THREE ESSAYS ON

BIOFUEL'S AND FOSSIL FUEL'S STOCHASTIC PRICES

by

ZIBIN ZHANG

(Under the Direction of Michael E. Wetzstein)

ABSTRACT

The dissertation consists of three essays on biofuel's and fossil fuel's stochastic prices focusing on the U.S. corn-based fuel-ethanol market. The research objectives include investigating competitive structures in the alternative fuels market, selecting dynamic efficient portfolios based on policy preferences, and revealing prices and price volatilities relationships among energy and agricultural markets.

The first essay, published in *Agricultural Economics*, employs a structural vector autoregression (SVAR) model of the ethanol fuel market to test the limit-pricing hypothesis that may explain the lack of ethanol entry into the fuel-additives market. The results support the hypothesis of limit- pricing behavior on the part of MTBE (methyl tertiary butyl ether) refiners, and suggest that the U.S. corn-based ethanol industry is vulnerable to limit-price competition, which could recur. Without federal support, U.S. ethanol refiners may find it difficult to compete with cheaper sugar-cane-refined ethanol, chiefly from Brazil.

The second essay, published in *American Journal of Agricultural Economics*, builds dynamic fuel portfolios yielding diversification among petroleum gasoline, U.S. fuel ethanol, and Brazilian ethanol by employing a multivariate generalized autoregressive conditional heteroskedascity (MGARCH) model. Results indicate that if the U.S. develops a comprehensive auto fuel policy, gasoline price fluctuations can be decreased with a corresponding reduction in vehicle environmental costs. Results led to the discovery that shifting policies toward encouraging the use of biofuels (ethanol), fuel-price volatility can be reduced with an associated overall higher gasoline price. When accounting for vehicle environmental costs (local air quality, congestion, and accidents), this higher gasoline price may be socially desirable.

The third essay, submitted for publication, investigates long-run equilibrium and short-run dynamic relations between U.S. energy (oil, gasoline, and ethanol) prices and U.S. agricultural commodity (corn and soybeans) prices, as well as price volatilities relations among these markets using vector error correction models (VECM) and MGARCH models. Results indicate there is no long-run equilibrium (cointegrating) relationship between energy prices and agricultural commodity prices. However, short-run price temporal causalities between energy prices and agricultural commodity prices are found using a VECM model. In terms of price volatilities, results indicate that agricultural commodity price volatilities influence energy price volatilities.

INDEX WORDS: Biofuel market, Ethanol market, Price volatility, Fuel portfolio, Food versus fuel, Cointegrating analysis

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1. Background

Ethanol has been used as a fuel in the United States since 1908. In 1908, Henry Ford produced the Model T, a flexible fuel vehicle which could run on ethanol, gasoline, or a combination of the two. During World War I and II, ethanol production for fuel use increased due to a massive wartime increase in demand for fuels. Once World War II ended, with reduced demand for war materials and the low price of petroleum fuels, ethanol use as a fuel was drastically reduced. From the late 1940's until the late 1970's, virtually no commercial fuel ethanol was available anywhere in the U.S. (EIA, 2005).

In the 1970s, with oil supply disruptions in the Middle East and concerns over energy security, developing and promoting a domestic biofuels industry, primarily from ethanol, has become a major U.S. policy. In 1978, the U.S. Energy Tax Act was passed which authorized the first federal highway excise tax exemptions for biomass derived fuels, mainly ethanol, and was designed to establish and support a U.S. biofuel industry. The act authorized a tax exemption of 40¢ per gallon of ethanol to fuel-marketing firms blending ethanol with petroleum gasoline. Since this Energy Tax Act, the ethanol subsidy (tax exemption) has varied in the range of 40¢ to 60¢. In years 1998 to 2000, it was 54¢, 2001 and 2002, 53¢, 2003 and 2004, 52¢, and in 2005 to 2008, 51¢. In 2004, the tax exemption, which was modified to a tax credit, amounted to just over $1.7 billion with the majority of the subsidy returned to consumers in the form of lower gasoline prices (Swisher, 2005).

This current 51¢ per gallon ethanol fuel subsidy is received by fuel-marketing blenders regardless of ethanol's country of origin. An ethanol tariff of 54¢ per gallon was then established to offset this subsidy, so American taxpayers do not subsidize imported foreign ethanol, chiefly from Brazil, which is the second largest producer of ethanol behind the U.S. Currently over 90% of vehicles sold in Brazil are flexible fuel vehicles capable of using up to an 85% fuel-ethanol mix with 15% petroleum fuel (called E85). Within the U.S., over six million vehicles are flexible fuel vehicles ranging in 27 different 2007 models, up from 20 in 2006, and more than triple the number available in 2000 (Giametta, 2006).

The subsidy/tariff combination is based on the classic infant industry theory where an infant industry (U.S. ethanol producers) experiences dynamic learning effects that are external to the producers. The infant industry is protected using domestic production subsidies and tariffs in order to maximize domestic welfare (Melitz, 2005). This subsidy/tariff combination has resulted in limited ethanol imports. In 2006, only 0.34% of U.S. gasoline consumption was from Brazilian ethanol (EIA 2008a) while domestically produced ethanol accounted for 3.66% (EIA 2008b).

The promotion of alternatives to petroleum, especially fuel ethanol, has been an ongoing goal of U.S. energy policy. In addition to subsidies and import tariffs, the U.S. ethanol industry has benefited from several significant policies. For example, the 1990 Clean Air Act Amendments (CAAA 1990) established the Oxygenated Fuels (Gasoline) Program and the Reformulated Gasoline (RFG) Program, both of which created a new demand for ethanol blended with gasoline. Recently, ethanol demand received a major boost when a petroleum fuel oxygenate called methyl tertiary butyl ether (MTBE) used to manufacture reformulated gasoline was banned in most states in the U.S. because it was contaminating groundwater. The rapidly expanding market received a further boost from the 2005 and 2007 Energy Bill which set new goals for expanding domestic fuel supplies with renewable fuels mainly ethanol and biodiesel. In particular, the 2005 Energy Bill sets a national minimum usage requirement of 4 billion gallons in 2006 with a mandated increase to 7.5 billion gallons in 2012, while the 2007 Energy Bill requires fuel producers to use at least 9 billion gallons of biofuel in 2008 with a mandated increase to 36 billion gallons of biofuel in 2022.

The growing demand for ethanol is stimulating an increase in the construction of new ethanol refineries and expansion of existing refineries. Twenty-nine new ethanol refineries were built in 2007 alone (Renewable Fuels Association, 2008). By the mid-October 2008, 176 refineries are operated with a total of over 10.7 billion gallons annual ethanol production capacity. With another 27 refineries under construction and refineries to expand existing refineries, ethanol production capacity was expected to increase by another 3 billion gallons in 2008. However, all of these refineries rely on corn as the raw inputs. For this reason, the ethanol is produced mostly in the Midwest, where corn, the main feedstock for domestic ethanol production, is grown.

Along with the growth in U.S. ethanol production capacity, the growth in U.S. ethanol production over recent years has also been well-documented (Figure 1.1). In 2007, U.S. ethanol plants produced 6.48 billion gallons of ethanol, up 90.59 percent from 3.4 billion gallons in 2004. It is estimated that in 2008 U.S. production will exceed 13 billion gallons, double 2007 levels (Kroh, 2008).

