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Ethanol, Mandates, and Drought: Insights from a Stochastic Equilibrium Model of the U.S. Corn Market

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Abstract

The outlook for U.S. corn markets is inextricably linked to what happens to the U.S. ethanol industry, which depends, in turn, on the level of government subsidies and mandates. We develop a stochastic partial equilibrium model to simulate outcomes for the corn market for the 2008/09 marketing year to gain insight into these linkages. The model includes five stochastic variables that are major contributors to corn price volatility: planted acreage, corn yield, export demand, gasoline prices, and capacity of the ethanol industry. Our results indicate that integration of gasoline and corn markets has increased corn price volatility and that the passage of the expanded ethanol mandates in the Energy Independence and Security Act (EISA) has had modest effects on corn prices. Model results indicate an expected average marketing year price of $4.97 per bushel and a price volatility of 17.5% without the 10 billion gallon EISA mandate but with maintenance of the $0.51-per-gallon tax credit. Imposition of the mandate increases the expected price by 7.1% and price volatility by 12.1%. The effects of the mandate are modest, as ethanol production would average 9.5 billion gallons without the mandate because of high gasoline prices. The mandate is binding with a probability of 37.8%, which indicates that an additional tax or subsidy will be needed to ensure that the mandate is met. High corn prices caused by drought can cause the mandate to bind. Fixing 2008 corn yields at extreme drought levels increases expected corn prices to $6.59 per bushel without a mandate and to $7.99 per bushel with the EISA mandate. An average additional subsidy of $0.73 per gallon of ethanol would be needed to ensure that the mandate is met in this drought scenario. Elimination of the current blenders tax credit would result in the mandate not being met in all cases. On average, a subsidy of $0.41 per gallon would ensure that ethanol production is at least 10 billion gallons in the 2008/09 marketing year.

Keywords

EISA mandate, ethanol, price volatility of corn, stochastic equilibrium

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1 Introduction

U.S. corn ethanol production has increased from 1.77 billion gallons in 2001 to an estimated 7.23 billion gallons at the end of 2007 (RFA). Increasing production of corn ethanol has linked corn and gasoline markets. This new market integration has been supported by a host of federal legislation in hopes that corn ethanol will reduce U.S. dependence on foreign oil and help fight global warming.

In August 2005, the Energy Policy Act of 2005 (H.R. 6) was signed into law. The comprehensive energy legislation included a nationwide renewable fuels standard (RFS) that would have resulted in the use of more than 7.5 billion gallons of ethanol and biodiesel by 2012. In December 2007, the Energy Independence and Security Act (EISA) was signed into the law. This act mandates the use of 36 billion gallons of biofuel by 2022, of which no more than 15 billion gallons may come from corn ethanol.

Increased demand for corn from the ethanol industry has led to record high nominal corn prices. The futures market shows that the 2008 new-crop corn harvest price is well above \$5.00 per bushel. Market estimates of implied volatility of corn prices have increased dramatically as well. Yearly average implied volatility of corn prices was below 22% from 1997 to 2005. In 2006 it jumped to 28.8% and jumped further in 2007 to 32.4%. Currently (February 2008), the implied volatility of the 2008 new-crop corn harvest is about 35%.[1] This increase in volatility potentially affects the decisions of market participants significantly. Information about the factors that determine price levels and price volatility in the corn market can help market participants make better input and output decisions and assess alternative allocations of resources in a sound manner.

Historically, corn price volatility was caused primarily by shocks to supply. Changing weather, pests, diseases, and land put into production all play their part in corn supply volatility. In recent years the volatility of the corn price has been influenced to a large extent by demand shocks as well. Demand shocks come primarily from changes in export demand, ethanol production, and the gasoline price. In the past few years the ethanol industry has expanded to become a significant buyer of corn. The future demand for corn for ethanol is difficult to estimate given the rapid growth of the industry. Thus, uncertain ethanol production capacity contributes to uncertainty about future corn demand. Integration between energy markets and agricultural markets and the high volatility in gasoline prices contribute to corn price volatility as well. At today's volumes, integration flows one way: gasoline prices determine ethanol prices. Thus, low gasoline prices combined with high

[1] http://www.cbot.com. The value of 35% implies that, if prices are normally distributed, 68% of the time the December 2008 corn futures price on the expiration date of the December option will be within ±35% of the December corn futures price used to compute the implied volatility.

corn prices will squeeze ethanol plant margins. If an ethanol plant's revenue cannot cover its variable cost, then the plant will shut down until margins improve. Given heterogeneity in plant efficiency we will tend to see the least efficient ethanol plants shut down first. The gasoline price and the corn price together determine the percentage of ethanol capacity that operates, and thus they determine the corn demand from ethanol production. Therefore, the stochastic gasoline price contributes to stochastic demand of corn from ethanol.

We address two questions in this study. How will the continued use of corn for producing ethanol affect its price volatility, and how will EISA affect the corn market? We develop a stochastic partial equilibrium model to simulate the price variability of corn during the 2008/09 marketing year. In our model, the price risk of corn is due to stochastic supply and demand. We allow for five sources of uncertainty to the current U.S. corn market: two affecting corn supply and three affecting corn demand. Stochastic supply is due to the uncertainty of planted acreage and stochastic yield. Export demand and input demand for ethanol are also stochastic. The stochastic export demand is due to the fluctuation of the value of the dollar against the currencies of other exporting and importing countries and stochastic feed grain production in other countries. Demand for corn from ethanol is caused by the uncertain ethanol production capacity and uncertain percentage of ethanol plants operating due to stochastic margins. Our model attempts to decipher the primary causes of uncertainty in the U.S. corn market in the midst of an increasing demand for corn as an energy substitute and new legislation.

The next section of the paper reviews the literature on the price risk of commodities. The third section presents the structural model and assumptions used in the present study. The fourth section reports the results of the simulation under different scenarios. The fifth and final section presents a summary and conclusions.

2 Literature Review

A limited number of studies attempt to provide direct estimates of price risk of agricultural commodities, even though there is a huge literature on price risk of financial instruments. Price risk of commodities varies over time, and accurate prediction is far from easy. The two basic approaches are either to compute the realized volatility over the recent past from historical price data or to calculate the "implied volatility" from current option prices in the market by solving the pricing model for the volatility that sets the model and market prices equal. One of the most attractive features of the Black-Scholes option pricing model is that volatility is the only input to be forecast while all the other parameters are observable. The agricultural economics literature focuses on studying the impact of government policy on commodity price volatility. Zulauf and Blue (2003) found that corn and soybean implied volatilities covering the preharvest and storage seasons increased 16-23% between 1987-1995 and 1997-2001. The increase was statistically significant at the 90% confidence level. The standard deviation of corn and soybean prices derived from the implied volatility increased 7%-25%, but only the increase for preharvest corn was statistically significant. However, they also found a decline in the variability of annual U.S. average corn and soybean cash prices. These mixed findings point to continuing disagreement about government's role in managing farm risk in the post-1996 Farm Bill world. Isengildina-Massa et al. (2008) used an event study to investigate the impact of USDA World Agricultural Supply and Demand Estimate (WASDE) reports on implied volatility in corn and soybean markets over the period 1985-2002. They found that WASDE reports lead to a statistically significant reduction of implied volatility that averages 0.7 percentage points for corn and 0.8 percentage points for soybeans. The magnitude of the reduction is largest for the group of WASDE reports containing both domestic and international situation and outlook information. This group of reports reduces implied volatility by an average of 1.1 percentage points in corn and by almost 1.5 percentage points in soybeans. They also found that the market impact of WASDE reports is strongest in the most recent 1996-2002 sub-period.

