed Use</u>: Feed use is specified as a function of the price of corn and number of cattle on feed, as follows:

$$Fd_t = \mathrm{f}(P^c_t, N^c_t) \tag{4}$$

where Fd_t = the quantity of corn used for feed in time t, P^c_t = real price of corn in time t, and N^c_t = number of cattle on feed in time t.

It is expected that feed use has a negative relationship with corn price while the number of cattle on feed will have a positive impact on feed use.

When ethanol is produced from corn in the U.S., by-products can be used for animal feeding. Thus, the quantity of by-product (*BP*) from ethanol should be subtracted from Fd_t as:

$$NFD_t = Fd_t - BP_t\,. \tag{5}$$

The quantity of by-product (bp) from ethanol production for feed is calculated as:

$$BP_t = a(b{*}E_t) \tag{6}$$

where E_t = corn used for ethanol, a = conversion rate from by-product to animal feed, and b = conversion rate from corn to by-product.

We assumed that a=70% and b=30%, and the by-products are being fed to cattle. One pound of corn used in ethanol production will produce about 0.3 pounds of by-product that can be fed to livestock (FAPRI 2005, Lardy 2003, Iowa Beef Center 2002). One pound of by-product can substitute for about 0.7 pounds of corn (FAPRI 2005, Oleson 2005).

<u>Corn Used for Ethanol Production</u>: It is expected that corn-based ethanol production will have a negative relation with the price of corn and a positive relation with gasoline prices. A dummy variable is used to indicate the year in which California mandated the removal of MTBE from gasoline within the state, which created an immediate increase in demand for ethanol. Demand for corn for ethanol use is specified as:

$$E_t = \mathrm{f}(P^c_t, P^g_t, D_t, E_{t-1}) \tag{7}$$

where E_t = corn used for ethanol production in time t, P^c_t = real price of corn in time t, E_{t-1} = corn used for ethanol production in time t-1, and P^g_t = gasoline price. The lagged dependent variable is used as an independent variable to capture dynamics in the use of corn for ethanol production (Nerlove).

Corn Used for Other Industrial Purposes: It is expected that high corn price will have a negative impact on the industrial use of corn for other purposes, such as HFCS, starch, glucose, and dextrose, and that high soybean price will have a positive impact on the industrial use of corn. The demand model for other industrial use is specified as:

$$I_t = \mathrm{f}(P^c_t, P^{sb}_t) \tag{8}$$

where I_t = the quantity of corn used for other industrial uses in time t, P^c_t = real price of corn in time t, P^{sb}_t = real price of soybeans.

Carry-over Stocks: Corn price should have a positive impact on carry-over stock. As the price of corn increases, total production of corn increases while demand for corn decreases, resulting in increases in carry-over stock. The opposite will occur as the price of corn decreases. Thus, the carry-over stocks equation is specified as a function of the price of corn and lagged carry-overstock as follows:

$$ES_t = \mathrm{f}(P^c_t, ES_{t-1}) \tag{9}$$

where ES_t = carry-over stocks.

ROW Import Demand and Export Supply: ROW import demand is the summation of the import demand from other countries (Canada, Taiwan, Mexico, Japan, South Korea, Algeria, Egypt, and Latin American countries). Corn price is expected to have a negative impact on import demand, while soybean price is expected to have a positive impact. The import demand model for the ROW is specified as:

$$ED^w_t = \mathrm{f}(P^c_t, P^{sb}_t, Y_t) \tag{10}$$

where ED^w_t = ROW import demand for corn in time t, P^c_t = real world price of corn in time t, P^{sb}_t = real world price of soybeans in time t, and Y_t = weighted average real per capita income in t.

ROW export supply increased from about 700 million bushels in 1998 to 1 billion bushels in 2006. ROW export supply is a function of export price and a trend variable to capture changes in technology. The ROW excess supply equation is specified as:

$$ES^{w}_{t} = f(EP_t, T_t) \tag{11}$$

where ES^{w}_{t} = ROW excess supply in time t, EP_t = real export price of corn in time t, and T_t= trend variable. It is expected that both the export price of corn and trend variable will have a positive impact on excess supply.

Similarly, behavioral equations for soybeans are specified in the same way presented in Equations 1 through 11. One exception is the specification of soybean demand. While demand for corn is divided into demand for feed use and demand for industrial use, demand for soybean is only for domestic consumption.

Equilibrium Condition

Equilibrium conditions for corn and soybeans are established in such a way that the sum of all excess supply of corn in all countries/regions equals zero. Excess supply equals beginning stocks plus production minus domestic feed use, ethanol use, other industrial use, and carry-over stocks, as follows:

$$XS^{n}_{t} = ES_{t-1} + Pd_t - NFd_t - E_t - I_t \tag{12}$$

where XS^{n}_{t} = excess supply in country/region n in time t. excess supply of each crop is positive for exporting country and negative for importing country.

