Risk, Infrastructure and Industry Evolution

Proceedings of a conference June 24-25, 2008, in Berkeley, California

Edited by

Burton C. English
Department of Agricultural Economics
The University of Tennessee
Knoxville, TN

R. Jamey Menard
Department of Agricultural Economics
The University of Tennessee
Knoxville, TN

Kim Jensen
Department of Agricultural Economics
The University of Tennessee
Knoxville, TN

Sponsored by

Farm Foundation
USDA's Office of Energy Policy and New Uses
USDA Economic Research Service
Energy Biosciences Institute

75 Farm Foundation
SINCE 1933

New Relationships: Ethanol, Corn, and Gasoline Volatility

Zibin Zhang and Michael E. Wetzstein[1]

Background

With upward-trending gasoline prices accompanied by heightened price volatility, diversifying into biofuels, made from renewable recently living biological materials, has become a major U.S. policy objective. Vehicle fuel prices are more volatile than prices for 95 percent of products sold by domestic producers (Regnier, 2007). Such price volatility retards the entire macroeconomy and is at least partially responsible for the U.S. economy falling into the 2001 and possibly 2008 recessions. Ferderer (1996) notes fuel-price volatility affects the entire U.S. economy through sectoral shocks and uncertainty. Castillo, Montoro, and Tuesta (2007), demonstrate that fuel-price volatility stimulates inflation and results in Kneller and Young's (2001) conclusion that fuel-price volatility is robustly and negatively correlated with economic growth.

Although biofuels, such as ethanol, are generally more expensive than their petroleum counterparts, portfolio theory suggests diversification can reduce fuel-price volatility and thus may offer a socially preferred trade-off in terms of expected price and variance. This social preference for higher expected price and lower variance is supported when vehicle-fuel externalities (greenhouse gases, fuel security, air quality, road congestion, and vehicle accidents) are price internalized, yielding a better true social cost of burning fuels.

However, food versus fuel security has recently emerged as another major external cost of biofuels. In 2007, the price of corn, the nation's number one crop in total production in terms of yield, doubled. The popular press attributes much of this run-up in corn prices to the swelling demand for ethanol fuel (Etter, Brat, and Gray, 2007). Market economics predicts this high price of corn will be mitigated by a supply response and a softening of demand (Meekhof, Tyner, and Holland, 1980; Webb, 1981). Corn acreage was quite responsive to the sharp price hike with acreage reaching historic highs (USDA-ERS, 2008). The recent boom in ethanol refining capacity has dampened, with the ethanol price in conjunction with high corn prices forcing some ethanol refineries to shutdown and retard the expected entry of others (Hargreaves, 2007). This current fluid ethanol/corn market manifests in both the first and second moments of corn and ethanol prices. Not only does ethanol potentially influence the level of corn prices but it can also impact corn's price volatility.

As an aid in shedding some light on the relations among biofuel and fossil fuel prices with consideration of environmental and food security implications, the results of two recent investigations based on time series analysis are presented (Zhang *et al*., 2008a and 2008b). First, research results indicate if the U.S. develops a comprehensive vehicle fuel policy, gasoline price fluctuations can be mitigated and at the same time reduce harmful vehicle environmental effects. Second, past research on the economics of biofuels has generally adopted a static framework with difficulties in determining causality among the variables and not extending policy analysis to environmental implications. Such shortcomings are particularly acute in the investigation of biofuel's and fossil fuel's price volatilities. A static framework will generally not aid in the investigations of dynamic price relationships and the causality among biofuel and fossil fuel prices. This causality is important when considering the current food versus fuel security issue with food prices increasing faster in developing countries where people living in poverty devote over half of their income to food (Senauer, 2008).

The following section presents observations related to the stochastic biofuels market by two recent reviews of the biofuel economic literature. Based on this foundation, the next section discusses a policy which both mitigates volatile U.S. gasoline prices and internalizes vehicle external costs. However, this policy does not address the food versus fuel issues, so an initial attempt at addressing this issue is then presented.

[1] Zhang is a Graduate Student and Wetzstein is a Professor, all respectively, in the Department of Agricultural and Applied Economics at the University of Georgia, Athens, Georgia.

Current Biofuel Industry Observations

Recent reviews on biofuel economics yield a number of observations on the current state of the biofuels industry (Rajagopal and Zilberman, 2007; Zhang and Wetzstein, 2008). Most notable in terms of stochastic fuel prices and fuel externalities are the following observations. With the automobile and gasoline industries on a long-run gasoline trajectory, some large shock is required for a shift in trajectory toward alternative renewable fuels, otherwise network externalities will prevent such a shift (Dimitri and Effland, 2007). Such a shock can be in the form of government programs designed to support biofuels. However, these programs result in many independent decisions at different levels of government yielding policies that are often poorly coordinated and targeted (Koplow, 2006). For instance, restrictions on world trade, such as ethanol tariffs, can support an emerging industry but distort market prices and discourage ethanol adoption (Kojima and Johnson, 2005). This results in the United States increasingly trading an export in which it has a tremendous comparative advantage (corn) for a product in which it has a comparative disadvantage (ethanol) (Runge and Senauer, 2007). In terms of the environment, recent scientific articles question if biofuels reduce greenhouse gas emissions relative to fossil-based fuels (Rajagopal *et al*., 2007; Searchinger *et al*., 2008) and biofuels may compete for renewable and nonrenewable resources which impact its sustainability and that of food (Rajagopal and Zilberman, 2007). Finally, agricultural markets are in general very responsive to price shocks, which will tend to mitigate food inflation (Webb, 1981). However, at least in the short-run, market gyrations will occur which negatively impact the world's poor (Daschle, 2007).

A Vehicle Fuel Portfolio

Diversifying into renewable fuels has become a major U.S. policy objective. Considering ethanol, which is currently the main U.S. renewable fuel, the United States has two choices in acquiring fuel ethanol: home-grown domestic production or imports, with Brazil as the major source. A vehicle fuel price-efficiency frontier composed of efficient petroleum and ethanol portfolios can be estimated by mating a generalized autoregressive conditional heteroskedasticity (GARCH) model to portfolio-efficiency analysis. This frontier reveals a trade-off between risk (volatile fuel prices) and reward (low fuel prices). Policymakers can then employ their subjective risk preferences, which may consider vehicle-fuel externalities, in selecting an optimal portfolio on the efficiency frontier.

For this approach, the data set consists of monthly wholesale fuel prices for Brazil anhydrous ethanol, U.S. ethanol, and U.S. conventional gasoline from 1998 to 2007. Prices for Brazilian and U.S. ethanol were adjusted to reflect differences in fuel efficiency, transportation costs, and the ethanol fuel subsidy. By diversifying into Brazilian and U.S. ethanol, the United States can achieve the lowest possible price volatility at a given price. Negatively correlated fuels can result in significant reductions in the overall fuel portfolio, and even positive correlations can yield a reduction in portfolio volatility.