The third approach to predicting price risk is to examine the factors that determine the stochastic supply and stochastic demand. Several papers used a stochastic partial or general equilibrium model to study the impact of the 1996 Farm Bill on the price variability of commodities. Ray et al. (1998) introduced stochastic yields and random export shocks to the POLYSYS modelling framework to study the variability of prices for corn, wheat, soybeans, and cotton and projected higher planted acreage variability, ending stock variability, and significantly higher variability for corn prices and more variability for wheat and soybean prices during the 1998-2006 period. Westcott (1998) addressed the question of whether supply management and government stock programs have made the agricultural sector more or less variable, particularly for prices. Corn sector simulations under alternative policy environments were performed to analyze the short- and long-run responsiveness to assumed yield shocks. Yield shocks result in larger initial price impacts than if stocks were larger. However, greater supply responsiveness from increased planting flexibility combined with the initially greater price impacts can result in lower price deviations over a multiyear, postshock adjustment period than occur in a higher stocks/lower supply response environment. McNew and Gardner (1999) explored how progressive income taxes influence storage decisions and the price variability for storable commodities. Under a progressive tax system, commodity storage tends to be lower in the aggregate and, as a consequence, price volatility increases. Lence and Hayes (2002) used a dynamic three-commodity, rational-expectation model to compare the impact of the Federal Agricultural Improvement and Reform (FAIR) Act of 1996 with a free-market policy, and with the agricultural policies that preceded the FAIR Act. Their results suggest that the changes enacted by FAIR did not lead to permanent significant increases in the volatility of farm prices or revenues.

The present study is the first one to examine the impact of the EISA mandate on the price variability of corn. This paper is also the first one to introduce five shocks to the market for corn: the gasoline price, yields, export demand, ethanol capacity, and acreage. This study attempts to explain the influence of major short-term factors on the corn market during this time of change. Because our approach is based on a structural model, the impacts of alternative weather and policy scenarios on corn prices and price volatility can be easily analyzed.

3 Model Structure and Assumptions

A stochastic partial equilibrium model is developed to study the impact of ethanol expansion and the mandate on the price risk of corn. A schematic of the model is presented in Figure 1. As shown, the model solves for equilibrium corn prices in the 2008/09 marketing year. The model is stochastic in the sense that the equilibrium price depends on the realizations of five random variables. Expectations about the corn price and price volatility can be made by solving the model for multiple draws of the random variables and then taking averages across all draws. We assume that random draws are obtained given information available at the end of February in 2008. Thus, planted acres and yield are both uncertain, so corn supply is stochastic. Corn demand is stochastic as well. We consider three random variables that cause demand uncertainty: the position of the export demand curve, gasoline prices, and the capacity of the U.S. corn ethanol industry. Because we do not account for all sources of uncertainty that affect corn prices, our estimated price volatilities are lower than implied volatilities in the market.[2]

3.1 Stochastic Corn Supply in the 2008/09 Marketing Year

Corn supply in the 2008/09 marketing year is determined by planted acreage, the ratio of harvested acres to planted acres, and the yield per harvested acre. Uncertainty in supply comes from the uncertain planted acreage and uncertain yield. In February 2008, planted acreage is stochastic because most corn is not planted until April. Corn prices in 2008 will

[2] In addition, our estimated price volatilities do not account for the proportion of implied volatilties that generate returns to options traders.

be sensitive to planted acreage and yield because stock levels are relative low and/or the demand of corn is robust. According to the USDA supply and demand review on February 8, 2008, U.S. ending stocks for 2007/08 were pegged at 1.438 billion bushels, which is about 11% of projected use. The demand for corn is strong because of the rapidly expanding consumption of corn used for ethanol production and the strong outlook of export demand due to the falling value of dollar. The function of corn supply is

$$Q_{c,t}^{S} = \widetilde{A}_{c,t} * h_t * \widetilde{y}_{c,t} \tag{1}$$

where $Q_{c,t}^{S}$ denotes the supply of corn, $A_{c,t}$ is realized planted acreage of corn at time t, h_t is the ratio of harvested to planted acres, and $y_{c,t}$ is realized yield per harvested acre.

We use historical yields from 1957 to 2007 to estimate the probability distribution of the yield per harvested acre of the 2008 corn crop. We assume the mean yield of corn per harvested acre follows a linear trend and estimate the percentage deviation in actual corn yields from trend yields from 1957 to 2007.[3] The average percent deviation multiplied by the 2008 trend yield is used as the standard deviation of national yield. The five-year moving average of the ratio of acreage harvested to acreage planted is taken as the 2008 estimate. The data of planted acres, harvested acres, and yield in the United States from 1957 to 2007 are from the National Agricultural Statistics Service (NASS). The estimator of ratio of harvested to planted acres in 2008 $\widehat{h}_t = 91\%$. The beta distribution for 2008 U.S. corn yield (in bushels per acre) (Figure 2) is

$$\widetilde{y}_{c,2008} \sim beta(\overline{y}, \sigma_y^2, p_y, q_y) \tag{2}$$

where $\overline{y}_c = 151$, $\sigma_{y_c}^2 = 194, \max \widetilde{y}_{c,2008} = 177, \min \widetilde{y}_{c,2008} = 113, p_c = 2.43$, and $q_c = 1.66$.

We assume yield and planted acreage are independent of each other. A forward looking rational farmer decides to plant corn, soybeans, wheat, or other crops to maximize expected profits based on the information set he has about expected prices, yields and costs of different crops. The farmer's expected profit maximization provides us with information about expected acreage of corn but does not provide information about uncertainty of planted acreage. We base expected planted acres (90 million acres) in 2008 on USDA projections made in February.[4] Because U.S. farmers planted 93.6 million acres in 2007 when corn prices were relatively higher than they are today, we place a 94-million- acre upper bound on 2008 planted acreage. Our lower bound on planted acreage is 88 million acres. Uncertainty about

[3] More sophisticated trend models were fit to the yield model, but the 2008 projected trend yield and the estimated percent deviations from trend over the time series differed little from those obtained from a simple linear trend.