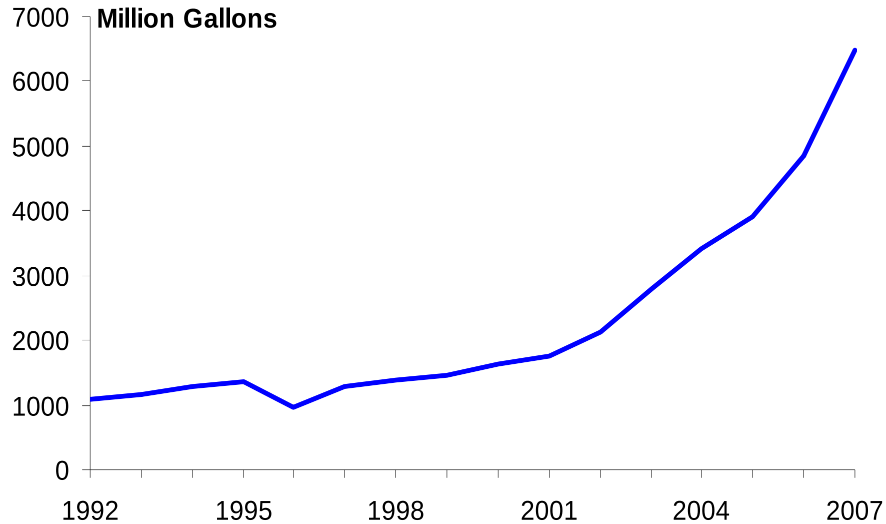

Figure 1.1. U.S. fuel ethanol production, 1992-2007
(Source: Energy Information Administration, EIA-819 Monthly Oxygenate Report)

Currently, a blend of 10% ethanol with 90% gasoline (E10 or gasohol) is commercially available in nearly 70% of the gasoline sold in the U.S. (Renewable Fuels Association, 2009). While E10 may be use in any vehicle without modifications to the engine (U.S. Department of Energy, 2005), gasoline blends with higher proportions of ethanol – in particular E85, which combines 85% ethanol and 15% gasoline – require additional modifications to the engine. However, the number of so-called "flex-fuel vehicles" (FFVs) which can operate both on gasoline and E85 has been steadily increasing. Currently, more than 6 million FFVs are on the roads, with some 1400 fuel stations nationwide offer E85 ((Renewable Fuels Association, 2008).

1.2. Problem Statement

For a view into the future of this U.S. dynamic ethanol market, an understanding of its market structure relative to its related markets is necessary. How the U.S. domestic ethanol market interacts with foreign suppliers of ethanol, oil and gasoline markets, and the markets for agricultural commodities will determine its future place as a vehicle fuel. Although there is a tax exemption and other policies supporting ethanol, until the early 2000s, the U.S. ethanol industry was constrained to a regional market, mainly in the Midwest, where the majority of ethanol is produced from corn feedstock. Before flex-fuel cars went to market, and state bans on MTBE, ethanol as a gasoline oxygenate additive was dominated in the market by its close substitute the oxygenate MTBE. From an EIA (1999) report, in 1997, only 14.29% oxygenates in volumes came from ethanol, whereas 80.67% oxygenates came from MTBE, and 5.04% oxygenates came from others, mainly ethyl tert-butyl ether (ETBE) and tert-amyl methyl ether (TAME)) in reformulated and oxygenated gasoline control areas. Only after MTBE was found to contaminate both ground and surface waters, leading to state bans on its use as a fuel additive, did the demand for ethanol expand nationally (Blue Ribbon Panel, 1999).

Limit pricing on the part of MTBE refiners is one hypothesis that may explain this lack of ethanol entry into the fuel-additives markets. Using limit pricing, MTBE refiners could restrict price markups above marginal cost in response to the threat of potential entry by ethanol refiners. Ethanol in the U.S. is produced predominantly from corn. If this technology results in relatively high refining costs, then refiners of ethanol substitutes, MTBE, could either explicitly or implicitly suppress ethanol entry by maintaining the price of MTBE at levels that prevent a profitable entry of ethanol into the markets. The future health of the U.S. ethanol industry is predicated on the limited competitiveness of ethanol, and an extensive analysis of the relative competitiveness of the U.S. ethanol industry will aid in understanding refiners' long-run sustainability.

Investigating ethanol's competitiveness is particularly acute when considering the potential of foreign ethanol entering the U.S. market. However, it is hypothesized that such entry maybe beneficial if it increases the diversity of U.S. vehicle fuels and in a portfolio context reduces fuel-price volatility. Since the turn of the 21st century, the volatility in gasoline prices causing price “spikes” has become increasingly common (Ashton and Upton, 2004). Such volatility harms the entire macroeconomy and is at least partially responsible for the U.S. economy falling into the 2001 and 2008 recessions. Ferderer (1996) notes that fuel-price volatility affects the entire U.S. economy through sectoral shocks and uncertainty. As demonstrated by Castillo et al. (2007), this stimulates inflation and results in Kneller and Young’s (2001) conclusion that fuel-price volatility is negatively correlated with economic growth. World growth and price stability require stable fuel markets (Noureddine, 2006a). Congress is requesting an investigation into this diversification, and specifically into the effect of eliminating the 54¢ import tariff on ethanol. Senator Lugar has called for a study on the effects of removing this trade barrier (Lugar 2007).

This current increasing diversification of vehicle fuels into ethanol has potential external benefits and costs. In particular, the American Coalition for Ethanol states ethanol production improves air quality, leads to energy security, spurs economic development, lowers greenhouse gases, and lowers price of vehicle fuels. However, some of these benefits are uncertain and with the 2008 parallel increase in agricultural commodity prices and ethanol prices, a possible major external cost of refining ethanol is the food versus fuel security issue. These rising and volatile commodity prices have resulted in increasing political unrest around the world. Such volatility in the short-run harms the entire world economy and in the long-run the resulting malnutrition yields lost learning potential, through stunted intellectual and physical growth. This food versus fuel debate is magnified by the lack of information on the interrelation among agricultural commodity and ethanol prices.

1.3. Objectives

The overall objective of this dissertation is to model how the U.S. domestic ethanol market interacts with foreign suppliers of ethanol, oil and gasoline markets, and the markets for agricultural commodities. By employing time series methods, the following three related essays concerning the U.S. ethanol fuel market are developed

1. Possible limit-price behavior on the part of MTBE refiners and the future potential of this behavior on the part of foreign ethanol importers.
2. Determine the risk-efficiency frontier of U.S. vehicle fuels by considering U.S. ethanol, foreign ethanol, and petroleum gasoline in alternative fuel portfolios.
3. Identify the long-run relationships and short-run dynamics between energy prices and agricultural commodity prices.

These three essays are all based on a dynamic multivariate modeling framework, which opens the door to better understanding of the current and future ethanol market centering around the dynamics of ethanol, corn, and soybean prices.