Mathematically the expected portfolio price considering Brazilian and U.S. ethanol, along with petroleum fuel is

$$(1)\quad E(p) = \alpha_B E(p_B) + \alpha_E E(p_E) + \alpha_G E(p_G),$$

where $E(p)$, $E(p_B)$, $E(p_E)$, and $E(p_G)$ are the expected portfolio, Brazilian ethanol, U.S. ethanol and petroleum prices, respectively, and α_B, α_E, and α_G are the associated weights for the respective expected prices with their sum equaling unity. The volatility associated with $E(p)$ is represented by the portfolio's variance

$$(2)\quad \sigma^2 = \alpha_B^2 var(p_B) + \alpha_E^2 var(p_E) + \alpha_G^2 var(p_G) + 2\alpha_B\alpha_E cov(p_B, p_E) + 2\alpha_B\alpha_G cov(p_B, p_G) + 2\alpha_E\alpha_G cov(p_E, p_G),$$

where $var(p_B)$, $var(p_E)$, and $var(p_G)$ are the variances of Brazilian and U.S. ethanol and petroleum fuel prices, and cov represents the associated covariance.

The efficient portfolio frontier is the set of all dominant portfolios. Using mathematical programming, a portfolio dominates an alternative portfolio, if the expected portfolio price cannot be decreased holding variance constant and variance cannot be reduced holding price constant. Standard estimation assumes constant volatility over time, which in the current vehicle-fuel market is probably too restrictive. A multivariate GARCH (MGARCH) model solves this problem by allowing the volatility to vary with time. For estimating the volatility, MGARCH weights past variances and covariances with the weights determined by the data with the use of maximum-likelihood estimation. The MGARCH model assumes the best predictors of future volatility is a weighted average of the long-run volatility, the predicted current volatility, and any new information. This is called adaptive or learning behavior and in a statistical sense can be thought of as Bayesian updating.

Results

The efficient portfolio frontier for year 2006, illustrated in Figure 1, was derived based on equations (1) and (2). Selected frontier points are listed in Table 1. The trade-off between volatility and price is observed given the negative sloping convex efficiency frontier. Gasoline alone, not blended with ethanol, is on the frontier with the lowest price and highest volatility. The relative higher prices for Brazilian and U.S. ethanol account for gasoline's frontier minimum price. Reducing fuel volatility is possible by increasing the percentage of Brazilian and U.S. ethanol used in the U.S. fuel market. As indicated in Table 1, such a reduction in volatility is achieved

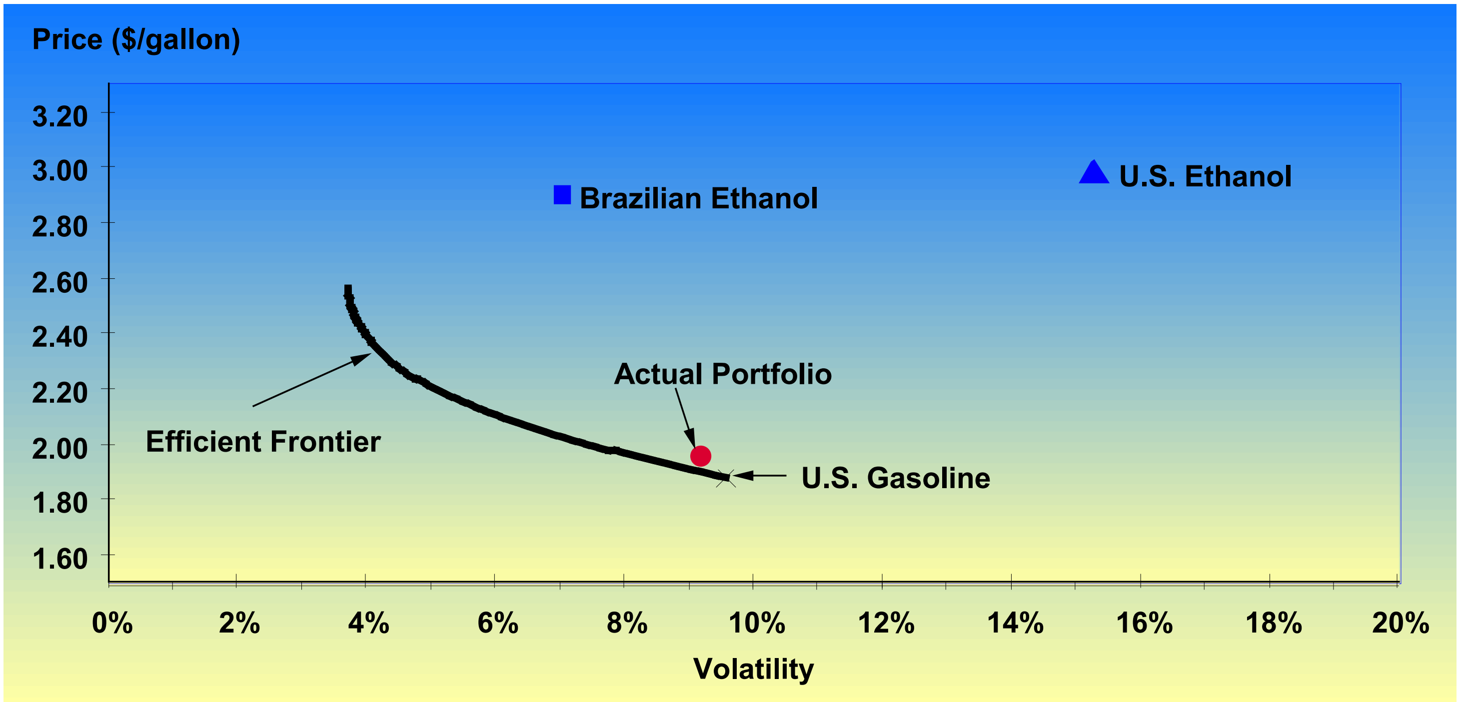

Figure 1. Efficient Portfolio Frontier with Current Subsidy/Tariff Policy, Year 2006

Table 1. Selected Frontier Points for Year 2006

Price ($/gal)	Subsidy/Tariff				Free-Market			
	Volatility	Weights			Volatility	Weights		
		Ethanol		Gasoline		Ethanol		Gasoline
		Brazil	U.S.	U.S.		Brazil	U.S.	U.S.
1.9	0.092	0.02	0	0.98	0.106	0.02	0	0.98
2.0	0.075	0.12	0	0.88	0.086	0.13	0	0.87
2.1	0.061	0.23	0	0.77	0.069	0.24	0	0.76
2.2	0.051	0.33	0	0.67	0.056	0.35	0	0.65
2.3	0.044	0.41	0.02	0.57	0.046	0.46	0	0.54
2.4	0.040	0.47	0.06	0.47	0.040	0.56	0	0.44
2.5	0.038	0.51	0.11	0.38	0.036	0.67	0	0.33

by a greater percentage increase in Brazilian ethanol compared with U.S. ethanol. As an example, from Table 1, at a price of $2.50, the lowest volatility portfolio, with an ethanol subsidy and import tariff, is 51 percent Brazilian ethanol, 11 percent U.S. ethanol, and 38 percent petroleum gasoline.