[4] http://www.cbot.com/cbot/pub/cont_detail/0,3206,1213+54918,00.html

planted acreage is captured by a parameterized beta distribution (Figure 3):

$$\widetilde{A}_{c,2008} \sim beta(\overline{A}, \sigma_A^2, p_A, q_A) \tag{3}$$

where $\overline{A}_c = 90$, $\sigma_{y_c}^2 = 1, \max \widetilde{A}_{c,2008} = 94, \min \widetilde{A}_{c,2008} = 88, p_A = 2.33$, and $q_A = 4.67$.

3.2 Corn Demand in the 2008 Marketing Year

Corn demand is comprised of five components: food, feed, storage, exports, and the demand from the ethanol industry.

3.2.1 Feed, food, and storage demand

Food, feed, and storage demand are assumed to be nonstochastic. This simplifying assumption will reduce estimated price volatility. The demand curves depend on the average price received by farmers in the 2008/09 marketing year: $Q_{c,t}^{D,feed} = g^{feed}(P_{c,t}); Q_{c,t}^{D,food} = g^{food}(P_{c,t}); Q_{c,t}^{D,\text{storage}} = g^{storage}(P_{c,t})$ where $Q_{c,t}^{D,feed}$ is domestic feed demand of corn at time t, $Q_{c,t}^{D,food}$ is domestic food demand of corn at time t, and $Q_{c,t}^{D,\text{storage}}$ is the demand of corn from storage. $Q_{c,t}^{D,feed}$, $Q_{c,t}^{D,food}$, and $Q_{c,t}^{D,\text{storage}}$ are functions of $P_{c,t}$, the price of corn at time t. Parameters for these demand curves are obtained by assuming a demand elasticity and calibrating to the latest USDA projections in the WASDE on February 8, 2008.[5] The feed demand elasticity is fixed at -0.25. The food demand elasticity is fixed at -0.096. And storage demand elasticity is set equal to -0.65. Thus, the three demand curves (in million bushels) in the 2008/09 marketing year are

$$Q_{c,2008}^{D,feed} = 8687 - 435 * P_{c,2008} \tag{4}$$

$$Q_{c,2008}^{D,food} = 1485 - 32.5 * P_{c,2008} \tag{5}$$

$$Q_{c,2008}^{D,\text{storage}} = 2443 - 240 * P_{c,2008} \tag{6}$$

3.2.2 Stochastic export demand

We assume that the export demand uncertainty is mainly due to the uncertainty of the value of the dollar relative to the currencies of the major corn exporting and importing countries and the uncertainty of feed grain production in other countries. Over 2007, the value of the

[5] http://www.usda.gov/oce/commodity/wasde/latest.pdf

dollar fell against many currencies. A falling dollar makes corn exports look more attractive to importers and often increases export demand.

The reduced demand function of corn from export is a function of the cash price

$$Q_{c,t}^{D,\text{export}} = g^{\text{export}}(P_{c,t}, \varepsilon_{c,t}^{D,\text{export}}) \tag{7}$$

where $Q_{c,t}^{D,\text{export}}$ is the export demand of corn, which is a function of $P_{c,t}$ and $\varepsilon_{c,t}^{D,\text{export}}$, a realization of export demand shock. We introduce the export demand shock through the intercept of the demand curve. We assume the short-term export demand elasticity is -0.6 and calibrate the export demand curve based on WASDE. Thus, the export demand curve of corn (in million bushels) in the 2008/09 marketing year is

$$Q_{c,2008}^{D,\text{export}} = 3920 * (1 + 10\% * \varepsilon_{c,2008}^{D,\text{export}}) - 367.5 * P_{c,2008} \tag{8}$$

where $\varepsilon_{c,2008}^{D,\text{export}} \sim N(0,1)$.

3.2.3 Stochastic demand of corn from ethanol

The demand of corn from ethanol is determined by ethanol production capacity, the percentage of capacity that is in operation, and the number of bushels of corn required to produce a gallon of ethanol:

$$Q_{c,t}^{D,ethanol} = \lambda_t * \widetilde{E}_t * \theta_t$$

where $Q_{c,t}^{D,ethanol}$ is the demand of corn from ethanol, λ_t is the percentage of the ethanol capacity with a nonnegative operating margin, $\widetilde{E}_t$ is the capacity of ethanol production, and θ_t is the number of bushels of corn required to produce a gallon of ethanol.

First, we estimate θ_t. Following FAPRI (2007), we assume that the average efficiency of dry mill ethanol plants results in 2.75 gallons of ethanol and 17 pounds of distillers grains for each bushel of corn processed. Distillers grains are a substitute for corn in livestock feed rations. According to Babcock (2008), each bushel of corn processed returns one quarter of a bushel of corn equivalent back to the market as livestock feed. Thus, it takes 0.75 net bushels of corn to produce the industry average of 2.75 gallons. Equivalently, each bushel of corn diverted from feed creates 3.67 gallons of ethanol on average. Thus, $\theta_t = 1/3.67$.

Second, we estimate the distribution of ethanol production capacity $\widetilde{E}_t$. Keeping track of industry capacity has been a challenge given the explosive growth. Ethanol industry capacity numbers are reported by at least two entities. The lists of plants are given by the Renewable Fuel Association and the American Coalition for Ethanol. These sources suggest that industry capacity at the end of 2007 was around 7 billion gallons. There is expected to be continued strong growth in capacity coming online in the first half of the 2008/2009 marketing year. The rate of new capacity coming online is expected to slow in the second half of the marketing year. Based on the information from these resources, we assume the maximum capacity in the 2008/09 marketing year is 13.5 billion gallons, the minimum capacity is 9 billion gallons, and the average capacity is 11.5 billion gallons. A beta distribution is again used to capture uncertainty (Figure 4):[6]

$$\widetilde{E}_{2008} \sim beta(\overline{E}, \sigma_E^2, p_{E,} q_E) \tag{9}$$

where $\overline{E}_{t+1} = 11.5, \sigma_E^2 = 0.5, \min \widetilde{E}_{t+1} = 9, \max \widetilde{E}_{t+1} = 13.5, p_E = 5, q_E = 4.$

The last demand component is λ_{t+1}. Negative processing margins will cause ethanol plants to shut down. Because plants pay the same price for corn, those plants that produce the least ethanol per bushel of corn processed will tend to shut down first. We denote gallons of ethanol produced per bushel of corn as γ. The distribution of γ determines the proportion of existing capacity that will operate given input and output prices. With a mean of 2.75 gallons per bushel, we assume a maximum efficiency of 2.9 gallons per bushel and a minimum efficiency of 2.5 gallons per bushel. There are no reliable data on which to base plant heterogeneity; thus, we make a reasonable approximation by fixing the variance equal to 0.005. Using a beta distribution again, we specify the distribution of γ as follows:

$$\widetilde{\gamma} \sim beta(\mu_\gamma, \sigma_\gamma^2, p_\gamma, q_\gamma) \tag{10}$$

where $\mu_\gamma = 2.75$, $\sigma_\gamma^2 = 0.005, \underline{\gamma} = 2.5, \overline{\gamma} = 2.9$, $p_\gamma = 4.0625$ and $q_\gamma = 2.4375$. See Figure 5 for a graph of this distribution.