The sum of all the excess supply and ROW excess supply of each crop should be equal to zero under the equilibrium condition, as follows:

$$\sum_{1}^{n} XS^{n}_{t} + (ES^{w}_{t} - ED^{w}_{t}) = 0.0 \text{ for corn and soybeans.} \tag{13}$$

Equation 13 represents two equilibrium conditions; one for corn and the other for soybeans. Since these equations are a function of prices of corn and soybeans, the equations are solved simultaneously for the prices of corn and soybeans. Equilibrium demands, supply and carry-over stocks corn and soybeans also are obtained. Since the base year for the simulation is 2007, the simulation is continued for 10 years until 2016. Because the Energy Acts of 2005 and 2007 increase corn-based ethanol production to 2012 and 2015, respectively, the simulation in 2016 is based on production level in 2012 and 2015.

Base and Alternative Scenarios

The federal renewable fuels standard in the 2005 Energy Act requires 7.5 billion gallons of ethanol or bio-diesel to be consumed annually by 2012. Domestically-produced corn-based ethanol will likely account for most of this mandate, but not all of it. FAPRI analysis assumed U.S. production of corn-based ethanol will increase to much more than 7.5 billion gallons in 2012 as a result of the requirements. Our study makes the same assumption. Scenario 1 in our analysis allows ethanol production to reach the mandated 7.5 billion gallon level by 2012 and continue to produce the same level until 2016. Since the U.S. produced approximately 4.5 billion gallons of corn-based ethanol in 2005, the additional increase is only 3 billion gallons in this scenario (Ethanol 7.5). The 2007 Energy Act sets the RFS at 15 billion gallons of bio-fuel, mainly corn-based ethanol, by 2015. To analyze this, Scenario 2 (Ethanol 15) increases ethanol production to 15 billion gallons by 2015 and maintains the same level of production in 2016. In addition, scenario 3 is introduced to examine the impact of a more aggressive policy for corn-based ethanol production. Scenario 3 (Ethanol 25) increases ethanol production to 25 billion gallons by 2015 and maintains the same level of production in 2016. Under these scenarios, ethanol production is increased an equal amount each year so it totals 15 billion and 25 billion gallons under scenarios 2, and 3, respectively, by 2015, and continue the same production level in 2016.

Data

Historical harvest area, yield, production, feed use, import demand, domestic consumption, and carry-over stocks data were obtained from the Production Supply & Demand database from the Economic Research Service (ERS) for the years 1980 to 2007. Corn and soybean prices and ethanol corn use were obtained from ERS. Gasoline prices, historical and forecasted, were obtained from the U.S. Department of Energy, and cattle on feed numbers were obtained from the National Agricultural Statistics Service (NASS). All price data were converted to real terms using the GDP deflator.

Results

The model was simulated with three different levels of corn-based ethanol production for the 2007-2016 period. Before simulation, the model is calibrated with the 2007 data.

The Price of Corn:

Table 1 displays the actual and the equilibrium prices of corn in 2007, 2008, 2012, and 2016 under the three scenarios. For the scenarios, ethanol production in 2007 is allowed at 6.5 billion gallons in Scenario 1, 7.5 billion gallons in Scenario 2, and 8.5 billion gallons in Scenario 3. Since the Energy Act of 2005 is effective from 2006 through 2012, ethanol production increases to 7.5 billion gallons by 2012 and continue to produce the same level through out 2016 in Scenario 1. In the scenario, the corn price increases from $3.65 per bushel in 2007 to $3.78 in 2008 and $4.40 in 2012, but is settled at $3.69 in 2016. The increases in corn price to 2012 is explained in Figure 6. This figure shows equilibrium conditions in the U.S. corn industry in the short and long run as demand for corn increases due to ethanol production. Before major increase in corn-based ethanol production, the equilibrium price and quantity of corn are P_0 and Q_0, respectively. However, if demand for corn shifts outward from D_0 to D_1 with a surge of corn-based ethanol production, the price of corn increases from P_0 to P_1 and the quantity of corn supplied increases from Q_0 to Q_1. Supply of corn in the long run, however, is more responsive to price than in the short run. As the price of corn increases, producers produce more corn in the U.S. and other countries by switching their land for corn production and increasing yields by adopting new farming technologies. As a result, supply curve shifts outward from S_0 to S_1. In the long run, corn price would be settled at P_2 which is lower than that in the short run price. Supply of corn would be Q_2.