Policy Analysis I: Considering Free-Market Ethanol

Investigating the removal of the tariff in conjunction with eliminating the federal ethanol subsidy results in the portfolio illustrated for year 2006 in Figure 2, along with selected frontier points listed in Table 1. For the more volatile year 2006, there is not a marked reduction in volatility. Thus, moving toward free-trade does not lead to a marked shift in the efficiency frontier, but does shift the efficient portfolios away from U.S. ethanol toward Brazilian ethanol. This indicates that caution is warranted for advocating a free-trade biofuels market with the objective of shifting the efficient frontier toward lower prices and price volatility. Depending on the current correlations among the fuels, the efficient frontier may or may not exhibit a marked inward shift.

Policy Analysis II: Considering Environmental Costs

The market prices for Brazilian and U.S. ethanol and gasoline do not reflect the true social costs of vehicle fuel consumption. Parry, Walls, and Harrington (2007) summarize these external costs in terms of greenhouse gases, oil dependency, air quality, congestion, and accidents (Table 2). Air quality, congestion, and accident costs do not vary with fuel type. While employing a total lifecycle analysis, EPA has estimated greenhouse gas emissions from ethanol are reduced approximately 20 percent with corn-based ethanol compared with petroleum gasoline emissions. Brazilian eth-

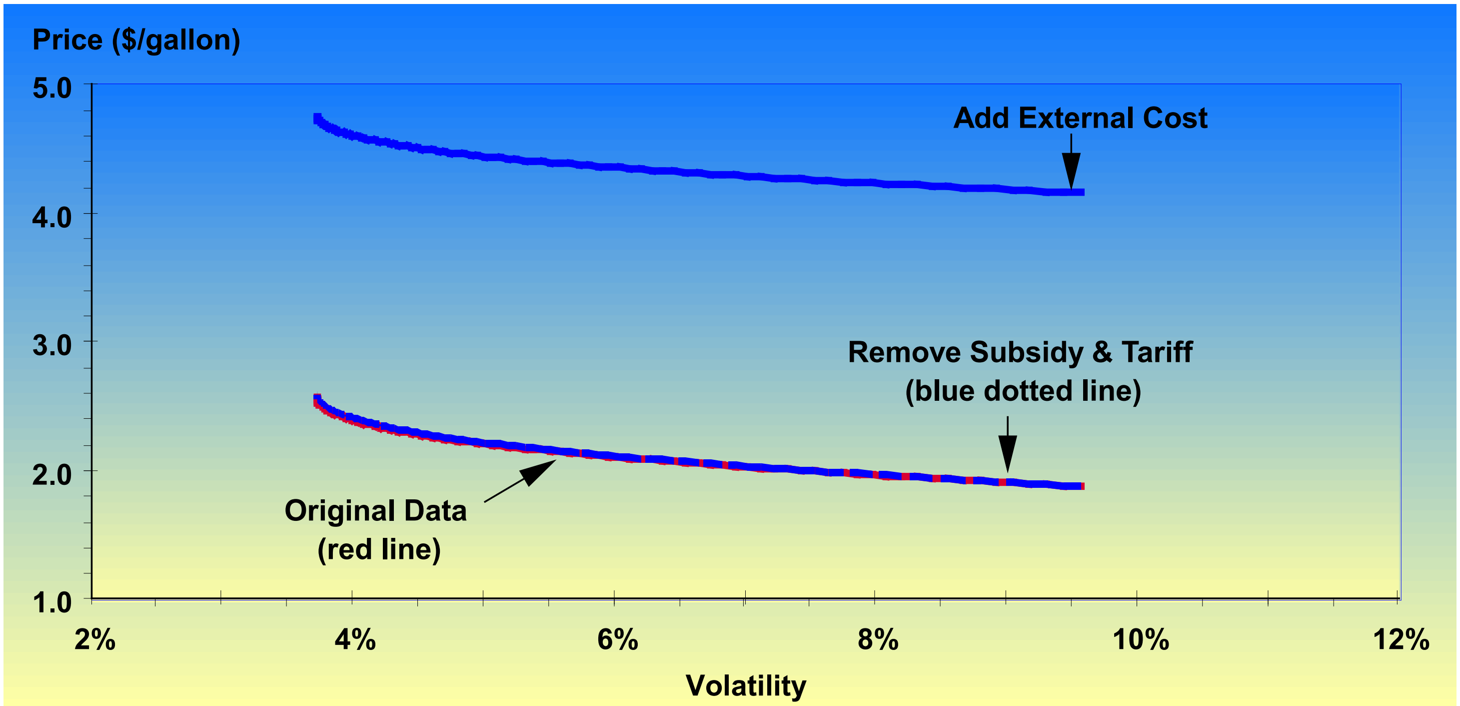

Figure 2. Free-Trade and Added Environmental Cost Efficient Portfolio Frontiers for Year 2006

Table 2. External Costs

External Costs	Ethanol		Gasoline
	Brazil	U.S.	
		(cents/gallon)	
Fuel Related Costs			
Greenhouse Gases	4.8	4.8	6.0
Oil Dependency	0	0	12
Mileasge Related Costs			
Local Air Quality	42	42	42
Congestion	105	105	105
Accidents	63	63	63
Total	214.8	214.8	228.0

anol, chiefly produced with sugarcane, has the potential for a larger emission reduction. However, as indicated from Table 2, and addressed by Parry, Walls, and Harrington (2007), the fuel related externalities are small compared to the mileage related costs. There are no oil dependency externalities for ethanol; however, air quality emissions are not reduced with a larger use of ethanol in the portfolio (Jacobson, 2007). Incorporating these costs into the analysis by augmenting each vehicle fuel with its respective environmental costs, yields a new set of expected prices and associated volatilities. As illustrated in Figure 2, incorporating the environmental costs results in essentially an upward vertically parallel shift in the efficiency frontier. The lack of a marked variation in environmental costs among the three fuel types accounts for this parallel shift.

Implications

Results indicate the current U.S. vehicle-fuel policies yield an efficient portfolio of alternative fuels on the efficiency frontier. However, the policies either implicitly or explicitly are generally minimizing the expected price at the expense of high fuel-price volatility.

By shifting policies, yielding an upward movement along the efficiency frontier, fuel-price volatility is reduced at a cost of higher prices. Depending on social preferences, such a shift, possibly promoting economic stability and growth, may be desirable. In fact, given the major environmental costs of vehicle fuels are not currently accounted in the fuel-market price, the cost of higher fuel prices from reducing volatility may instead be socially desirable. Thus, if the United States is truly interested in developing a comprehensive vehicle-fuel pricing policy, consideration of policies designed to reduce volatility and increase fuel prices would be appropriate. Such policies would take the form of providing incentives for the adoption of alternative flex-fuel vehicles and supply of blended ethanol fuels. Consideration of reducing trade barriers may also be considered. However, as this analysis indicates, care should be taken in developing such policies. In more volatile years, moving toward free-trade may not lead to a marked shift in the efficiency frontier, and may shift the efficient portfolios away from U.S. domestic toward foreign fuel supply.

Food Versus Fuel Issue

An emerging major external cost of fuel-based ethanol is the possible spillover effects of biofuel refining on agricultural commodities. If ethanol is causing upward pressure on commodity prices and/or increasing commodity price volatility, then such costs should be accounted for in developing the above efficient fuel portfolio frontier.