The operating margin per bushel of corn processed for a dry mill ethanol plant is

$$\pi_{E,t} = [\gamma * P_{ethanol,t} + D_t * P_{distillers,t}] - (P_{c,t} + \gamma * OPC_t) \tag{11}$$

where $\pi_{E,t}$ is the operating profit margin per bushel, D_t is tons of coproduct distillers grains per bushel, $P_{ethanol,t}$ is the ethanol price per gallon, $P_{distillers,t}$ is the distillers grains price per ton (1 ton equals 2,000 pounds), OPC_t is the operating cost per gallon, $[\gamma * P_{ethanol,t} + D_t * P_{distillers,t}]$ is the revenue per bushel of corn, and $P_{c,t} + \gamma * OPC_t$ is the variable cost per bushel of corn. According to F.O. Lichts (2006), the operating cost for an ethanol plant OPC_t is \$0.54 per gallon. One bushel of corn processed returns 17 pounds of distiller grains; thus, $D_t = \frac{17}{2000}$.

We assume the value of the distillers grains as a function of the price of corn. Following

[6] Capacity for 2008 in the ethanol industry was largely determined before EISA came into force; thus, we assume the ethanol capacity distribution is exogeneous to the EISA mandate.

Babcock (2008), the relationship between the per ton value of distillers grain and the per bushel price of corn is

$$P_{distillers,t} = 52.5 + 16.406 * P_{c,t} \tag{12}$$

For any ethanol plant, the operating profit margin function can be written

$$\pi_{E,t} = \gamma * (P_{ethanol,t} - 0.54) - 0.860\,55 P_{c,t} + 0.446\,25 \tag{13}$$

For each realization of ethanol price $P_{ethanol,t}$ and corn price $P_{c,t}$, we can calculate the threshold efficiency index $\widehat{\gamma}$ with zero profit:

$$\pi_{E,t} \mid_{\gamma=\widehat{\gamma}} = 0 \tag{14}$$

Thus, ethanol plants with a production efficiency index above $\widehat{\gamma}$ make positive operating profit. Ethanol plants with a production efficiency index below $\widehat{\gamma}$ shut down in the short run. Therefore,

$$\lambda_t(\widetilde{P}_{c,t}, \widetilde{P}_{ethanol,t}, \widetilde{\gamma}) = \Pr(\gamma \geq \widehat{\gamma}) \tag{15}$$

where λ_t is the percentage of the ethanol capacity with a nonnegative operating margin. Therefore, the demand of corn from ethanol for the 2008/09 marketing year $Q_{c,2008}^{D,ethanol}$ is

$$Q_{c,2008}^{D,ethanol} = \widetilde{E}_{2008} * \lambda_{2008}(\widetilde{P}_{c,2008}, \widetilde{P}_{ethanol,2008}, \widetilde{\gamma}) * \theta_{2008} \tag{16}$$

For example, if $\lambda_{2008} = 90\%$ and $\widetilde{E}_{2008} = 10$, 90% of ethanol capacity is running and 9 billion gallons of ethanol is produced. Thus, 2.452 billion bushels of corn are needed when we consider the coproduct distillers grains as a substitute for corn in feed rations.

3.3 Stochastic Ethanol Supply

The analysis above also gives us the stochastic supply of ethanol for the 2008/09 marketing year as follows:

$$Q_{Ethanol,t}^{S} = \widetilde{E}_t * \lambda_t(\widetilde{P}_{c,t}, \widetilde{P}_{ethanol,t}, \widetilde{\gamma}) \tag{17}$$

where $Q_{Ethanol,t}^{S}$ is the ethanol supply, which is a function of the percentage of ethanol plants with a nonnegative operating margin λ_t and capacity of ethanol production $\widetilde{E}_t$.

3.4 Stochastic Ethanol Demand

We assume a perfectly elastic demand for ethanol at its energy value. In the baseline, we add the blenders tax credit of \$0.51 per gallon to this energy value to capture the willingness to pay for ethanol by blenders. Although we might expect to see ethanol selling above its energy value for aggregate ethanol volumes in the range of 10 to 13 billion gallons per year, transportation bottlenecks that need to be overcome in delivering ethanol to population centers have tended to reduce prices. For example, gasoline for December delivery in New York was quoted at \$2.48 per gallon on February 28. Ethanol for December delivery was quoted on the CBOT for \$2.22 per gallon. The energy value of ethanol is 67.81% that of gasoline, or \$1.68 per gallon. Adding in the \$0.51 blenders credit results in a demand price of \$2.19, which is only three cents below the CBOT price. Thus we specify the price of ethanol as being equal to

$$\widetilde{P}_{ethanol,t} = 0.6781 * \widetilde{P}_{gas,t} + 0.51 \tag{18}$$

where $\widetilde{P}_{gas,t}$ is a realization of the gas price.

We assume that the gas price for the 2008/09 marketing year follows a lognormal distribution with mean \$2.55 per gallon and standard deviation 0.64 (Figure 6). The mean for the gas price distribution is estimated as the average of the gasoline RBOB futures price at NYMEX.[7] The standard deviation is estimated based on the implied volatility of the gasoline RBOB option at NYMEX.

3.5 Equilibrium in the Corn Market

For each realization of yield, acreage, export, ethanol production capacity, and gas price, we will have one realization of the equilibrium corn price at which the corn market clears:

$$Q^{S}_{c,t} + Q^{D,\text{storage}}_{c,t-1} = Q^{D,feed}_{c,t} + Q^{D,food}_{c,t} + Q^{D,\text{storage}}_{c,t} + Q^{D,\text{export}}_{c,t} + Q^{D,ethanol}_{c,t} \tag{19}$$

where $Q^{D,\text{storage}}_{c,t-1}$ is the beginning stock of corn at time t, which is the demand of corn from storage at time $t-1$.

4 Results

We simulate the short-term corn market equilibrium for the 2008/09 marketing year under different scenarios regarding corn ethanol production mandates, gasoline price volatility,

[7] http://www.nymex.com/index.aspx

extreme weather conditions, and ethanol tax credits. Table 1 presents the results for all the scenarios. We establish a baseline against which we can compare different scenarios using pre-EISA government policies. The baseline includes the $0.51-per-gallon blenders tax credit but no mandate. The average corn price is $4.97 per bushel with a price volatility of 17.5% for the 2008/09 marketing year. On average, 82.4% of ethanol production capacity will be operating. The average ethanol supply is approximately 9.5 billion gallons, which is 500 million gallons below the EISA mandate. The probability that the ethanol production would be less than 10 billion gallons without an extra tax credit is 37.8%. The possibility that ethanol plants will shut down will tend to decrease the correlation between market price deviations and yield deviations. The baseline level of price-yield correlation is -0.68.