As discussed before, the price of corn is $4.40 per bushel in 2012 because of a gradual increase of corn-based ethanol production. However, the price of corn is settled at $3.69 per bushel in 2016, which is much lower than the short run price, due mainly to additional increases in corn production in the U.S. as well as other countries.

Table 1. Projected Corn Price Under Ethanol Production of 7, 15, and 25 Billion Gallons

	2008	2012	2016
	----------------------dollars/ bushels------------------------		
7 billion gallons	3.78	4.4	3.69
15 billion gallons	3.91	4.75	5.28
25 billion gallons	4.07	5.94	7.11

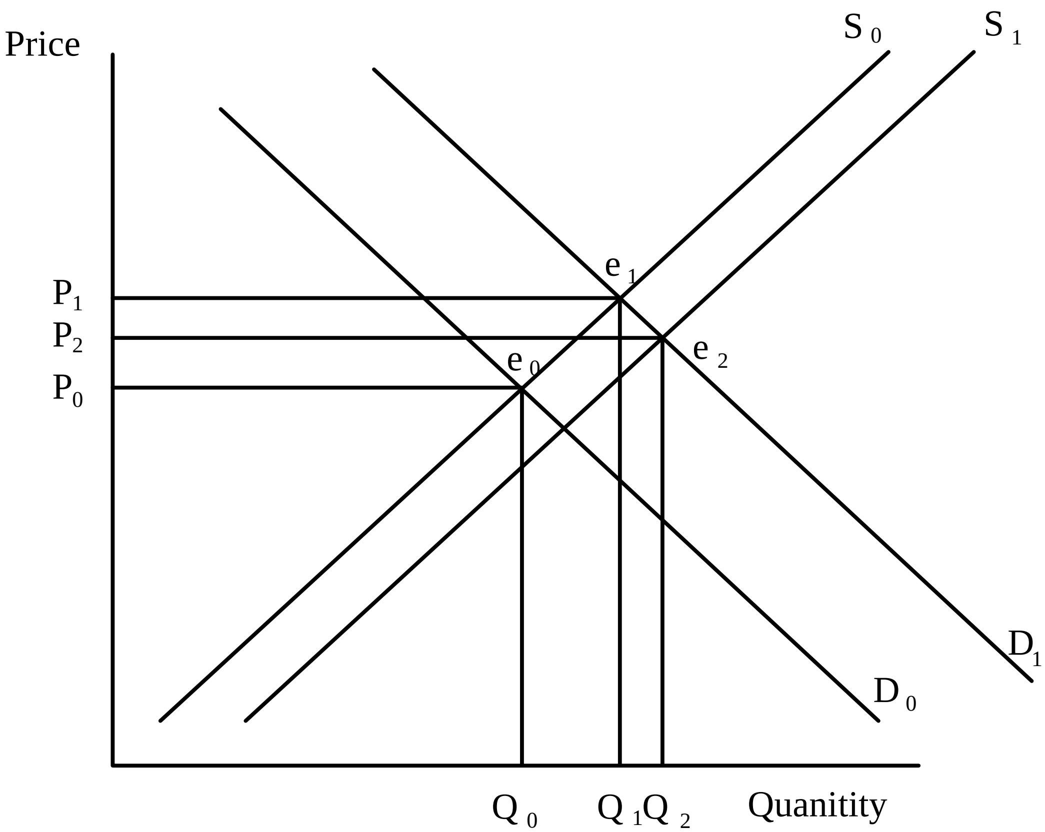


Figure 6. Short and Long Run Dynamic Price Responses
to Increasing Demand

In Scenario 2, the price of corn increases from $3.65 per bushel in 2007 to $3.91 in 2008, $4.75 in 2012 and $5.28 per bushel in 2016. The corn price rises 43% in 2016 if corn-based ethanol production increases from 7.5 billion to 15 billion gallons. In Scenario 3 with a corn-based ethanol production of 25 billion gallons, the price of corn is much higher; $4.07 per bushel in 2008, $5.94 per bushel in 2012 and $7.11 per bushel in 2016. The price of corn increases 93% in 2016 if ethanol production is increased from 7.5 billion to 25 billion gallons.

The relationship between corn price and quantity of corn-based ethanol production is estimated.. The model was run with ethanol production from 7.0 billion gallons to 25 billion gallons with an interval of 1 billion gallons per year. The price of corn was found for each level of ethanol production. Then corn prices are regressed with ethanol production in a linear functional form as

$$\text{Price} = \underset{(61.37)}{2.33} + \underset{(88.64)}{0.199}*\text{Ethanol} \qquad (14)$$

$R^2 = 0.973$

DF = 17

The relationship between the price of corn and ethanol production is statistically significant at the 1% significant level and positive, indicating that corn-based ethanol production has resulted in increases in the price of corn. The corn price flexibility with respect to ethanol production is calculated at mean levels of corn price and ethanol production from equation 14. The flexibility is 0.49, indicating that a 1% increase in ethanol production leads to a 0.49% increase in the price of corn.