These possible spillover effects are addressed with weekly price series for U.S. ethanol, corn, conventional gasoline, and oil. From the log price changes, volatility is estimated using two procedures. First, a six-week overlapping window for ethanol and corn prices are used to calculate standard deviations as measures of price volatility. This is the classical descriptive tool for forecasting variances. It is the first autoregressive conditional heteroskedascity (ARCH) model given the assumption that the variance of the next period price is a simple average of the past standard deviations (Engle, 2001). As noted by Campbell *et al*. (2001) and Pindyck (2004), this relatively simple procedure for measuring volatility has an advantage of not requiring a parametric model describing the evolution of volatility over time. Second, series for conditional volatility are estimated with an MGARCH model incorporating not only ethanol and corn prices, but also prices of conventional gasoline and oil. The advantage of MGARCH over a fixed-lag standard deviation approach is dropping the restrictive assumptions of constant weights within the lagged period and zero weights prior to the period. MGARCH lets these weights be parameters to be estimated and yields parsimonious parameter estimation which is relatively easier to estimate by assuming adaptive behavior (Bayesian updating) than ARCH models. The technical links among price volatilities of corn, ethanol, gasoline, and oil suggest interactions within these prices. Thus, recognizing this feature through a multivariate modeling framework should lead to more relevant empirical models than working with separate univariate models.

The focus is on prices, with the acknowledgment there are other measures of volatility. Instead volatility associated with consumption, production, or inventories could be addressed. However, interest is in the overall market with the spot prices as the best single statistic for market conditions. As noted by Pindyck (2004), spot price volatility reflects the volatility of current as well as expected future values of production, consumption, and inventory demand.

As discussed by Adrangi *et al*. (2001), for the California oil and diesel fuel markets, microeconomic theory explains the demand for corn as a derived demand, where the price of the final good, ethanol, influences the quantity and thus price of the intermediate good, corn. Based on this theory, the hypothesized direction of dynamic prices would flow from the price of ethanol to the corn price. This provides a theoretical justification for the current food versus fuel debate. The increased demand for ethanol fuel translates into an associated higher price which directly impacts the price of corn. However, if the dynamics do not support this derived demand hypothesis, market power on the part of corn producers' ability to market their production to non-ethanol markets may exist. Corn prices would then tend to dictate ethanol prices.

Data

The data set includes four weekly price series: U.S. ethanol, corn, conventional gasoline, and oil from the last week of March 1989 through the first week of December 2007. Except for U.S. oil prices, all price series are averaged over different locations. Weekly nominal wholesale prices for U.S. ethanol are collected from Ethanol & Biodiesel News (formerly Renewable Fuel News) at three U.S. locations: Los Angeles, Houston, and New York City. U.S. weekly corn prices mated with ethanol prices are collected from USDA Agricultural Marketing Service for three U.S. locations: Nebraska, Kansas, and Texas. The conventional gasoline spot prices for the same three U.S. locations as ethanol prices are collected from the "Weekly Petroleum Status Report" available at the Energy Information Administration website (USDOE-EIA, 2007a), and U.S. FOB weekly West Texas Intermediate oil spot prices are also taken from the Energy Information Administration website (USDOE-EIA, 2007b).

Each series is tested for the presence of a unit root with all the series failing to reject the null hypothesis of a unit root at a 10 percent significant level, except for the ethanol price series. However, all first differencing the logarithm of the price series result in rejecting the null hypothesis at a 1 percent significant level, indicating stationarity.

Measurement of Corn and Ethanol Volatility

Classical Measurement (Sample Standard Deviation)

Employing a six-week overlapping window, the volatilities of ethanol and corn stationary prices, $p_t = 100 ln(P_t/P_{t-1})$, where P_t is the price time-series variable, are estimated by computing separately their respective sample standard deviations (volatility)

$$(3)\ \hat{\rho}_t = \sqrt{\frac{1}{5}\sum_{\tau=0}^{5}(p_{t-\tau} - \bar{p}_t)^2},$$

where $\hat{\rho}_t$ is the standard deviation covering the price window of a series (ethanol or corn prices) and $\bar{p}_t$ is the mean value of the price window.

MGARCH Measurement

As noted by Pindyck (2004), use of overlapping window methods introduces serial correlation and imprecise estimates of the standard deviation. These disadvantages are mitigated by employing an MGARCH model for estimating conditional variances (volatilities), along with a vector autoregressive (VAR) model for estimating the evolution of the ethanol, corn, gasoline, and oil standardized price series.

Sample Standard Deviation Estimation

Figures 3 and 4 illustrate the price series and volatility for ethanol and corn, where volatility is measured as the sample standard deviations of log price changes (3). From Figure 3, ethanol price volatility tends to be volatile at the beginning, less so in the mid to late 90s, followed by a marked increase in volatility at the turn of the 21st century. Ethanol prices have been particularly sensitive to short-run supply and demand shifts in recent years because of the highly inelastic nature of this market. With the ban and liability issues of the fuel oxygenate additive MTBE (methyl-tertiary-butyl ether), in the short-run, fuel blenders are limited in their ability to switch from ethanol as an oxygenate additive. Also, significant lead time is required in order to bring additional domestic ethanol supplies to market and foreign supply is restricted with a 54¢ per gallon import tariff. This has contributed to the recent increase in ethanol price volatility. In contrast, corn volatility does not exhibit this decline in volatility swings in the mid to late 90s. Both price series have a high degree of skewness and kurtosis, but less so for the log price changes. The Jarque-Bera test statistic rejects the hypothesis of normality at the 1 percent level for both price series.

The sample standard deviation regressions were estimated for both ethanol and corn. Own-lagged volatility regressions with and without a time trend were first estimated followed by regressions also considering the cross volatility effects (corn for the ethanol regression and ethanol for the corn regression). In all the regressions with a time trend, the associated time coefficients are significant at the 5 percent level, indicating increased volatility overtime. However, the coefficients are all quite small yielding approximately only a 0.24 percent and 0.60 percent yearly increase in ethanol and corn volatility, respectively. Also, the time coefficients have almost no effect on the other coefficients.

Comparing the restricted and unrestricted regressions, Wald tests for Granger causality are reported in Table 3. At the 5 percent level of significance, the test statistics indicate neither price volatility is "causing" the other price volatility. However, at the weaker 10 percent level ethanol-price volatility is "causing" corn price volatility. This indicates other variables, possibly gasoline and oil prices, may be contributing to the observed changes in both corn and ethanol volatility.