4.1 Impact of the EISA Mandate

The new Renewable Fuel Standard in EISA requires 9 billion gallons of corn-based ethanol in 2008 and 10.5 billion gallons in 2009. With two-thirds of the 2008/09 marketing year in 2009, this translates into a requirement of 10 billion gallons for the marketing year. The mandate increases the average corn price to $5.32 per bushel and increases the average price volatility to 19.8%. Compared to the baseline results, the mandate increases the average corn price by 7.1% and price volatility by 12.9%. The price-yield correlation increases dramatically to -0.93.

Higher average corn prices decrease operating margins for ethanol plants. Without some mechanism to keep plants running, ethanol production would not be high enough to fill the mandate. EISA does not specify how the mandates are to be met. In theory, the government could mandate the production of corn ethanol even though plants produced it at a loss. Or the government could force ethanol blenders to buy and blend mandated levels of ethanol even if they lost money doing so. An alternative mechanism would be to increase the blenders credit when the market price for ethanol (which already reflects the existing $0.51 tax credit) is insufficient to keep enough ethanol plants running. A measurement of the additional taxpayer cost of the mechanism is the difference in ethanol market prices. Over all simulations, the average ethanol price with the mandate in place is $2.37 per gallon, which is $0.13 above the average ethanol price in the baseline scenario. This $0.13 also measures the expected cost to blenders if they were forced to blend ethanol at mandated levels.

4.2 Impact of Gasoline Price Volatility on Corn Price Volatility

In the baseline, with a gasoline price volatility of 25%, the corn price volatility is 17.5%. If gasoline price volatility increases by 20%, corn price volatility increases by 6.5%. If gasoline price volatility increases by 40%, simulated corn price volatility increases by 13.6% against the baseline. If gasoline price volatility decreases by 60%, simulated corn price volatility increases by 20.8% against the baseline. If gasoline price volatility decreases by 20%, simulated corn price volatility decreases by 5.8%. Thus, the gasoline price volatility and corn price volatility are positively correlated (Figure 7). The positive correlation between gasoline price volatility and corn price volatility indicates that the integration between energy and corn markets have increased the price volatility of corn.

4.3 Impacts of a Drought With and Without a Mandate

A low stocks-to-use ratio for corn combined with robust corn demand increases the vulnerability of livestock producers and the ethanol industry to a production shortfall. To obtain an estimate of the effects of a drought, we simulate what would happen to corn prices if a 1988-style drought occurs in 2008. As of February 26, 2008, the U.S. Climate Prediction Center was predicting that strong La Niña conditions would continue through the spring of 2008. Furthermore, half of the forecasting models indicate that La Niña conditions could continue through the summer of 2008.[8] The existence of La Niña conditions substantially increases the probability that yields will be lower than in neutral years (Phillips, Rosenzweig, and Cane, 1996). The last major drought affecting Corn Belt yields was in 1988.

To simulate the effects of a major drought, the corn yield was fixed at 113 bushels per harvested acre, which was the trend-adjusted national yield in 1988. Assuming that all other stochastic elements remain as they are in the baseline, the resulting corn distribution has a mean of $6.42 per bushel and a price volatility of 14.3%. This corn price is 29% above baseline levels. Price volatility decreases because corn yield variability has been eliminated. On average, only 27% of the ethanol capacity will operate, which means that the average ethanol supply will be far less than the RFS. With 92.95% probability, ethanol production would be less than 10 billion gallons without an extra credit if a 1988-style drought returns in 2008.

Of course, the above results hold only if the mandate is relaxed. The combination of a drought and the EISA mandate would push corn prices even higher. With a mandate, the average corn price would equal $7.99 per bushel, which is 50% higher than the average corn price under the unconditional distribution of corn yields. Of course, ethanol blenders would have to be heavily subsidized to be willing to pay a high enough corn price to keep ethanol plants running at these high corn prices. The average price of ethanol in the drought year would be $2.97 per bushel, which is $0.73 above the average ethanol price in the baseline

[8] The Climate Prediction Center weekly update is available at http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/index.shtml

scenario and $0.60 higher than with a mandate under the unconditional distribution of corn yields. At 10 billion gallons of production, this represents an average increase in taxpayer cost of $6 billion.

4.4 Impacts of a Bumper Crop With and Without a Mandate

In this scenario we fix the yield of corn at 169 bushels per harvested acre, which is the trend-adjusted national average yield for 2004. The results show that the price distribution of corn has a mean of $4.06 per bushel and a volatility of 10.3%. On average, 99% of the ethanol capacity operates, and the average ethanol supply is 11.4 billion gallons, well above the RFS. With only 4.4% probability, ethanol production would be less than 10 billion gallons without extra tax credit. If we assume the mandate is met and set the minimum ethanol supply at 10 billion gallons, the equilibrium average corn price is $4.07 per gallon, just one cent above the price without a mandate under the 2004 bumper crop scenario. The mandate has little effect on the expectation and volatility of the corn price. The average ethanol price required to meet the mandate is almost the same as the ethanol price for the baseline. This implies that the mandate will be easily met if a 2004-style bumper crop happens.

4.5 Removal of the $0.51 Tax Credit With and Without a mandate

Removal of the $0.51 tax credit decreases the ethanol price by the same amount if no mandate is in place. A lower ethanol price reduces the demand for corn by the ethanol industry, which leads to a lower corn price. Under this scenario, the average corn price is $4.15 per bushel, which is 16.5% below baseline levels. The price volatility of corn increases to 22.4%. On average, only 54% of ethanol plant capacity is utilized. The average ethanol supply would be 6.2 billion gallons and the probability that ethanol production would be less than 10 billion gallons is 71%. These results imply that some other mechanism will be needed to achieve EISA mandates if the tax credit is eliminated. As discussed above, one such mechanism is a variable tax credit that gives ethanol blenders just enough incentive to willingly purchase 10 billion gallons of ethanol. Under this mechanism, the average ethanol price is $2.14 per gallon, which is $0.41 per gallon higher than the average energy value of ethanol. Under this variable tax credit, the average corn price is $5.20 per bushel. This result compares to the average $0.64-per-gallon subsidy required to achieve the EISA mandate with the minimum $0.51-per-gallon tax credit in place. This implies that replacing a policy that provides a minimum of $0.51-per-gallon tax credit with a policy that provides only the tax credit that is needed to meet the mandate would significantly reduce the average taxpayer cost of the subsidy.

5 Conclusions

This study provides insight into the impacts of ethanol and ethanol policy on the expected level and volatility of corn prices during the 2008 marketing year. Our results show that the EISA ethanol mandate increases expected corn prices by 7.1% and price volatility by 12.9%. The relatively small impact of EISA on 2008 corn prices reflects the fact that 2008 capacity in the ethanol industry was already largely determined before EISA came into force. Thus, the EISA mandate only affects the demand for corn when ethanol margins are low enough to drive production below the mandated level of 10 billion gallons. Without EISA mandates, ethanol production would average 9.5 billion gallons. With the mandate, average production is 11.2 billion gallons. Without an enforcement mechanism, ethanol production would fall short of mandated levels when corn prices are too high or gasoline prices are too low to keep enough ethanol capacity operating. The probability that the ethanol production would be less than 10 billion gallons without an extra tax credit is 37.8%. To ensure the mandate is met in all states of nature would require a $0.13-per-gallon average increase in ethanol subsidies. This increase in subsidy is in addition to the $0.51-per-gallon subsidy received by blenders.