1.4. Literature Review

A major literature review on the economics of biofuel was conducted by Zhang and Wetzstein (2008). Generally, research is directed toward investigating a particular policy or program effect on the ethanol market. The seminal article modeling the ethanol market is by Rask (1998), which provides insights into the ethanol supply and demand market for the period 1984-1993. His results indicate the ethanol industry is in no position to fill a major role as a vehicle fuel supplier without continued government subsidies. Kelley (2004) employs the similar supply and demand models to analyze ethanol market for the period 1989-2002, and concludes that with the Clean Air Act Amendments resulting in the establishment of a demand for ethanol in non-attainment states, the continued federal and state subsidies for ethanol may have outlived their usefulness.

A number of papers investigate the subsidy issues in the ethanol market. Rask (2004) investigates the effect that ethanol subsidies have on the highway trust fund. He concludes there are significant and differential transfers of wealth across states with the use of the ethanol tax exemption. After reviewing the overall subsidy effects in ethanol industry, Lohr, Escalante, and Wetzstein (2008) conclude that the ethanol fuel subsidy has outlived its usefulness in improving the environment, energy security, economic development, and in lowing gasoline prices. Based on utility maximization, Vedenov and Wetzstein (2008) derive the socially optimal U.S. ethanol subsidy incorporating a comprehensive evaluation of the environmental, security, and economic development benefits. Their results indicate that the optimal subsidy is sensitive to income elasticity given a change in the subsidy. Relatively small changes in the estimates used for this elasticity will result in the subsidy switching from positive to negative.

A number of studies have analyzed specific aspects of the corn-ethanol market. Recent examples include analysis of impacts of phase out MTBE on the ethanol market (Cunningham et al., 1999; USDA, 1999; EPA, 1999; EIA, 2000; Gallagher et al., 2000).

1.5. Organization of the Study

This dissertation consists of five chapters; this introductory chapter (Chapter 1), the three essays (Chapters 2, 3, and 4), and a concluding chapter. Chapter 2, published in *Agricultural Ecoonmics*, 37(2007):105-112, analyzes the competitive structure between ethanol and MTBE producers in the early stages of the ethanol industry employing a structural vector autoregression (SVAR) model of the ethanol fuel market. Employing a multivariate generalized autoregressive conditional heteroskedascity (MGARCH), Chapter 3, published in *American Journal of*

*Agricultural Economics,*90(2008):1218-1225, is devoted to developing a time-varying efficient fuel portfolio composed of petroleum and ethanol fuels. Chapter 4, to be submitted to *Energy Economics* for publication, investigates the food versus fuel issue employing cointegration analysis and vector error correction (VECM) models. Conclusions and discussions relating these three essays are provided in the Chapter 5.

CHAPTER 2

CAN THE U.S. ETHANOL INDUSTRY COMPETE IN THE ALTERNATIVE FUELS MARKET?[1]

[1] Zhang, Z., D.V. Vedenov, and M.E. Wetzstein. 2007. *Agricultural Ecoonmics*. 37:105-112.
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Abstract

The U.S. ethanol fuel industry has experienced preferential treatment from federal and state governments ever since the Energy Tax Act of 1978 exempted 10% ethanol/gasoline blend (gasohol) from the federal excise tax. Combined with a 54¢/ /gal ethanol import tariff, this exemption was designed to provide incentives for the establishment and development of a U.S. ethanol industry. Despite these tax exemptions, until recently, the U.S. ethanol fuel industry was unable to expand from a limited regional market. Ethanol was dominated in the market by MTBE (methyl-tertiary butyl ether). Only after MTBE was found to contaminate groundwater and consequently banned in many states did the demand for ethanol expand nationally. Limit pricing on the part of MTBE refiners is one hypothesis that may explain this lack of ethanol entry into the fuel-additives market. As a test of this hypothesis, a structural vector autoregression (SVAR) model of the ethanol fuel market is developed. The results support the hypothesis of limit-pricing behavior on the part of MTBE refiners, and suggest the U.S. corn-based ethanol industry is vulnerable to limit-price competition, which could recur. The dependence of the corn-based ethanol price on supply determinants limits U.S. ethanol refiners' ability to price compete with sugar-cane-based ethanol refiners. Without federal support, U.S. ethanol refiners may find it difficult to compete with cheaper sugar-cane-refined ethanol, chiefly from Brazil.

2.1. Introduction

The U.S. ethanol fuel industry has experienced preferential treatment from federal and state governments ever since the Energy Tax Act of 1978 exempted 10% ethanol/gasoline blend (gasohol) from the federal excise tax. Combined with a 54 ¢/gal ethanol import tariff, this exemption was designed to provide incentives for the establishment and development of a U.S. ethanol industry. Various states, mainly in the corn producing Midwest, have subsequently enacted additional ethanol fuel tax credits to further promote the industry (North Carolina Solar Center, 2005). Recently, the major increase in ethanol is as a fuel oxygenate additive, designed to improve combustion and decrease emission. In 1998, ethanol as a fuel additive comprised 25% of the ethanol gasohol. This percentage increased to well over 40% in 2004 (Federal Highway Administration, 2005).

Despite these tax exemptions, until the early 2000s, the U.S. ethanol fuel industry was unable to expand from a limited regional market into a major national supplier of fuel additives. Ethanol as an oxygenate additive was dominated in the market by its close substitute the oxygenate MTBE (methyl-tertiary-butyl ether). Only after MTBE was found to contaminate both ground and surface waters, leading to state bans on its use as a fuel additive, did the demand for ethanol expand nationally (Blue Ribbon Panel, 1999).

Limit pricing on the part of MTBE refiners is one hypothesis that may explain this lack of ethanol entry into the fuel-additives market. Using limit pricing MTBE refiners would restrict increasing their prices above marginal cost, given the threat of potential entry by ethanol refiners. According to this hypothesis, the major impediment to the development of an ethanol industry is the U.S. ethanol refining technology combined with Bertrand competition in the fuel-oxygenate market. Ethanol in the U.S. is produced predominantly from corn. If this technology results in relatively high refining costs, then refiners of ethanol substitutes, MTBE, could either explicitly or implicitly suppress ethanol entry by maintaining the price of MTBE at levels preventing a profitable entry of ethanol into the market.

Under this limit-price hypothesis, the ethanol price would be primarily driven by shocks in supply of the raw input (corn). In contrast, the price of MTBE would closely follow changes in ethanol prices as MTBE refiners attempt to prevent ethanol market entry. As outlined by Chowdhury (2002), such competition results in the incumbent firms supplying the whole of demand with the entrant firms obtaining no demand. As a test of this hypothesis, a structural vector autoregression (SVAR) model of the ethanol fuel market is developed and applied to an empirical analysis of the historical U.S. ethanol market. Specifically, we examine whether the response of prices and quantities of ethanol and its substitute MTBE to market shocks are consistent with limit-price competition. Results suggest the markets for ethanol and MTBE are indeed affected by different shocks despite the fact both additives are close substitutes.

While ethanol refiners currently benefit from reduced MTBE, the limited competitiveness of ethanol still exists. The future health of the U.S. ethanol industry is predicated on this relative competitiveness. The industry is currently facing another threat from cheaper sugar cane-based ethanol from Brazil (Renewable Fuels Association, 2005) and ethanol imports from Central American countries. Ethanol refiners in Central American are exempt from the 54 ¢/gal ethanol import tariff under the Caribbean Basin Initiative (Lilliston, 2005). Thus, an analysis of the relative competitiveness of the U.S. ethanol industry will aid in understanding refiners' long-run sustainability.