The breakeven price of corn for ethanol production is estimated to be $4.52 per bushel with a production subsidy of $0.51 per gallon of ethanol with the assumed price of gasoline of $2.50 (Babcock). With the breakeven price, corn-based ethanol production would be 11 billion gallons based on Equation 14. Since the price of corn cannot exceed the breakeven price for profitable ethanol production, the long run price of corn would be equal to the breakeven price of corn with corn-based ethanol production of 11 billion gallon. However, the optimal production may change with changes in corn yield and the price of gasoline. With higher corn yield, the optimal ethanol production would be much larger at the given breakeven price of corn. Also, higher gasoline price would stimulate ethanol production.

To produce 15 billion gallons of corn-based ethanol by 2015 under the EISA of 2007 with the breakeven price of corn of $4.52, there should be sufficient increases in supply of corn in the U.S. to meet increasing demand for corn for ethanol production. The increase in supply of corn could come from yield increases of corn above the historical trend line through higher input use. The National Corn Growers Association (NCGA) indicated that the United States could produce

15 billion bushels of corn by 2015, up from about 10.5 billion bushels in 2006 (NCGA 2007). It indicated that, based on historic trends, corn yields will increase from about 150 bushels/acre in 2005 and 2006 to 173-180 bushels/acre by 2015.

Alternatively, the increase in land planted to corn could come from Conservation Reserve Program (CRP) acres. There are about 37 million acres of CRP land in the United States (Farm Service Agency, March 2007). Some portion of the CRP land could be converted to produce corn. However, converting the CRP land for corn production may be limited because of the following reasons. First, the CRP land, with major concentrations in Texas, Kansas, and North Dakota, is of questionable quality for agricultural production, especially corn production. Some of this land could be switched into wheat, but switching into corn would be unlikely. Second, farmers with CRP land could opt out of the contract, but they would incur penalties to do so (Pates 2006). Thus, early opt-outs are unlikely without a change in the rules. In sum, it is unlikely that much CRP area would be returned to production without a change in the rules. Furthermore, using some CRP land for corn production could lead to the destruction of wildlife habitat and increase erosion.

An alternative for increasing corn production is to use acres currently devoted to production of other commodities. Most of the acres would come from soybeans, followed by wheat. If the United States planted over 90 million acres of corn, there would be a reduction of about 10 million acres or more in land planted to wheat and soybeans. This implies that expansion of corn acres to produce targeted amounts of corn-based ethanol may affect U.S. agriculture significantly in terms of production of all other agricultural commodities. If corn production cannot keep pace with the growing demand created by the ethanol industry, corn price will rise and the supply of corn available for feed use or export will become limited. Prices of other commodities could rise as acres shift to corn production. The increased price of corn affects livestock production in the United States, and it could significantly affect production costs of agricultural commodities through increases in land values, cash rents, prices of fertilizer and chemicals, and prices of other inputs. The increased production costs will make U.S. agriculture less competitive in global markets and increase prices of food in the United States.

Production, Utilization, and Export of Corn:

Production of corn increases from 12.5 billion bushels in 2008 to 13.9 billion bushels in 2012 as a result of increased corn price under Scenario 1 (Table 2). Corn production increases further to 14.5 billion bushel in 2016 even though the price of corn decreases. This is mainly because the model allows corn yield to increase based on the historical trend. Under Scenario 2, corn production increases to 14.8 billion bushels in 2012 and 16.2 billion bushels in 2016. Corn production increases further under Scenario 3; 15.5 billion bushels in 2012 and 18.2 billion bushels in 2016. The increases in corn production are due mainly to increases in corn acres as well as corn yields based on the historical trend.

Table 2. Projected Corn Production and Utilization of Corn Under Ethanol Production of 7, 15, and 25 Billion Gallons

	2008	2012	2016
Production	----------------------billion bushels----------------------		
7 billion gallons	12.5	13.9	14.5
15 billion gallons	12.5	14.8	16.2
25 billion gallons	12.5	15.5	18.2
Exports			
7 billion gallons	2.7	3.2	3.8
15 billion gallons	2.5	2.4	2.2
25 billion gallons	2.2	1.1	0.5
Feed Use			
7 billion gallons	5.2	5.3	5.4
15 billion gallons	5.2	5.1	5
25 billion gallons	5.2	4.8	3.8
Ethanol Use			
7 billion gallons	2.5	2.5	2.5
15 billion gallons	2.8	4.1	5.4
25 billion gallons	3.2	6	8.9

Corn demanded for feed uses is generally known to be inelastic to the price of corn primarily because there are few corn substitutes for animal feeding in the United States. There are very few changes in corn used for feed in Scenarios 1 and 2, but there is a 37% decrease in feed use in Scenario 3. However, most of the reduction is replaced by dry distillers grain (DDG) which is a by-product in ethanol processing. Corn for ethanol production increases 93% under Scenario 2 and 178% under Scenario 3. Exports increase under Scenario 1 due mainly to increase in production, but decrease under Scenarios 2 and 3 as more corn is used for ethanol production.