The impact of a drought in 2008 would be large. Under a 1988-style drought, the average corn price would increase to $6.42 per bushel without a mandate and to $7.99 per bushel with a mandate. The probability that the ethanol production would be less than 10 billion gallons without an extra tax credit is 92.9%. To meet the mandate under this scenario, the required average ethanol price will have to be increased to $2.97 per bushel. If the 2008 corn crop is a bumper crop as was experienced in 2004, then the 10-billion-gallon mandate would be easily met.

Removal of the $0.51-per-gallon blenders credit would have a large impact on corn markets only if the EISA mandate were also eliminated. With both eliminated, the average price of corn would drop by about 22%. Elimination of the blenders credit with the EISA mandate in place would cause the price of corn to decline by only 2.3%. The probability that ethanol production would be less than 10 billion gallons is 71% if the blenders credit is removed. Of course, some mechanism to induce ethanol producers to produce mandated ethanol amounts and to induce ethanol blenders to buy mandated amounts would have to be implemented. One mechanism would be a variable tax credit. The average tax credit needed to ensure mandated production levels is $0.41 per gallon.

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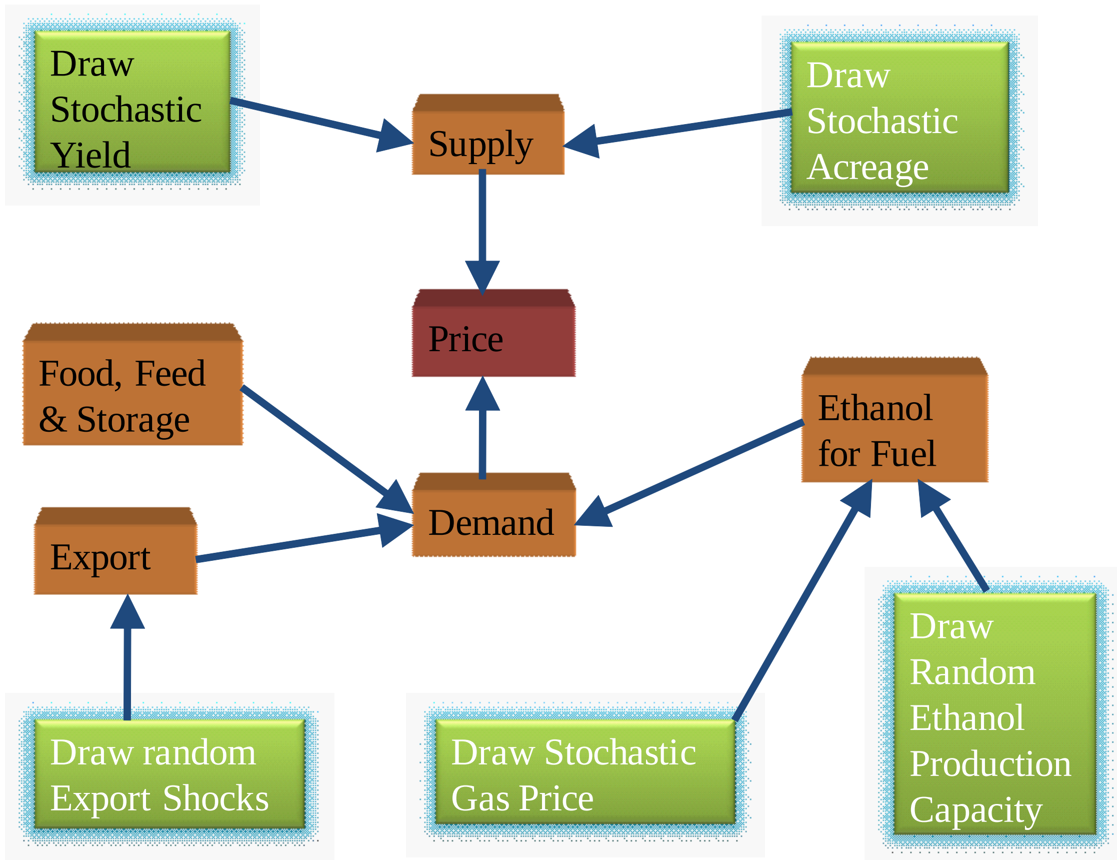