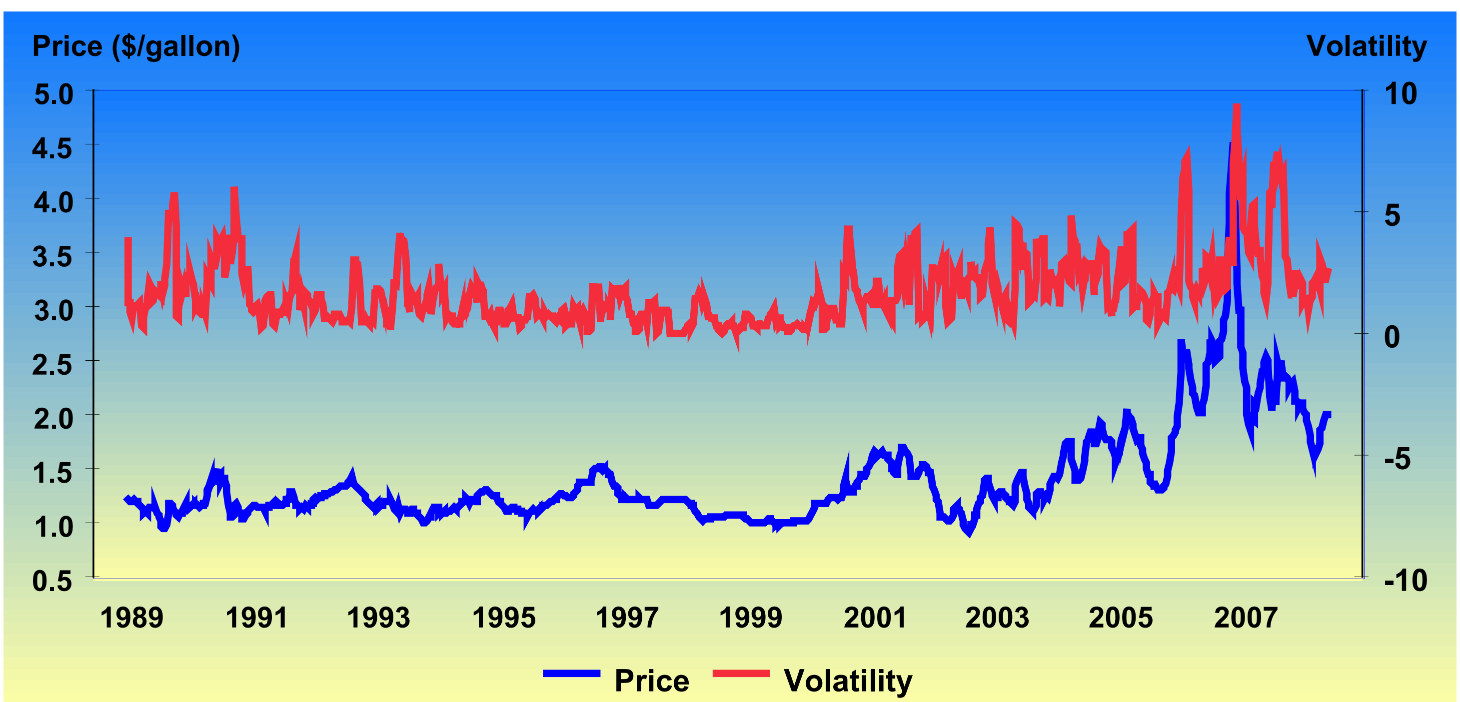

Figure 3. Ethanol Price Series and Price Volatility

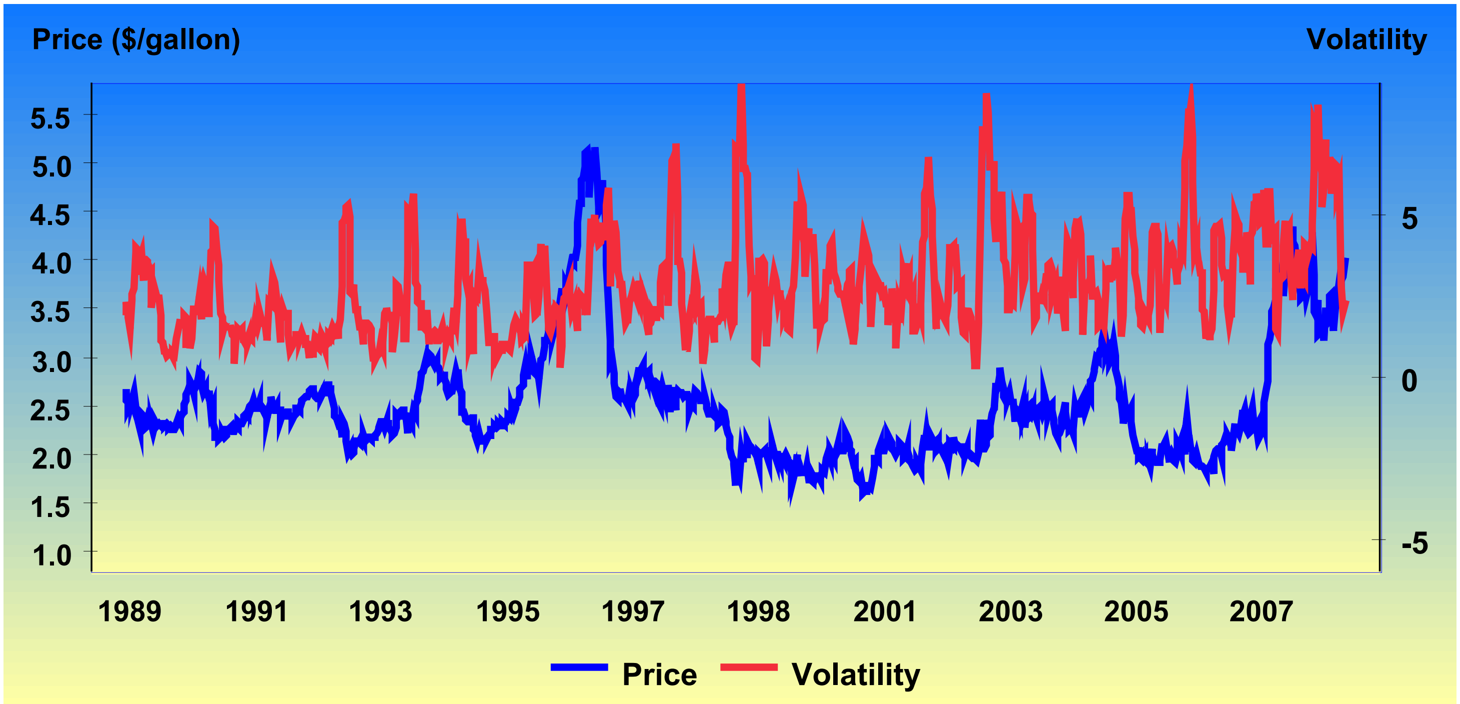

Figure 4. Corn Price Series and Price Volatility

Table 3. Granger Causality Wald Tests for the Null Hypotheses of No Granger Causation

Direction of Price-Volatility Causality[a]	χ^2	Result[b]	Conclusion
$\rho_c \rightarrow \rho_e$	8.54*	Do Not Reject Null	No Causation
$\rho_e \rightarrow \rho_c$	11.23*	Reject Null	Granger Causation

[a]The arrow, $\rightarrow$, indicates the direction of Granger causality. Ethanol, corn, gasoline, and oil price volatility are denoted ρ_e, ρ_c, ρ_g, and ρ_o respectively.
Note: * indicates significance at the 10 percent level.

Although the results may indicate ethanol-price volatility is Granger causing corn-price volatility, the shocks to corn-price volatility appear to be quite transitory as indicated by the estimated half-life. As discussed by Seong, Morshed, and Ahn (2006), half-life, $\hat{\kappa}$, is a measure of the persistence of a deviation in price volatility from its trend, and is measured as

$$\hat{\kappa} = -ln2/ln[\sum AR(i)].$$

The half-life of a corn-price volatility deviation is estimated at less than five weeks indicating a rather transitory effect.