2.2. U.S. Ethanol Market

The market for ethanol fuel had a very limited and regional appeal until the passage of the 1990 Clean Air Act Amendments. The amendments established the Oxygenated Fuels Program which requires a minimum oxygen content of 2.7% by weight in winter fuels for non-attainment regions, which do not meet carbon monoxide air quality standards. The act also mandated reformulated gasoline with 2% oxygenates by weight to be used in cities with the worst smog pollution to reduce harmful emissions of ozone. A number of regions increased this minimum federal requirement of oxygenate content to 3 -3.5% by weight. As a result, two fuel additives, ethanol and MTBE, came into widespread use in all non-attainment regions throughout the U.S. MTBE is refined by reacting methanol, generally obtained from natural gas, with isobutylene.

Fuel-marketing firms purchase conventional (unblended) gasoline, blend stock for reformulated gasoline, and blending agents on the wholesale market. Firms then sell blended fuels to retailers. The determination of which oxygenate to use depends on the relative prices of ethanol and MTBE. Gallagher et al. (2000) illustrate this substitutability between ethanol and MTBE by considering a 2.7% oxygenate fuel requirement that can be met by either a 7.7% ethanol blend or a 15% MTBE blend. They demonstrate how the price wedge between ethanol and MTBE determines which oxygenate will be used.

Unfortunately, for the ethanol fuel industry, MTBE instead of ethanol emerged as the oxygenate of choice. Even with the subsidies, ethanol refiners could not efficiently price-compete with MTBE. Ethanol's lack of competitiveness with MTBE relegated it to remain a regional market with limited growth potential. As a result, in the late 1990s, the market share of ethanol fuel remained fairly constant (Figure 2.1). This situation changed in early 2000s as MTBE was found to contaminate ground and surface waters. Since 2002, states initiated proposals and enacted policies restricting and banning the future use of MTBE. In January 2004, California, Connecticut, and New York discontinued the use of MTBE in reformulated gasoline with ethanol as the substitute. In 2005, a total of 16 states discontinued MTBE with other states either phasing out MTBE within two years or considering similar bans (Dinneen, 2005). Currently, MTBE is losing its competitive edge on ethanol, resulting in a boom in ethanol refining and use (Figure 2.1).

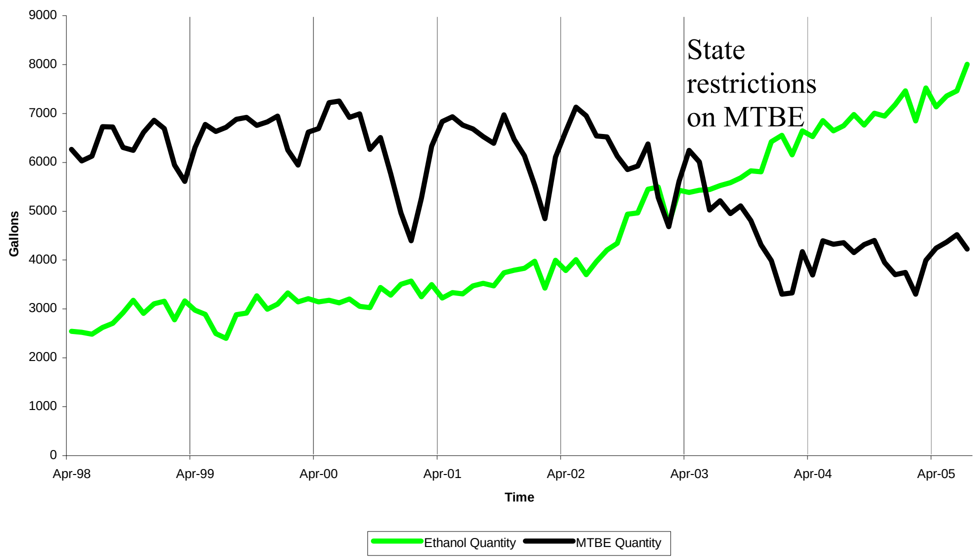

Figure 2.1. U.S. refining of ethanol and MTBE from 1998 through 2005 (Source: Renewable Fuel Association)

This rapidly expanding market received a further boost from the 2005 and 2007 Energy Bill which, while eliminating the oxygenate requirement, sets a new goal for expanding domestic fuel supplies with renewable fuels mainly ethanol and biodiesel. In particular, the 2005 Energy Bill sets a national minimum usage requirement of 4 billion gallons in 2006 with a mandated increase to 7.5 billion gallons in 2012, while the 2007 Energy Bill requires fuel producers to use at least 9 billion gallons of biofuel in 2008 with a mandated increase to 36 billion gallons of biofuel in 2022.

The growing demand for ethanol is stimulating an increase in the construction of new ethanol refineries and expansion of existing refineries. Twelve new ethanol refineries were built in 2004 alone (Dinneen, 2005). However, all of these refineries continue to rely on corn as the raw input as opposed to the technologically more efficient use of sugar cane. Corn yields less sugar per acre than sugar cane, and in refining uses substantial amounts of energy. By comparison, most of ethanol production in Brazil, the largest world ethanol producer and exporter, is based on sugar cane. In contrast, the U.S. sugar cane industry has little incentive to diversify into ethanol refining. Sugar import quotas support the U.S. domestic sugar prices well above world levels, and U.S. expansion of sugar cane acreage is limited. With this lack of private market interest, the 2005 Energy Bill authorized a federally funded three-year demonstration refinery for refining ethanol from sugar cane.

However, as indicated by McNew and Griffith (2005), the above-normal returns stimulating this refinery construction are unlikely to be sustainable. This may be a classic Cournot competitive market structure leading to a substantial drop in price especially if lower cost ethanol imports are able to penetrate the U.S. domestic market. Ethanol refiners have announced plans or have completed construction on refineries in El Salvador, Jamaica, Trinidad and Tobago, and Panama. These refineries are designed to take advantage of the U.S. duty-free importation of 240 million gallons of ethanol under the Caribbean Basin Initiative (Lilliston, 2005). Even with the existing import tariffs, 2004 saw a mark increase in ethanol imports from Brazil, 112 million gallons (Dinneen, 2005). Thus, with the growing U.S. demand for ethanol creating an attractive target for importers, the U.S. ethanol industry may again find itself price-competing with less costly alternatives.

2.3. Literature Review

The literature on the modeling of the ethanol fuel market is somewhat limited. Generally, research is directed toward investigating a particular policy or program effect on the ethanol market. For example, Rask (2004) investigates the effect that ethanol subsidies have on the highway trust fund. He determines there are significant and differential transfers of wealth across states with the use of the ethanol tax exemption. The seminal article modeling the ethanol market is also by Rask (1998). In this article, he provides insights into the ethanol market for the period 1984–1993. His results indicate the ethanol industry is in no position to fill a major role as a vehicle fuel supplier without continued government subsidies.

Overall analysis of fuel markets is considerably richer, especially in the investigation of the broader gasoline market. Recent examples include analysis of competitiveness and vertical relationships in retail gasoline markets (Eckert and West, 2005; Hastings, 2004). Weinhagen (2003) employs the SVAR approach to investigate the nature of price shocks on the consumer gasoline market.