Table 3 presents corn production in major corn producing countries under Scenarios 1 through 3. Corn production in Argentina remains the same for the 2008-2016 period in Scenario

1, but increases 3% under Scenario 2 and 8% under Scenario 3. However, corn production in Brazil and the EU increase significantly; 20-29% increase for the 2008-2016 period in Brazil and 26-39% increase in the EU. There are no changes in corn production in China for the time period under the scenarios mainly because no arable land is available for additional corn production in China.

Table 3. Projected Corn Production in Major Corn Utilization Countries/regions Under Ethanol Production of 7, 15, and 25 Billion Gallons

	2008	2012	2016
Argentina	-----------------------million bushels--------------------		
7 billion gallons	807	807	821
15 billion gallons	809	823	832
25 billion gallons	812	852	875
Brazil			
7 billion gallons	1692	1877	2027
15 billion gallons	1694	1907	2125
25 billion gallons	1701	1950	2199
China			
7 billion gallons	5544	5874	6091
15 billion gallons	5544	5874	6091
25 billion gallons	5544	5874	6091
European Union			
7 billion gallons	2729	3221	3426
15 billion gallons	2729	3261	3608
25 billion gallons	2729	3335	3804

Since Brazil and the EU increase their production of corn for the time period under the scenarios, the two countries increase their exports of corn substantially. In 2008, Brazil imports corn under the scenarios, but export in 2012 and 2016. Brazil's exports of corn are 155 million bushels under Scenario 1, 175 million bushels under Scenario 2, and 234 million bushels under Scenario 3. The EU's exports increase from 504 million bushels in 2008 to 643 million bushels under Scenario 1. Its exports in 2016 are 1,197 million bushels under Scenario 2 and 1,885 million bushels under Scenario 3. China imports 625 million bushels in 2016 under Scenario 1 and 365 bushels under Scenario 2, and 92 million bushels under Scenario 3. As the price of corn increases China reduces its import of corn for the period.

Table 4. Projected Corn Exports by Major Exporting/importing Countries/region Under Ethanol Production of 7, 15, and 25 Billion Gallons

	2008	2012	2016
Argentina	------------------------million bushels---------------------		
7 billion gallons	648	602	546
15 billion gallons	650	628	602
25 billion gallons	655	674	673
Brazil			
7 billion gallons	-24	98	155
15 billion gallons	-22	128	175
25 billion gallons	-15	173	234
China			
7 billion gallons	-90	-425	-623
15 billion gallons	-68	-287	-365
25 billion gallons	-3	-24	-92
European Union			
7 billion gallons	504	724	643
15 billion gallons	524	927	1197
7 billion gallons	581	1304	1885

Impacts on other commodities

Since corn is competing with soybeans and wheat for crop land, an increase in corn price would increase the prices of soybeans and wheat. The price relationships among the three crop are shown in Figure 7. A fundamental question is what would be the prices of soybeans and wheat when corn price increases to the breakeven price for corn-based ethanol production. To examine the relationship, econometric models, in which the price of soybeans or wheat is a function of the price of corn, are developed. The data used for this estimation were obtained from the ERS/USDA. The estimated equations for soybeans and wheat prices with annual time series data from 1980 to 2007 are as follows;

$$PS_t = 2.09 + 1.60{*}PC_t + 0.80{*}DY_t \tag{15}$$

(3.18) (7.27) (1.86)

$R^2 = 0.73$

$$PW_t = 0.33 + 0.93{*}CP_t + 0.39{*}CP_{(t-1)} + 0.59{*}e_{(t-1)} \tag{16}$$

(0.46) (4.35) (2.12) (1.96)

$R^2 = 0.75$

where PS is the price of soybeans, PC is the price of corn, DY is a dummy variable for 2005 when China increased soybean imports from the U.S. substantially, PW represents the price of wheat, and e(t-1) is a lagged error term to adjust the first order serial correlation. The numbers in parentheses are t-statistics of the corresponding variables.