VAR and MGARCH Estimation

VAR and MGARCH models jointly are one method for addressing the restrictive assumptions associated with the sample standard deviation approach. Incorporating gasoline and oil prices into the model, along with corn and ethanol prices, the relationships of these level prices are investigated first with a VAR model.

The Final Prediction Error, Akaike's, and Hannan and Quinn information criterion statistics were computed for determining the lag length in the VAR specification. The Final Prediction Error and Akaike's statistics indicated a lag length of four compared to a lag of two for Hannan and Quinn criteria. The resulting discrepancy is the result of very small changes in the summary statistics for these tests across the lag number. Estimation of the model for alternative lag lengths yielded robust results with nearly identical estimated coefficients. For reporting the results, a four-lag specification was selected.

The VAR model estimated coefficients and associated standard errors indicate both the oil-price and ethanol-price regressions are significantly affected by conventional gasoline-price lags. These relations are further illustrated by the Wald tests for Granger causality (Table 4). The large highly significant (less than 1 percent) and low significant (greater than 15 percent) χ^2s for the ethanol and gasoline tests and gasoline and oil tests, support Granger causation for these prices. Specifically, from Table 4, gasoline prices are Granger causing both ethanol and oil prices. The price of gasoline is driving up ethanol and oil prices. This supports the microeconomic theory hypothesis of a derived demand for ethanol and oil associated with gasoline production. The ever increasing demand for gasoline within the United States and

Table 4. Granger Causality Wald Tests for the Null Hypotheses of No Granger Causation		
Direction of Price Causality[a]	χ^2	Decision
Ethanol & Corn Prices		
$\rho_e \rightarrow \rho_c$	6.118	Do Not Reject
$\rho_c \rightarrow \rho_e$	6.273	Do Not Reject
Ethanol & Gasoline Prices		
$\rho_e \rightarrow \rho_g$	6.657	Do Not Reject
$\rho_g \rightarrow \rho_e$	21.961*	Reject
Ethanol & Oil Prices		
$\rho_e \rightarrow \rho_o$	8.562***	Reject
$\rho_o \rightarrow \rho_e$	4.692	Do Not Reject
Gasoline & Oil Prices		
$\rho_g \rightarrow \rho_o$	28.408*	Reject
$\rho_o \rightarrow \rho_g$	3.825	Do Not Reject
Gasoline & Corn Prices		
$\rho_g \rightarrow \rho_c$	8.809***	Reject
$\rho_c \rightarrow \rho_g$	9.923**	Reject
Oil & Corn Prices		
$\rho_o \rightarrow \rho_c$	7.306	Do Not Reject
$\rho_c \rightarrow \rho_o$	9.059***	Reject

[a]The arrow, →, indicates the direction of Granger causality. Prices of ethanol, corn, gasoline, and oil, in terms of percentage change, are ρ_e, ρ_c, ρ_g, and ρ_o respectively.
Note: *, **, *** indicate significance at the 1 percent, 5 percent, and 10 percent level respectively.

the existing tight world oil market underlies this oil-derived demand. With ethanol as a fuel oxygenate, it is a complement with conventional gasoline in vehicle fuel production. As the demand for vehicle fuels increases, the complementary input demand for ethanol and conventional gasoline increases.

In terms of relatively low χ^2s, the other Wald tests in Table 4 are weak. Corn and ethanol prices appear not to be responding to their cross lag prices, while other prices, possibly gasoline and oil, are contributing to ethanol and corn price movements. These results are consistent with gasoline as the major market for oil, consuming approximately 70 percent of U.S. petroleum demand (USDOE-EIA, 2007), ethanol contributing less than 5 percent of vehicle fuel consumption, and corn having alternative food-marketing outlets when ethanol prices are depressed.

In addition to the direction of causation, the influence of one variable on another provides information on the relative magnitude of its causation. Performing variance-decomposition analysis yields this information by measuring the effect of shocks in each variable on the current and future values of the variables. Specifically, decomposition reflects the percentage of forecast variance of each variable in the VAR model caused by shocks to the other variables. Table 5 lists the decomposition matrix after five periods (weeks).

From Table 5, the variability of the ethanol (corn) price contributes only 0.8 percent (1.1 percent) of the forecast variance for the corn (ethanol) price. In contrast, for the gasoline price, the share of forecast variance from the oil and ethanol prices are 29.3 percent and 5.2 percent respectively. This variance-decomposition analysis further supports the influence of gasoline prices on oil and ethanol prices and the general lack of an ethanol/corn price relation.

The persistence of a deviation in price from its trend is revealed in impulse response curves. The response functions measure the effect of a one standard-deviation shock of a given variable on current and future values of the variables. With the exception of an ethanol price shock on its own price, there was little if any persistence to a price shock. In general, within one to two weeks any price shocks where dissipated. The ethanol persistence from its own shock was longer (five weeks). This relatively more persistent effect in the ethanol market may reflect its lack of maturity. In contrast to the oil, gasoline, and corn markets, the expanding nature of ethanol into a national market limits its price responsiveness. This persistence in ethanol prices and lack of any persistence in corn prices from an ethanol price stock are illustrated in Figure 5. Corn has little if any response to an ethanol price shock, while ethanol has a relatively large lag response which is persistent for a number of weeks.

Table 5. Variance-Decompositions after Five Periods (Weeks)

Variable Price	Percentage of Forecast Error ρ_g	ρ_o	ρ_e	ρ_c
Gasoline, ρ_g	0.939	0.004	0.041	0.016
Oil, ρ_o	0.293	0.659	0.039	0.009
Ethanol, ρ_e	0.052	0.004	0.932	0.011
Corn, ρ_c	0.007	0.007	0.008	0.980