2.4. Limit Pricing Analysis

The theory of an incumbent practicing limit-price competition is illustrated in Figure 2.2. An incumbent in this case is a MTBE refiner with an established market demand, while ethanol refiners represent entrants to the fuel additives market. The oligopoly structure of the U.S. MTBE industry, with only seven refiners in 2004, implies potential monopoly power. An MTBE incumbent firm is then facing a downward sloping average revenue (AR) curve and associated marginal revenue (MR) curve below it. Exercising full monopoly power the MTBE incumbent will set a price at P_m^*. However, the MTBE incumbent has considerable latitude in responding to any ethanol entrant price below this monopoly price of P_m^* down to the contestable market price of P_m'. As Figure 2.2 illustrates, the entry of ethanol fuels at any MTBE-equivalent price of ethanol P_e' in the range between P_m^* and P_m' can be made unprofitable by MTBE incumbents practicing limit pricing.

This limit-price behavior suggests the price of MTBE would exhibit matching responses to any shocks in the price of ethanol. Specifically, a downward movement in the ethanol price will then elicit a MTBE price reduction to thwart any possible ethanol entry into the oxygenated fuel market. In a real options environment, a MTBE incumbent may even lower its price below short-run average variable cost to prevent ethanol entry with the expectation that future prices will recover.

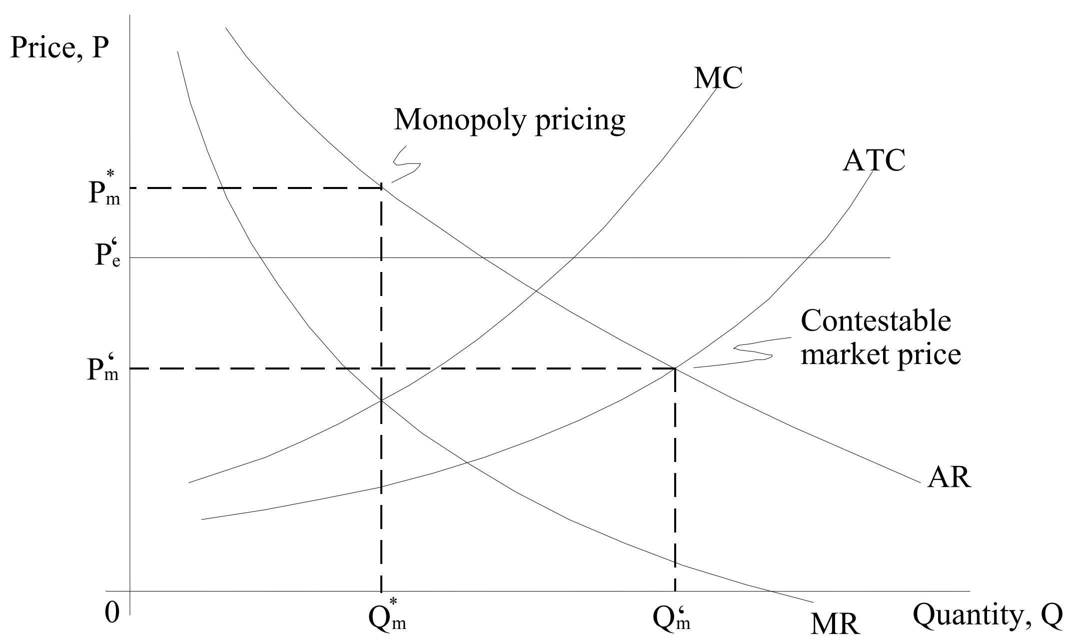

Figure 2.2. Pricing range for a MTBE incumbent

Limit-price analysis demonstrates that ethanol entrance into the fuel-oxygenated market could be blocked by the MTBE incumbent even in the presence of refining subsidies and tax exemptions. This hypothesis is consistent with the limited regional market for ethanol fuels observed in the U.S. until the use of MTBE was legally restricted, allowing ethanol entry. The hypothesis also implies that the U.S. ethanol refiners relying on relatively inefficient corn-based refining technology are residual claimants of market share and may be unable to compete effectively in an open market if facing competition from cheaper ethanol imports.

2.5. SVAR Model of the Ethanol Market

To analyze the validity of the limit-price hypothesis as an explanation of pricing patterns in the ethanol-fuel market, a six-variable SVAR model of supply and demand is developed. A vector autoregression (VAR) approach consists of regressing each current variable in the model on all the model variables lagged a specified number of times. VAR is a reduced form approach, so economic interpretation of the results is often difficult or not possible unless this reduced form is linked to an economic model. Using economic theory to provide this link results in a SVAR model. The SVAR approach stems from the seminal contributions of Sims (1986), Bernanke (1986), and Blanchard and Watson (1986) who employed economic theory to impose restrictions to recover the structure of the disturbances. SVAR models are now a major tool in macroeconomic analysis of monetary, fiscal, and technology shocks (Brggemann, 2004; Enders, 2004). Employing SVAR for analysis of the ethanol fuel market provides inferences on the impact corn, gasoline, and MTBE shocks have on this market.

Based on the contemporaneous interactions among the time series associated with ethanol, corn, gasoline, and MTBE, the following structural specifications are selected. The major determinant in ethanol fuel supply is the price of corn, p_c, measured as a percentage change.

Thus, in terms of supply, the percentage change in the price of ethanol fuel, p_e, is defined as a function of the price of corn percentage change. Given the possible complementary relation between gasoline and ethanol used as an oxygenate, percentage change in gasoline price, p_g, is also expected to influence the price of ethanol fuel along with the percentage change in ethanol quantity, q_e. This yields:

(Eq. 2.1) $p_e = \beta_1 p_c + \beta_2 p_g + \beta_3 q_e + \mu_1,$

where the uncorrelated error term μ_1 reflects supply shocks. The parameter β_1 is assumed to be positive, since it is hypothesized that the price of ethanol fuel varies directly with the price of its major input corn. In contrast, the parameter β_2 is hypothesized to be negative, given a decrease in the price of gasoline boosts gasoline demand which simulates an ethanol supply response and corresponding enhanced ethanol price. The quantity of ethanol parameter, β_3, would in general be positive in the short-run based on the Law of Diminishing Marginal Productivity. However, in the long-run it is possible $\beta_3 < 0$. Given the recent rapid expansion of ethanol refining, economics of size may result in a decreasing-cost industry with a negative sloping market supply curve.

Ethanol demand is hypothesized to be a function of its own price, p_e, the price of its close substitute MTBE, p_m, and price of its complement gasoline, p_g:

(Eq. 2.2) $q_e = \beta_4 p_e + \beta_5 p_m + \beta_6 p_g + \mu_2,$

where all prices are again measured in terms of percentage change, the parameters β_4 and β_6 are hypothesized to be negative and parameter β_5 is positive. Ethanol fuel is assumed to be an ordinary good, so the own price of ethanol fuel is inversely related to its quantity. Gasoline is a complementary good for ethanol fuel and MTBE is a substitute resulting in the negative and positive parameters, respectively.[2]

Finally, the inverse demand for MTBE is represented by

(Eq. 2.3) $p_m = \beta_7 p_e + \beta_8 p_g + \beta_9 q_m + \mu_3$,

where q_m is the percentage change in quantity of MTBE. The ethanol and MTBE limit pricing hypothesis and the complementary nature of MTBE with gasoline suggests positive signs for parameter β_7 and β_8. A negative sign is expected for parameter β_9 given MTBE is an ordinary good. Similar to μ_1, the uncorrelated error terms μ_2 and μ_3, reflect corresponding demand shocks. To complete the system:

(Eq. 2.4) $p_g = \mu_4, \quad p_c = \mu_5, \quad q_m = \mu_6$.