Figure 1: Stochastic corn supply and demand diagram

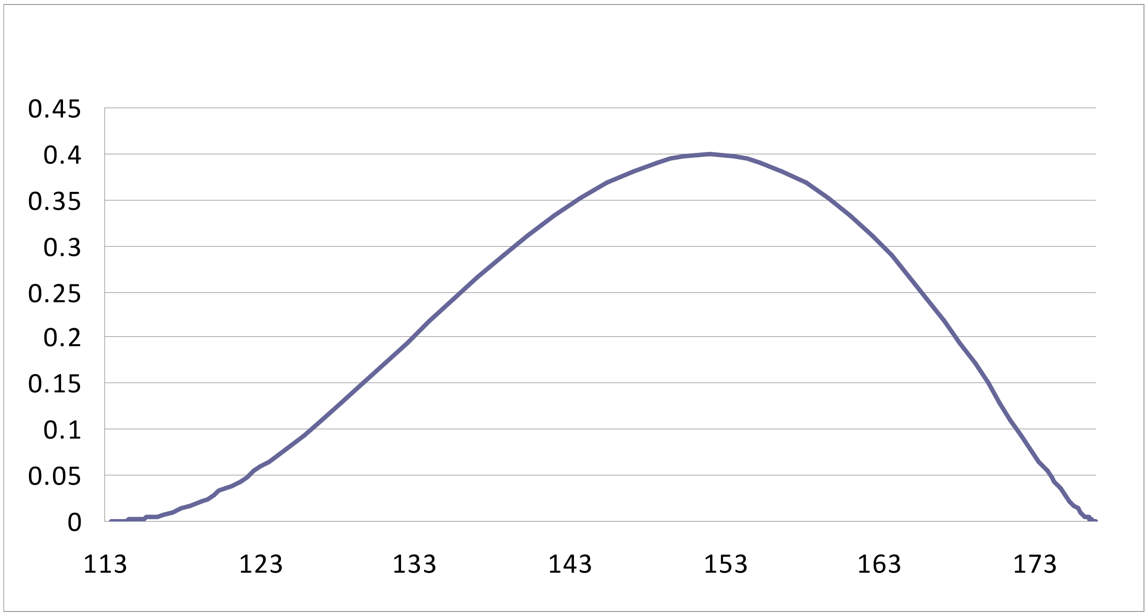

Figure 2: The distribution of corn yield (bushels per acre) for 2008

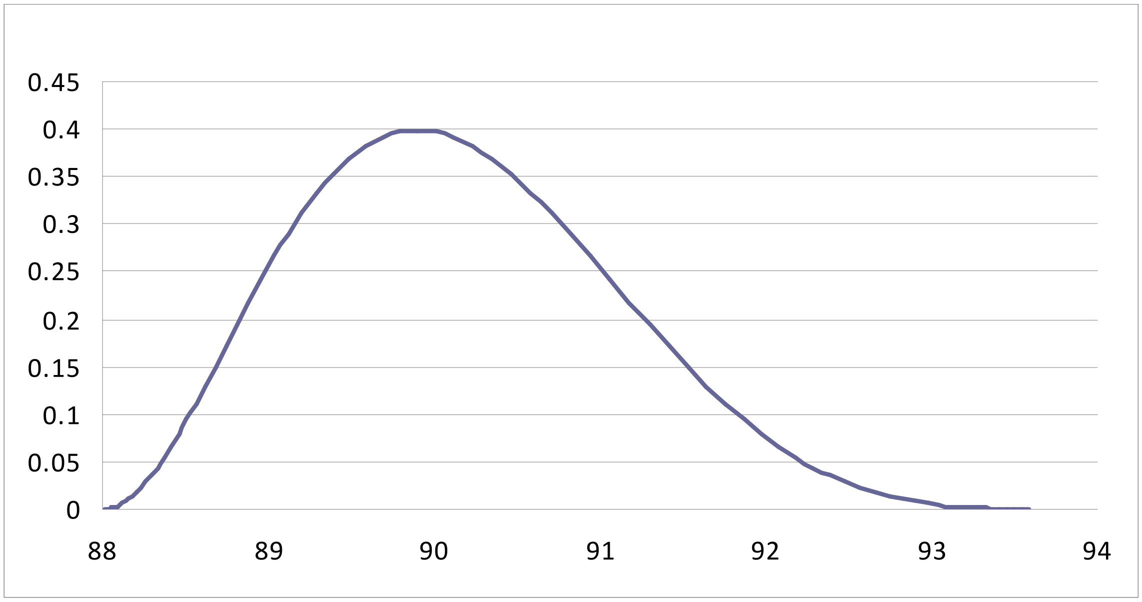

Figure 3: The distribution of planted acreage of corn (million acres) for 2008

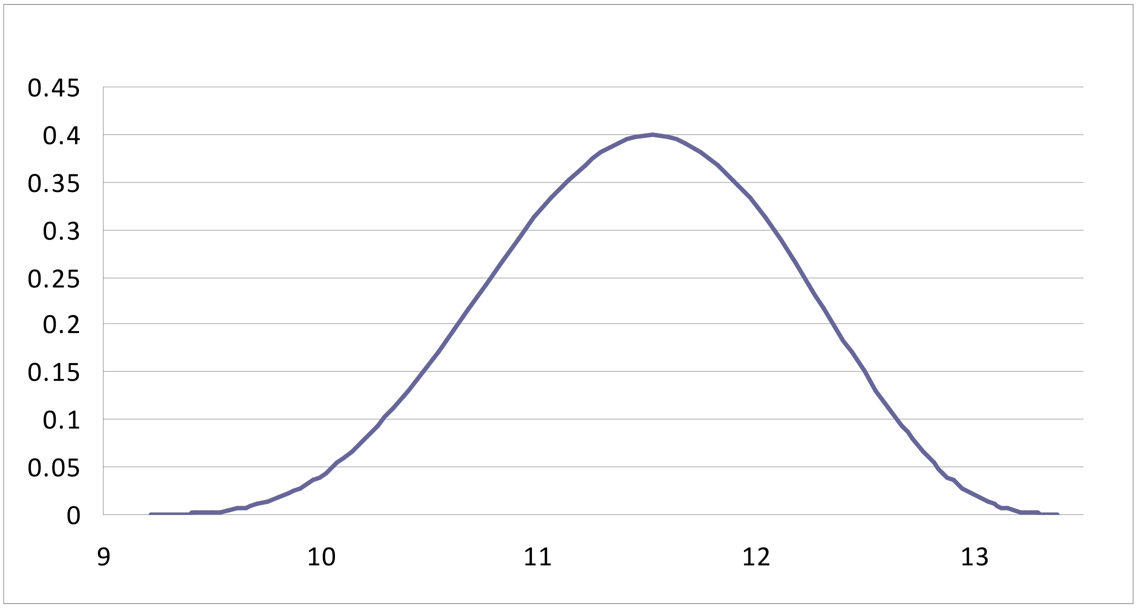

Figure 4: The distribution of ethanol production capacity (billion gallons) in the 2008/09 marketing year

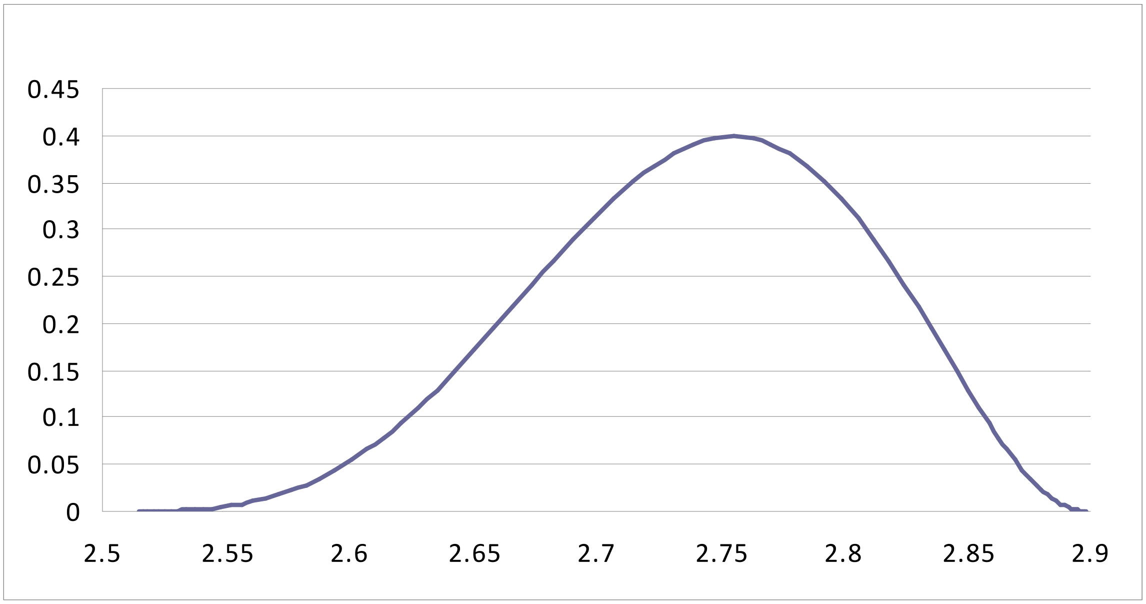

Figure 4: The distribution of ethanol production efficiency index (gallons per bushel)