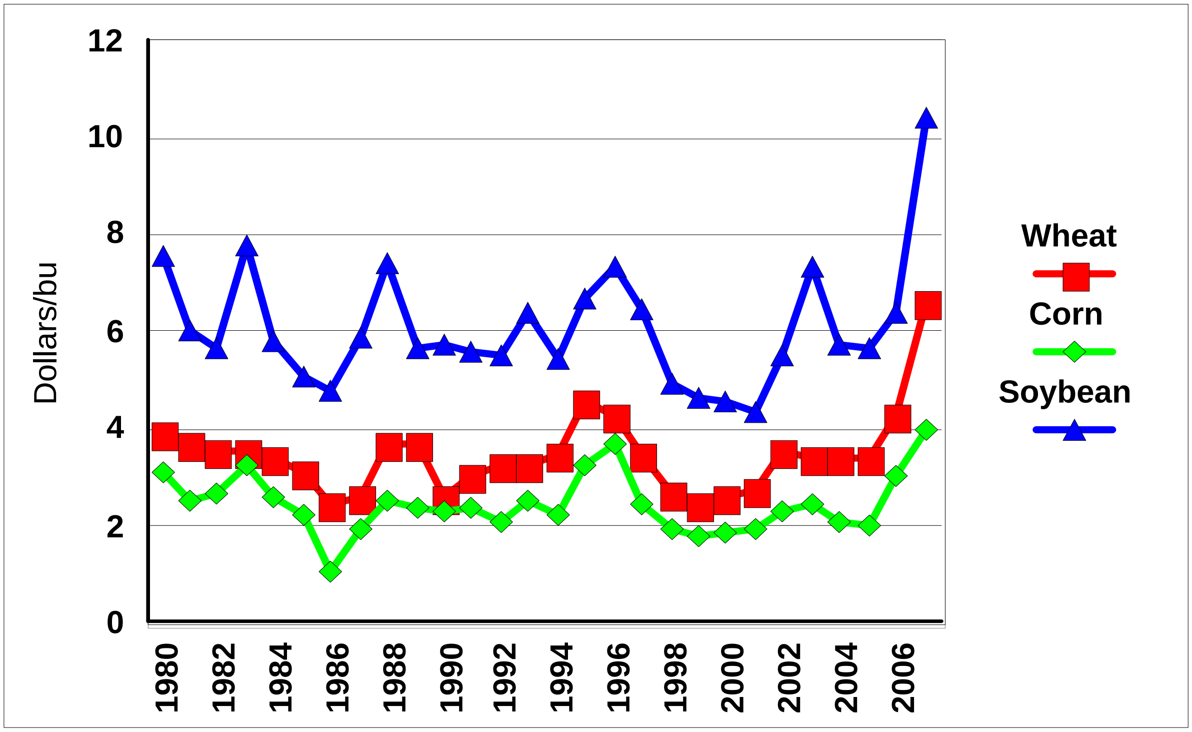


Figure 7. U.S. Wheat, Corn, and Soybean Prices

The t-statistics indicated that the corn price variable for both equations are significantly different from zero at the one percent significant level, indicating that the corn price is significantly correlated to the price of wheat or soybeans. The R^2s indicate that 73% and 75% of changes in soybean and wheat prices are explained by the price of corn. This implies that the remaining portion can be explained by other factors such as crop rotation, regional weather conditions, and international impacts.

Assuming that the breakeven price of corn for profitable ethanol production is $4.52 per bushel of corn, which can be considered as a long run price of corn in the U.S., the long run prices of soybeans and wheat can be calculated from the equations 15 and 16. The prices of soybeans and wheat calculated from the equations are $13.66 per bushel and $6.29 per bushel, respectively. It should be noted that these prices are obtained from the price of corn under normal marketing and weather conditions.

The increased prices of corn, wheat and soybeans are generally favorable for producers in the agricultural sector in the short run. However, a surge in farm income has contributed to increases in land value and cash rent, and prices of chemicals and fertilizers, and prices of farm equipments, eventually resulting in increase in production costs of the crops in the long run. In the North Dakota, land price has increased about 53% from $425 per acre to $650 per acre since

2003 (NASS). The prices of chemical, fertilizer, and farm equipment also increased in a similar proportion. This clearly indicates that even though there are substantially increase in the prices of agricultural commodities, the net farm income in the long run would be much smaller than the net farm income in the short run.

On the downside, the increased prices of the agricultural goods has increased production costs of livestock in the U.S. and this trend will continue in the near future. This will make the U.S. livestock sector less competitive in the U.S. and foreign markets. The U.S. may import more beef and reduce its exports to major importing countries, mainly because of higher production cost due to increased in prices of agricultural commodities.