Prices of gasoline and corn and supply of MTBE are treated as exogenous shocks, μ_4, μ_5, and μ_6, to the demand and supply system.

2.6. Data

Nominal monthly price series, from April1998 to July 2005, for ethanol and MTBE were collected from Renewable Fuel News, and matched up with conventional gasoline prices from the Energy Information Administration and corn prices from the USDA Economic Research Service. The resulting price series are plotted in Figure 2.3.

The trend in corn prices over this period is relatively flat with the exception of the spike in 2004 from unusually large international demand, especially from China, and a general economic expansion following 2001 recession. The trends in prices of ethanol, MTBE, and gasoline are more clearly defined with a general upward tendency except for the mild downturn

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[2] Inclusion of the gasoline price as an explanatory variable for the ethanol price reflects other uses of ethanol, for example, as an octane enhancer. In that market segment, possible limit-pricing behavior of MTBE refiners would not be present, and thus, the price of ethanol would be driven primarily by the price of gasoline.

during the 2001 recession. Particularly since the recession, ethanol prices have tended to track with corn prices, MTBE, and gasoline prices (0.24, 0.48, and 0.58 correlation, respectively) and MTBE prices track closely with the prices of gasoline (0.87 correlation). At the 1% significance level, employing a variance ratio test, prices of MTBE and gasoline exhibited higher volatility since the period immediately preceding the Iraq war. This volatility represents a tighter balance of supply and demand for oil observed in recent years. However, for the ethanol price there is no significant difference in pre and postwar standard deviation even at the 10% significance level.

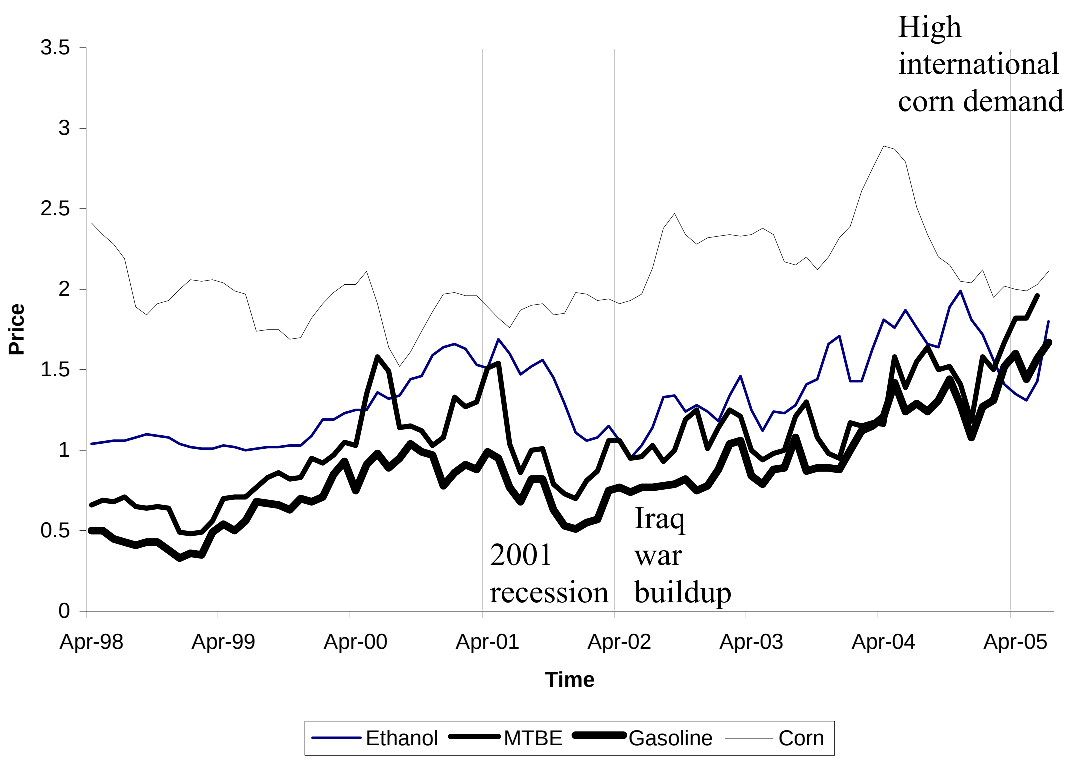

Figure 2.3. Monthly price series for ethanol, MTBE, gasoline, and corn from April 1998 to July 2005

For estimation, the nominal prices were deflated using the monthly Producer Price Index (PPI) data for refined petroleum products (series WPU057) available from the Bureau of Labor

Statistics website (BLS, 2004).[3] The data, including quantities of ethanol and MTBE collected from the Energy Information Administration, were transformed into percentage changes by taking the first differences of the natural logarithms. Following Pindyck (1999), the Dickey-Fuller test with the time trend, t, was performed by estimating the model

(Eq. 2.5) $\Delta y_t = \gamma_o + \gamma_1 t + \upsilon y_{t-1} + \varepsilon_t$

where y is the time-series variable and γ_o, γ_1, and υ are parameters. The results of the tests are presented in Table 2.1, where the p-values used for significance testing are interpolated MacKinnon approximate critical values for the t-statistics on υ. As indicated in Table 2.1, the hypothesis of a unit-root is rejected at the 1% significance level for all of the six time series, indicating stationary series.

Table 2.1. Dickey-Fuller unit root test

Time Series[a]	Dickey-Fuller Statistic
Quantity	
Ethanol	−14.35
MTBE	−8.60
Price	
Corn	−7.55
Ethanol	−7.34
MTBE	−8.15
Gasoline	−8.31

[a] All six series are the first differences of the natural logarithms, and the statistics indicate a significance level of 1% for all five of the series.

[3] The market for ethanol was mostly regional during the period considered, suggesting the ethanol prices in states primarily using it as an oxygenate might exhibit seasonality associated with different oxygenate requirements during the winter and summer. The SVAR model was estimated with winter dummy variables to capture this seasonality. Results indicate the dummy coefficients are relatively small and not significantly different from zero at the 10% significance level. In addition, the other model coefficients were not significantly different from those obtained with (Eq. 2.1)-(Eq. 2.4). Thus, only the estimation results for the (Eq. 2.1)-(Eq. 2.4) are reported in the paper.

2.7. SVAR results

Prior to estimating (Eq. 2.1)−(Eq. 2.4) by SVAR, the log likelihood, Akaike's, and Hannan and Quinn information criterion statistics were computed for determining the lag length in the specifications. The log likelihood statistic indicated a lag length of four compared to a length of only one for both the Akaike's and Hannan and Quinn criteria. The resulting discrepancy is the result of very small changes in the summary statistics for these tests when going from one to five or more lags. Estimation of the model in a SVAR framework for alternative lag lengths yielded robust results with nearly identical estimated coefficients. For reporting the results, a four-lag specification was selected.