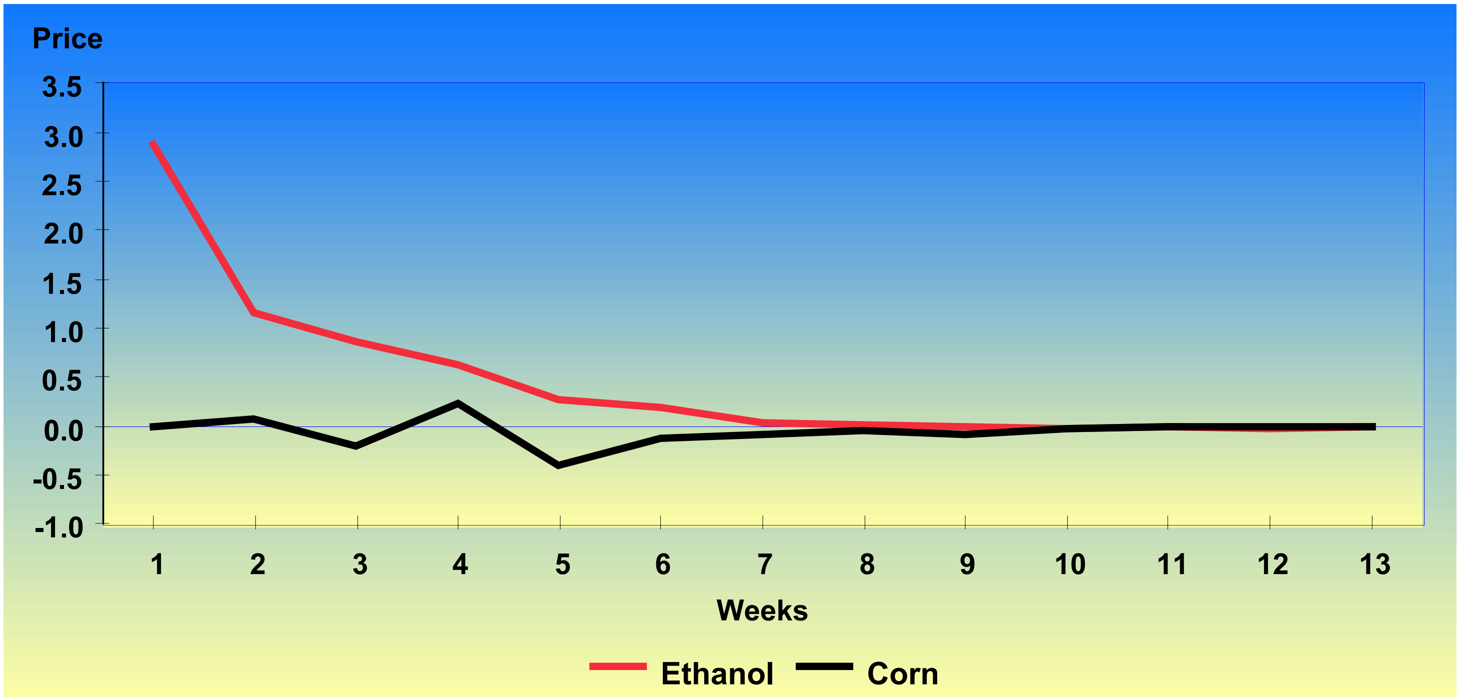

Figure 5. Impulse Response Function from a Shock in the Ethanol Price

A structural shift in the relationships among these prices may have occurred with rapid expansion of fuel ethanol after the implementation of states phasing out MTBE and replacing it with ethanol as a fuel additive. This shift was considered by estimating a VAR model on a sub-sample of the date from mid 2000 to the end of 2007. Results are similar to the whole data sample, indicating again the dominance of gasoline in driving the fuel market.

In contrast to the VAR results, the MGARCH results in modeling price volatility yields both a direct and indirect link between ethanol and corn price volatility. Consistent with the sample standard deviation results, the MGARCH results indicate ethanol-price volatility influences corn-price volatility directly through ethanol's conditional variance while corn-price volatility does not influence ethanol volatility. Considering the indirect relation through the ethanol/corn-price conditional covariance, ethanol-price volatility is positively related to the covariance, while corn-price volatility is negatively related. Recall from Figures 1 and 2, corn prices are generally more volatile than ethanol prices, so an increase in their covariance will tend to curb corn-price volatility and heighten ethanol-price volatility. Such inverse ethanol- and corn-price volatility effects are also revealed in the covariances between oil- and ethanol-price volatility and oil- and corn-price volatility. The oil- and ethanol-price volatility covariance has a positive influence on ethanol-price volatility, while the oil-corn price volatility covariance has a negative influence on corn-price volatility. Oil-price volatility also has a direct effect on gasoline-price volatility with the reverse also being true.

Similar to the VAR model, a possible structural shift was investigated by again considering the data sub-sample from mid 2000 to the end of 2007. In contrast to the VAR model, results do slightly differ for the sub-sample. The GARCH coefficients associated with corn and ethanol for their regressions are no longer significant at even the 15 percent level. This indicates the direct and indirect GARCH conditional variances and covariances do not influence corn and ethanol price volatility. However, the ARCH ethanol term is significant at the 1 percent level in the corn regression and the corn term is 1 percent significant in the ethanol regression. These two terms represent current shocks and indicate that corn-price volatility is influenced by the volatility of ethanol prices and vice versa. Although the nature of the volatility influence may differ between data sets, a link between ethanol- and corn-price volatility exists for both sets. Particularly for ethanol influencing corn, in terms of price volatility, results indicate an interrelation between the two price volatilities.

The sample standard deviation, VAR, and MGARCH results indicate that popular beliefs may be confusing the link of price volatility between ethanol and corn with instead the run-up in corn prices to the swelling demand for ethanol fuel. The sample standard deviation and MGARCH results indicate that ethanol price enhancement, from shifts in its demand, have increased the volatility of ethanol prices and exerted an associated increase in corn volatility. However, VAR results indicate the price level of corn is not impacted by ethanol prices. A positive ethanol price shock does increase corn prices, but the lack of corn-price persistence to an ethanol price shock results in the corn price relatively rapidly mean reverting. The flexibility of corn acreage and yield enhancement abilities mitigates any price shocks. The price of corn reflects this flexibility by integrating the current as well as expected future values of yields, consumption, and inventories.

Implications

These results are consistent with economic theory. In terms of derived demand theory, results support ethanol and oil demands as derived demands from vehicle-fuel production. Gasoline prices directly influence the prices of ethanol and oil. However, of greater significance for the food versus fuel security issues, results support the effect of prices as market signals which restore markets to their equilibriums after a demand or supply event (shock). As the results indicate, such shocks may increase the volatility of markets, but decentralized freely operating markets will mitigate the persistence of these shocks. As specifically addressed, the recent upward direction of corn prices may have been supported by an ethanol demand shift, but the results indicate that such an upward shift is only transitory. Market forces will restore corn prices toward their historical equilibrium levels. Corn-price volatility increases with the initial jump in prices followed by a return to equilibrium.

Conclusions

Based on the results of the analysis from these two investigations, consideration should be given to governmental policies that promote an increasing share of ethanol in our vehicle-fuel portfolio and also provide a buffer in the form of agricultural commodity surpluses. A greater share of ethanol in our vehicle-fuel portfolio has the potential of reducing fuel-price volatility and internalizing some of the external costs of motor vehicles. However, care is warranted in advocating policies of free trade in ethanol. As indicated for the year 2006, such free trade may not result in the desired inward shift of the efficiency frontier, but instead just result in a larger share of ethanol being imported at the expense of domestic refining. As the share of ethanol in our vehicle fuel mix increases, concern of arises with ethanol's impacts on agricultural commodity prices. The initial analysis on ethanol's effect on corn prices indicates, while it does not appear to influence the level of prices, it does potentially increase corn-price volatility. Such volatility may have an effect on U.S. economic growth, but the major impact is on the poor in developing countries. U.S. agricultural policy should be directed toward mitigating such commodity-price volatility with commodity buffers for supplementing supplies in years of insufficient harvests.

Further research is warranted in expanding the analysis by considering other grains, specifically soybeans, and improving on the methodology by considering incorporating cointegration. Work is presently under way in these directions. Further analysis should also be directed toward addressing the food versus fuel issue. Consideration of the causation among world fuel and commodities prices would shed light on the relationship of biofuels with agricultural commodities.