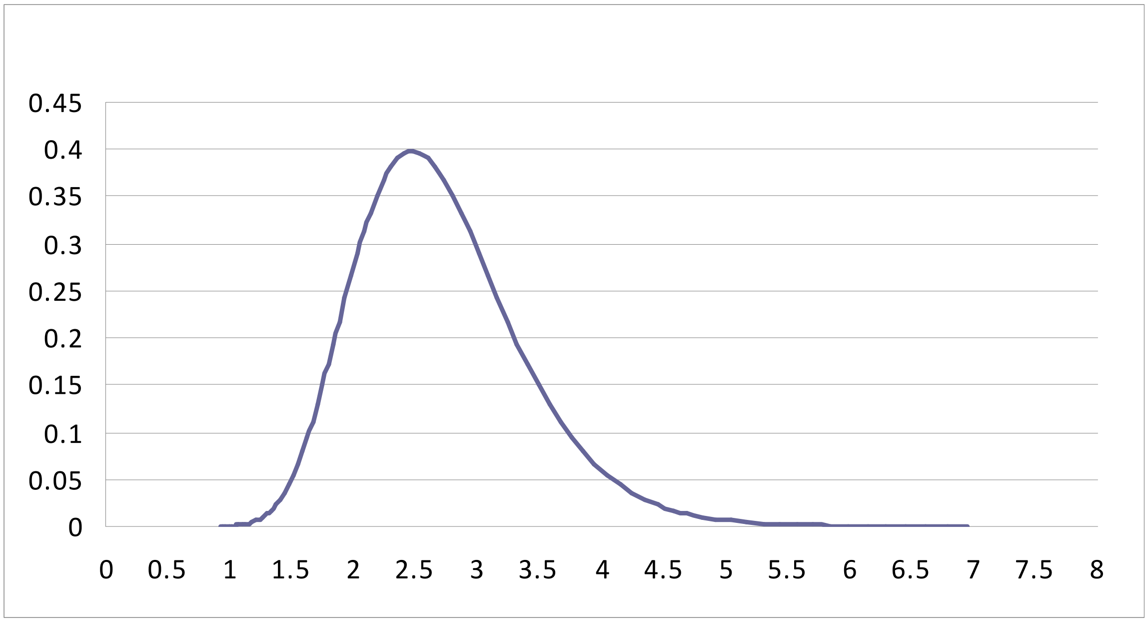

Figure 6: The distribution of gasoline price ($ per gallon) in the 2008/09 marketing year

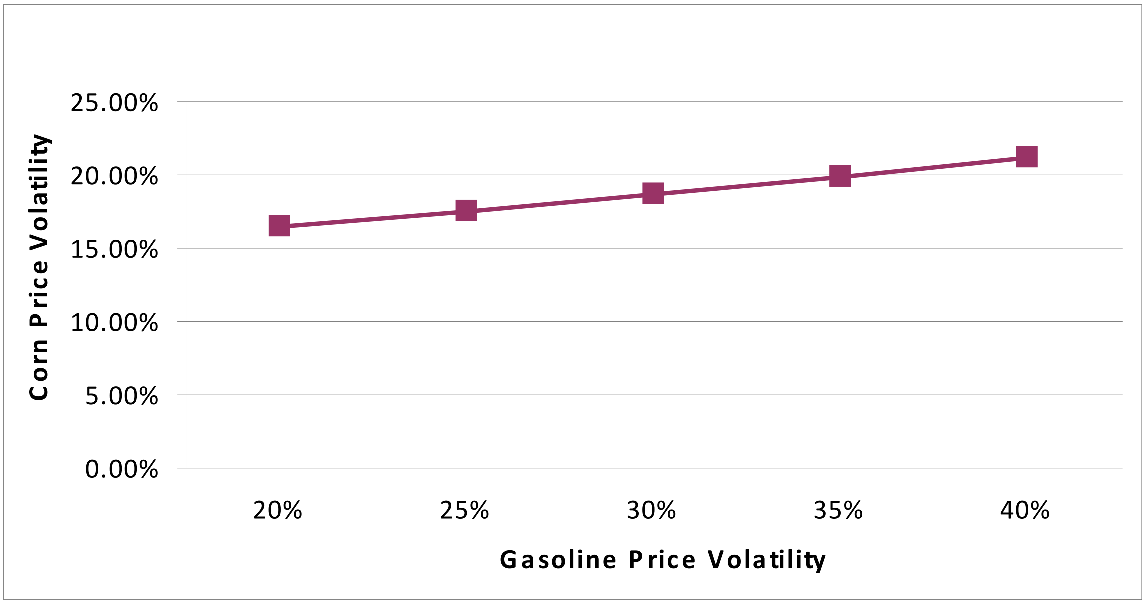

Figure 7: Sensitivity of corn price volatility to gasoline price volatility

	corn price ($ per bushel)	ethanol price ($ per gallon)	feed demand (million bushels)	food demand (million bushels)	export demand (million bushels)	% profitable ethanol plant	ethanol supply (million gallons)	demand of corn from ethanol (million bushels)	ending Stocks (million bushels)	total use of corn (million bushels)	required ethanol price to meet the mandate
baseline result											
average	4.97	2.24	6524	1323	2089	0.82	9482	2584	1250	12519	
volatility	0.18	0.19	0.06	0.02	0.20	0.32	0.32	0.32	0.17	0.08	
the EISA mandate											
average	5.32		6371	1312	1959	0.66	10871	2962	1165	12604	2.37
volatility	0.20		0.07	0.03	0.22	0.68	0.08	0.08	0.22	0.07	0.16
1988 drought											
average	6.24	2.24	5975	1282	1625	0.27	3145	857	947	9739	
volatility	0.14	0.19	0.06	0.02	0.28	1.13	1.13	1.13	0.23	0.02	
1988 drought with a mandate											
average	7.99		5210	1225	979	0.09	10077	2746	525	10161	2.97
volatility	0.05		0.03	0.01	0.27	3.02	0.03	0.03	0.17	0.01	0.05
2004 bumper crop											
average	4.06	2.24	6921	1353	2424	0.99	11382	3101	1469	13800	
volatility	0.10	0.19	0.03	0.01	0.11	0.04	0.07	0.07	0.07	0.01	
2004 bumper crop with a mandate											
average	4.07		6918	1353	2421	0.98	11413	3110	1467	13802	2.24
volatility	0.10		0.03	0.01	0.11	0.13	0.06	0.06	0.07	0.01	0.19
removal of the 51 cents tax credit											
average	4.15	1.73	6883	1350	2392	0.54	6225	1696	1448	12321	
volatility	0.22	0.25	0.06	0.02	0.19	0.68	0.69	0.69	0.15	0.09	
removal of 51 cents tax credit with a mandate											
average	5.20		6423	1316	2004	0.31	10397	2833	1194	12575	2.14
volatility	0.21		0.07	0.03	0.22	1.45	0.07	0.07	0.22	0.07	0.17

Table 1: Simulation results for different scenarios