The four-lagged specification used in a SVAR model based on (Eq. 2.1)−(Eq. 2.4) resulted in the following estimated coefficients

(Eq. 2.6) $p_e = \mathbf{0.927}p_c - \mathbf{0.244}p_g - \mathbf{1.871}q_e + \mu_1$,

(Eq. 2.7) $q_e = \mathbf{0.926}p_e + \mathbf{0.651}p_m - \mathbf{0.237}p_g + \mu_2$,

(Eq. 2.8) $p_m = \mathbf{0.584}p_e + \mathbf{0.251}p_g + 0.183q_m + \mu_3$.

The coefficients in **bold** are all significantly different from zero at the 5% significance level and have the anticipated signs, except for own price in the ethanol demand equation. This positive effect of own price of ethanol on demand for ethanol may be explained by the institutional structural shift in substituting ethanol for MTBE. With the banning MTBE, ethanol emerged as the only fuel oxygenate. At least for the time period covered by the data set, as ethanol replaced MTBE, demand for ethanol continued to grow even in the face of raising ethanol prices. Signs of the other parameters were as expected, with price of ethanol positively affected by shocks to corn prices, and prices of MTBE positively influenced by shocks to the price of ethanol.

The Wald test was employed to investigate Granger causality. As listed in Table 2.2, the test statistics for prices of ethanol and MTBE support the implication of the limit-price hypothesis that MTBE prices adjust in response to ethanol price shocks. The null hypothesis of ethanol prices not Granger causing MTBE prices is rejected at the 10% significance level. In contrast, the null hypothesis of MTBE prices not Granger causing ethanol prices cannot be rejected even at the 10% significance level. This result indicates that prior to government restrictions on the use of MTBE, MTBE refiners may have either implicitly or explicitly manipulated their prices in response to any changes in ethanol prices that would otherwise have made ethanol competitive in the market for fuel additives. Finally, the Wald test also indicates a one-way causation between prices for corn and ethanol. Corn prices appear to influence the price of ethanol, but the reverse is not true.[4]

Table 2.2. Granger causality Wald tests for the null hypotheses of no Granger causation

Direction of Causality[a]	χ^2	Decision[b]
Ethanol and MTBE Prices		
$p_e \rightarrow p_m$	12.86	Reject
$p_m \rightarrow p_e$	8.32	Do not reject
Ethanol and corn Prices		
$p_e \rightarrow p_c$	2.43	Do not reject
$p_c \rightarrow p_e$	12.15	Reject

[a] The arrow, →, indicates the direction of Granger causality. Prices of corn, ethanol, MTBE, and gasoline, in terms of percentage change, are p_c, p_e, p_m, and p_g, respectively.
[b] At the 10% significance level.

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

[4] In 2006, this condition may have shifted. The continued strong demand for ethanol is drawing down corn inventories and putting upward pressure on corn prices. Future analysis of these markets may reveal this shift.

and future values of the other variables in (Eq. 2.1) − (Eq. 2.3). Specifically, decomposition reflects the percentage of forecast variance of each variable in the SVAR model caused by shocks to the other variables. Table 2.3 lists the decomposition matrix after five periods (months).

From Table 2.3, ethanol price variability contributes only 2% of the forecast variance in the corn price. In contrast, for the ethanol price and quantity, the share of forecast variance from the corn price is 17% and 27%, respectively. Similarly, the variability of prices of ethanol and gasoline account for 26% of the variance in the MTBE prices. For the price of gasoline and quantity of MTBE variables, none of the variable shares are particularly large with the exception of corn price share in forecast variance of MTBE. This variance-decomposition analysis further supports the limit-pricing hypothesis by indicating the variability of ethanol prices has a relatively large impact on the prices of MTBE.

Table 2.3. Variance-decompositions after five periods (months)

Variable	Percentage of Forecast Error					
	p_c	p_e	p_g	p_m	q_e	q_m
Price						
Corn, p_c	0.57	0.02	0.29	0.08	0.01	0.02
Ethanol, p_e	0.17	0.08	0.26	0.14	0.30	0.05
Gasoline, p_g	0.06	0.01	0.83	0.01	0.00	0.09
MTBE, p_m	0.07	0.15	0.11	0.58	0.09	0.05
Quantity						
Ethanol, q_e	0.27	0.29	0.06	0.12	0.23	0.03
MTBE, q_m	0.21	0.03	0.03	0.03	0.01	0.68

Finally, if the limit-price hypothesis is to have any credence, the speed at which the MTBE price adjusts to a shock in ethanol prices should be relatively high. Such a rapid adjustment would indicate a targeted response rather than a random fluctuation of prices. As a measure of this response speed, impulse response functions were constructed for the variables in the SVAR model. The response functions measure the effect of a one standard-deviation shock of a given variable on current and future values of the variables in (Eq. 2.1)−(Eq. 2.3). For all the variables, the responses to a shock in one variable were found to die out after five periods (months) with a very narrow 95% confidence band encompassing zero impulse response. After ten periods all confidence bands collapsed to zero. This result indicates the price of MTBE adjusted to changes in ethanol prices and quantities within six months, providing further support to the hypothesis that MTBE refiners may have matched changes in the price of ethanol in order to prevent its entry into the alternative fuel market.

2.8. Implications and Conclusions

The estimated structural vector autoregression model indicates that although ethanol and MTBE were substitutes in the fuel additives market during the period analyzed, their prices were subject to different shocks. In particular, recent ethanol prices have been significantly driven by changes in supply. In contrast, the price of MTBE was significantly positively impacted by ethanol demand shocks. This differential supports a hypothesis of limit-pricing behavior on the part of MTBE refiners during the period analyzed. The coefficient associated with the price of ethanol in the MTBE price (Eq. 2.8) is significant, implying that the price of MTBE responds positively to shocks in ethanol prices. Granger causality further supports this result by indicating price changes in MTBE are caused by a shift in the price of ethanol. The magnitude of this causation is measured by the variance-decomposition statistic. This statistic indicates the price of ethanol has a major influence on MTBE current and future prices. The speed at which MTBE prices respond to ethanol price shocks also supports the limit-pricing hypothesis. Within six months MTBE prices were found to adjust to any ethanol price shocks.

These results suggest the U.S. corn-based ethanol industry is vulnerable to limit-price competition, which could reoccur. The dependence of corn-based ethanol price solely on supply determinants limits U.S. ethanol refiners' ability to price compete with sugar cane-based ethanol refiners. With the market restrictions in the form of a ban on MTBE and tariffs on imports, a window of opportunity is currently open for the U.S. ethanol industry. However, without these restrictions and given the homogeneous product nature of ethanol fuel, U.S. ethanol refiners will find it difficult to complete with lower priced sugar cane-refined ethanol, chiefly from Brazil. In a Bertrand type competition, Brazil's more technologically efficient sugar cane refining process would dump low-priced ethanol fuel onto the U.S. market and squeeze out any U.S. ethanol refiners' market share. If WTO agreements result in the elimination of the existing U.S. tariffs or if ethanol refiners begin to take advantage of the Caribbean Basin Initiative duty-free provisions on ethanol imports, low-priced Brazilian ethanol may flood the U.S. market. Brazil could become the OPEC of ethanol.