One major caveat to these conclusions is the partial equilibrium nature of the analysis. The analysis does not, in a general equilibrium framework, investigate how biofuels fit into a portfolio with other alternative energy sources. A parallel avenue for decreasing oil in the U.S. fuel portfolio is increasing the share of hybrid vehicles with the ability to tap into the electric power grid (plug-in hybrids). As CEO automobile manufactures have stated, the future of the automobile is in electric power. The question is what place if any will biofuels fit into this future.

References

Adrangi, B., A. Chatrath, K. Raffiee, and R. Ripple. 2001. "Alaska North Slope Crude Oil Price and the Behavior of Diesel Prices in California." *Energy Economics* 23(1):29-42.

Campbell, J., M. Lettau, B. Malkiel, and Y.Xu. 2001. "Have Individual Stocks Become More Volatile? An Empirical Exploration of Idiosyncratic Risk." *Journal of Finance* 56(1):1-43.

Castillo, P., C. Montoro, and V. Tuesta. 2007. "Inflation Premium and Oil Price Volatility." London School of Economics and Political Science, Centre for Economic Performance, Discussion Paper No 782. Available at http://prints.lse.ac.uk/19750/1/Inflation_Premium_and_Oil_Price_Volatility.pdf.

Daschle, T. 2007. "Food for Fuel? Myth versus Reality." *Foreign Affairs* 86(5):157-160.

Dimitri, C., and A. Effland. 2007. "Fueling the Automobile: An Economic Exploration of Early Adoption of Gasoline over Ethanol." *Journal of Agricultural & Food Industrial Organization* 5(2):Article 11.

Engle, R. 2001. "GARCH 101: The Use of ARCH/GARCH Models in Applied Econometrics." *Journal of Economic Perspectives* 15(4):157-168.

Etter, L., I. Brat, and S. Gray. 2007. "Corn's Rally Sends Ripples." The Wall Street Journal, January 18, Page A10. Available at http://209.85.165.104/search?q=cache:VGsqmUTDmAgJ:www.haywardecon.com/SupplyDemand_

Article.doc+Corn%E2%80%99s+Rally+Sends+Ripples+etter+brat+gray&hl=en&ct=clnk&cd=1&gl=us.

Ferderer, J. 1996. “Oil Price Volatility and the Macroeconomy.” *Journal of Macroeconomics* 18(1):1-26.

Hargreaves, S. 2007. “Calming Ethanol-Crazed Corn Prices.” CNNMoney.com, January 30. Available at http://money.cnn.com/2007/01/30/news/economy/corn_ethanol/index.htm.

Jacobson, M. 2007. “Effects of Ethanol (E85) Versus Gasoline Vehicles on Cancer and Mortality in the United States.” *Environmental Science & Technology* 41(No. 11):4150-4157.

Kneller, R., and G. Young. 2001. “Business Cycle Volatility, Uncertainty, and Long-Run Growth.” University of Manchester, Manchester School, Volume 69, Issue 5, pages 534-52. Available at http://ideas.repec.org/a/bla/manchs/v69y2001i5p534-52.html.

Kojima, M., and T. Johnson. 2005. “Potential for Biofuels for Transport in Developing Counties." Energy Sector Management Assistance Programme (ESMAP), Joint UNDP/World Bank. Available at http://www.esmap.org/filez/pubs/31205BiofuelsforWeb.pdf.

Koplow, D. 2006. "Biofuels: At What Cost? Government Support for Ethanol and Biodiesel in the United States." Global Subsidies Initiative (GSI) of the International Institute for Sustainable Development. Available at http://www.globalsubsidies.org/files/assets/pdf/Brochure_-_US_Report.pdf.

Meekhof, R., W. Tyner, and F. Holland. 1980. “U.S. Agricultural Policy and Gasohol: A policy Simulation." *American Journal of Agricultural Economics* 62(3):408-415.

Parry, I., M. Walls, and W. Harrington. 2007. “Automobile Externalities and Policies.” *Journal of Economic Literature* 45(2):373-399.

Pindyck, R. 2004. “Volatility in Natural Gas and Oil Markets.” *The Journal of Energy and Development* 30(1):1-19.

Rajagopal, D., S. Sexton, D. Roland-Hoist, and D. Zilberman. 2007. "Challenge of Biofuel: Filling the Tank Without Emptying the Stomach?" *Environmental Research Letters* 2(4):044004.

Rajagopal, D., and D. Zilberman. 2007. “Review of Environmental, Economic and Policy Aspects of Biofuels.” Policy Research Working Paper 4341, The World Bank, Development Research Group, Sustainable Rural and Urban Development Team. Available at http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2007/09/04/000158349_20070904162607/Rendered/PDF/wps4341.pdf.

Regnier, E. 2007. “Oil and Energy Price Volatility.” *Energy Economics* 29(3):405-427.

Runge, C., and B. Senauer. 2007. “Food for Fuel? Myth versus Reality-Reply.” *Foreign Affairs* 86(5):160-162.

Searchinger, T., R. Heimlich, R. Houghton, F. Dong, A. Elobeid, J. Fabiose, S. Tokgoz, D. Hayes, and T. Yu. 2008. “Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions form Land-Use Change.” *Science* 319(5867):1238-1240.

Senauer, B. 2008. “Food Market Effects of a Global Shift Toward Bioenergy.” *American Journal of Agricultural Economics*, Forthcoming.

Seong, B., A.K.M. Morshed, S. Ahn. 2006. “Additional Sources of Bias in Half-Life Estimation.” *Computational Statistics & Data Analysis* 51(3):2056-2064.

United States Department of Agriculture, Economic Research Service. 2008. "Briefing Rooms." *Agricultural Baseline Projections: U.S. Crops, 2008-2017*. Available at http://www.ers.usda.gov/briefing/Baseline/crops.htm.

United States Department of Energy, Energy Information Administration (EIA). 2007. *Annual Energy Review 2006*. Report No. DOE/EIA-0384(2006). Available at http://tonto.eia.doe.gov/FTPROOT/multifuel/038406.pdf.

United States Department of Energy, Energy Information Administration (EIA). 2007a. "Conventional Regular Gasoline Spot Prices." Available at http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm.

United States Department of Energy, Energy Information Administration (EIA). 2007b. "Cushing, OK WTI Spot Price FOB Crude Oil Prices." Available at http://tonto.eia.doe.gov/dnav/pet/pet_pri_wco_k_w.htm.

Webb, S. 1981. “The Impact of Increased Alcohol Production on Agriculture: A Simulation Study.” *American Journal of Agricultural Economics* 63(3):532-537.

Zhang, Z., L. Lohr, C. Escalante, and M. Wetzstein. 2008a. "Ethanol and Corn Price Relations in a Volatile Vehicle-Fuels Market." Selected presentation at the American Agricultural Economics Association Meetings, Orlando, Florida, July 27-29.

Zhang, Z., L. Lohr, C. Escalante, and M. Wetzstein. 2008b. “Mitigating Volatile U.S. Gasoline Prices and Internalizing External Costs: A Win-Win Fuel Portfolio.” *American Journal of Agricultural Economics,* Accepted.

Zhang, Z., and M. Wetzstein. 2008. “Economics of Biofuels: Past and Future.” *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, Accepted.