In addition, increased prices of agricultural commodities could attribute to an increase in retail prices of food. The food price index has increased more than the inflation rate for the last three years. Inflation in the U.S. food sector may affect the U.S. economy negatively.

Impacts on the U.S. Sugar Industry

The price of corn is also highly correlated with the price of HFCS. As shown in Figure 8, the two prices have moved in a similar way for the last three decades. However, the price of HFCS has been lower than the price of sugar in the U.S. until 2007. As a result of the difference in prices of these two, there has been a major increase in demand for HFCS as shown in the Figure 4 in section 2. The U.S. soft drink industry switched from sugar to HFCS for beverage production in 1980s. In addition, it has been a general knowledge that Mexico will import HFCS from the U.S. under the full implementation of NAFTA and use it to produce beverage and export its surplus sugar to the U.S.

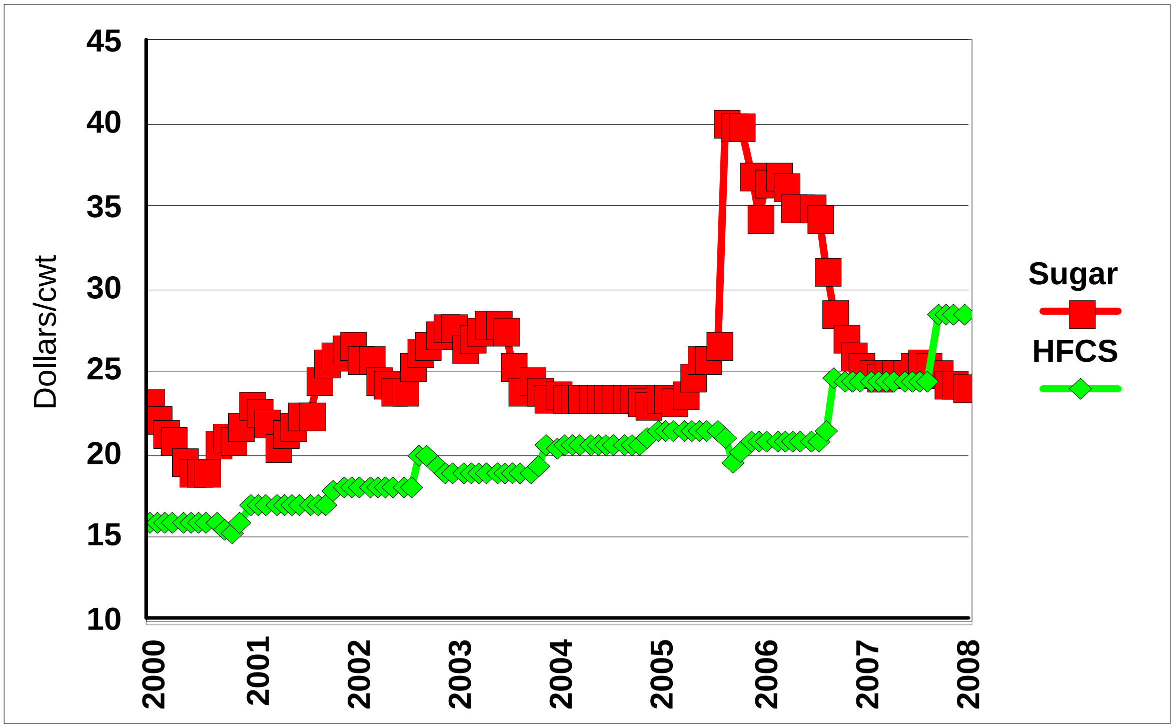


Figure 8. U.S. Wholesale Sugar and HFCS Price

A question is what is the price of HFCS when the price of corn is equal to the breakeven price of corn for ethanol production ($4.52/bushel). An econometric model was developed to examine the relationship between the prices of corn and HFCS. In the model, the price of HFCS is specified as a function of the price of corn. The model was estimated using an econometric technique with the monthly time series data from 1990 to 2007. The estimated model is presented as

$$PH_t = 10.32 + 3.94*PC_t \qquad (17)$$

$$(5.52) \quad (13.13)$$

$$R^2 = 0.64$$

where PH represents the price of HFCS and PC represents the price of corn. The number in the parentheses represents t-value of the corresponding variable.

The t-value indicates that the estimated coefficient of PC is different from zero at one percent significant level, indicating that the prices of HFCS and corn are highly correlated. The R^2 shows that 64% fluctuations of the price of HFCS can be explained by changes in the price of corn.

Assuming that the price of corn remains at $4.52 in the long run, the price of HFCS would be 28.22 cents per pound. This price is higher than the wholesale price of sugar in the U.S. If this price difference is sustained in the near future, demand for HFCS may decrease, while consumption of sugar increases. In addition, Mexico may not import HFCS from the U.S. to use it for beverage production. In fact, some beverage producers in the U.S. may start to use sugar for beverage production.

Conclusions and Implications

The two largest growth sectors for corn usage have been HFCS and ethanol production. Currently, these sectors use about 40% of the U.S. corn production, and livestock feeding consumes about 42% of the crop. Exports have remained at about 2.1 billion bushels (15%). Corn production has increased rapidly due to increased yields.

A global multi-commodity simulation model was developed to estimate the impact of changes in ethanol production on the U.S. corn industry. Increased ethanol production under the Energy Acts of 2005 and 2007 results in a significant increase in the price of corn. However, considering profitability of corn-based ethanol production, the price of corn would be less than or equal to$4.52 per bushel, the price which ethanol producers can pay and still breakeven, with a federal subsidy of $0.51 per gallon of pure ethanol. With the corn price of $4.52, the economically desirable ethanol production is approximately 11 billion gallons. To produce the mandated RFS of 15 billion gallons under the EISA of 2007 with the breakeven price of corn, supply of corn should be increased largely through increases in corn yields. Otherwise, the price of corn would be higher than the breakeven price.

The increased price of corn leads to increases in corn production in the United States and other countries such as Brazil and the EU. U.S. exports of corn would be reduced substantially due mainly to major increase of corn use for ethanol production. The reduction in the U.S. exports of corn would be replaced with those by other countries, especially the EU.

The increased price of corn also leads increases in the prices of soybeans, wheat, HFCS, and agricultural inputs, such as land value and cash rent, fertilizer and chemicals, and farm equipment. In addition, the price of corn has resulted in a increased production costs for livestock. The increases in prices of agricultural commodities and inputs would cause increase in retail prices of food in the U.S.

References

Babcock, Bruce A. "When Will the Bubble Burst." Iowa Ag Review, Winter 2008, Vol. 14. No. 1. Center for Agricultural and Rural Development. Iowa State University. Ames, Iowa.

Bothast, Rodney J. "New Technologies in Bio-fuel Production." Agricultural Outlook Forum 2005. Speech Booklet 2, February 24, 2005.

Collins, Keith. Statement of Keith Collins, Chief Economist, U.S. Department of Agriculture, Before the U.S. Senate Committee on Agriculture, Nutrition, and Forestry, April 11, 2000.

Farm Service Agency, U.S. Department of Agriculture. "Conservation Reserve Program: Monthly Summary – March 2007." March 2007. http://www.fsa.usda.gov/Internet/FSA_File/mar200 7.pdf.

Ferris, John N., and Satish V. Joshi. "Evaluating the Impacts of an Increase in Fuel-ethanol Demand on Agriculture and the Economy." Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, CO, August 1-4, 2004.

Food and Agricultural Policy Research Institute. "Implications of Increased Ethanol Production for U.S. Agriculture." FAPRI-UMC Report #10-05. August 22, 2005.

Iowa Beef Center. "Ethanol Coproducts for Cattle." Iowa State University Extension, IBC-18, February 2002.

Lardy, Greg. "Feeding Coproducts of the Ethanol Industry to Beef Cattle." North Dakota State University Extension Service. AS-1242, April 2003.

McNew, Kevin, and Duane Griffith. "Measuring the Impact of Ethanol Plants on Local Grain Prices." *Review of Agricultural Economics*. Vol. 27, No. 2, 164-180. June 2005.

National Corn Growers Association. "How Much Ethanol Can Come From Corn?" February 2007.

Nerlove, M. "The Dynamics of Supply: Estimation of Farmers' Response to Price." 1958. Baltimore: John Hopkins Press.

Oleson, Fred. Ag Canada. Personal conversation, 2005.

Otto, Daniel, and Paul Gallagher. "The Effects of Expanding Ethanol Markets on Ethanol Production, Feed Markets, and the Iowa Economy." A Report Submitted to the Iowa Department of Agriculture and Land Stewardship Office of Renewable Fuels. Iowa State University Department of Economics, Ames, IA. June 30, 2001.

Pates, M. Early Out?: CRP Contract Holders Seek Greener Pastures, AGWEEK, Dec. 11, 2006, Page 32.

U.S. Department of Agriculture, NASS. Cattle on Feed. Washington, DC, various issues.

U.S. Department of Agriculture, Economic Research Service. PS&D View (Website).

U.S. Department of Agriculture, Economic Research Service. Feed Grain Situation and Outlook Report. Washington, DC, various issues.

U. S. Department of Energy. Energy Information Administration. Annual Energy Outlook 2006 With Projections to 2030. (Website).