One avenue which could potentially avoid this Brazilian technological gap with associated Bertrand competition is for U.S. technology to provide a bridge for the corn-based ethanol industry to shift toward a cellulose-based technology. Currently, demonstration facilities are operating or under development to bridge this technological gap. The potential exists in 50 years for commercially feasible cellulose-based ethanol refining facilities to be operational (Perlack et al., 2005).

CHAPTER 3

MITIGATING VOLATILE U.S. GASOLINE PRICES AND INTERNALIZING EXTERNAL COSTS: A WIN-WIN FUEL PORTFOLIO[5]

[5] Zhang, Z., L. Lohr, C.L. Escalante, and M.E. Wetzstein. 2008. *American Journal of Agricultural Economics*. 90:1218-1225.
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3.1. Introduction

"America is addicted to oil"

President Bush, 2006 State of the Union Address

This addiction is most apparent in America's use of petroleum-based vehicle fuels which account for approximately 70% of U.S. petroleum demand (DOE, 2007). Compounding this petroleum-fuel addiction is the volatility of associated prices. Vehicle fuel prices are more volatile than prices for 95% of products sold by domestic producers (Regnier, 2007). Fuel-price volatility is expected to continue with a higher probability of increases above rather then decreases below the expected mean (Noureddine, 2006a). Coppejans et al. (2007) indicate such an addiction will result in reduced consumption as the price volatility of the addicted commodity increases.

Such price volatility and associated reduced consumption retards the entire macroeconomy and is at least partially responsible for the U.S. economy falling into the 2001 recession. Ferderer (1996) notes fuel-price volatility affects the entire U.S. economy through sectoral shocks and uncertainty. As demonstrated by Castillo, Montoro, and Tuesta (2007), this stimulates inflation and results in Kneller and Young's (2001) conclusion that fuel-price volatility is negatively correlated with economic growth. World growth and price stability require stable fuel markets (Noureddine, 2006b).

With upward-trending gasoline prices accompanied by heightened price volatility, diversifying into renewable fuels has become a major U.S. policy objective. Although these renewable fuels, 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 tradeoff in terms of expected price and variance. This social preference for higher expected price and lower variance is supported when vehicle-fuel externalities are price internalized, yielding the true social cost of burning fuels.

Considering ethanol, which is currently the main U.S. renewable fuel, the U.S. has two choices in acquiring fuel ethanol: home-grown domestic production or imports, with Brazil as the major source. In this context, Humphreys and McClain (1998) constructed an efficient portfolio frontier of U.S. coal, natural gas, and oil consumption. By employing a generalized autoregressive conditional heteroskedascity (GARCH) model for estimating variances and covariances, they developed time-varying efficient portfolios for minimizing the impact of energy price shocks.

Our objective is to employ a similar approach of mating a multivariate GARCH (MGARCH) model to portfolio-efficiency analysis to yield a vehicle fuel price-efficiency frontier composed of petroleum and ethanol fuels. Alternative portfolios yielding diversification among petroleum gasoline, U.S. fuel ethanol, and Brazilian ethanol are modeled with the objective of deriving the set of efficient portfolios which varies in response to market conditions. This frontier reveals a tradeoff 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.

It is hypothesized that relatively higher prices of both U.S. and Brazilian ethanol, but with different time-varying correlations with petroleum fuel, will yield diversified portfolios with lower variances relative to the current actual fuel mix. The resulting set of efficient portfolios will then reveal the relative share of Brazilian and U.S. ethanol with fuel petroleum as the volatility of the portfolio declines within the set. Policy analysis is then investigated by deriving the set of efficient portfolios when the federal fuel-ethanol tax credit is removed in conjunction with lifting of the ethanol import tariff. An analysis considering the external costs of these fuels is then also investigated. Results indicate the U.S. can efficiently reduce its volatility of vehicle fuels and at the same time account for the external costs of vehicle fuels by adjusting its vehicle-fuel portfolio toward greater ethanol consumption.

3.2. Portfolio Frontier

In terms of preferences, increased risk exposure is generally compensated with lower expected price. By diversifying into Brazilian and U.S. ethanol, the United States can achieve the lowest possible risk at a given price. As addressed by Humphreys and McClain (1998), the risk of an energy portfolio depends on the riskiness of the individual vehicle fuels and the covariances or correlation of the fuels. Although the expected aggregate portfolio-fuel price does not depend on these covariances, the covariances are a major determinant in portfolio risk. Negatively correlated fuels can result in significant portfolio risk reduction, and even positive correlations can yield a risk reduction.

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

(Eq. 3.1) $$E(p) = \alpha_B E(p_B) + \alpha_E E(p_E) + \alpha_G E(p_G),$$

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 risk associated with $E(p)$ is represented by the portfolio's variance

(Eq. 3.2) $$\sigma^2 = \alpha_B^2 \mathrm{var}(p_B) + \alpha_E^2 \mathrm{var}(p_E) + \alpha_G^2 \mathrm{var}(p_G) + 2\alpha_B\alpha_E \mathrm{cov}(p_B, p_E) + 2\alpha_B\alpha_G \mathrm{cov}(p_B, p_G) + 2\alpha_E\alpha_G \mathrm{cov}(p_E, p_G),$$

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 operator.

The efficient portfolio frontier is the set of all dominant portfolios. 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. With the United States interested in mitigating fuel-price variance and achieving low energy prices, its optimal vehicle-fuel portfolio should lie on this efficient frontier. The optimal portfolio selected will then represent the acceptable tradeoff between low vehicle-fuel prices and associated volatility.

(Eq. 3.1) and (Eq. 3.2) can be calculated given the expected prices and the covariance matrix of the vehicle fuels. A major shortcoming in computing the efficient frontier is in estimating the covariance matrix (volatility matrix) associated with (Eq. 3.2). Standard estimation assumes a constant covariance matrix across time, which in a vehicle-fuel market experiencing a state of flux with alternative fuel introductions, is probably too restrictive. An MGARCH model solves this problem by allowing the covariance matrix to vary with time. A time-varying covariance matrix for (Eq. 3.2) is thus computed using MGARCH introduced by Bollerslev, Engle, and Wooldridge (1988), Diebold and Nerlove (1989), Engle, Granger and Kraft (1986). Denoting this conditional covariance matrix as

$$\text{(Eq. 3.3)} \quad H_t = \begin{bmatrix} \text{var(B)} & \text{cov(B, E)} & \text{cov(B, G)} \\ \text{cov(E, B)} & \text{var(E)} & \text{cov(E, G)} \\ \text{cov(G, B)} & \text{cov(G, E)} & \text{var(G)} \end{bmatrix},$$

an MGARCH(1,1) is

$$\text{(Eq. 3.4)} \quad H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + G'H_{t-1}G,$$

where C, A, and G are 3×3 square matrices of parameters with C a lower triangular matrix and ε_{t-1} is the error term (deviations from the mean). The A matrix measures the extent that conditional variances are correlated with past squared errors and captures the effects of shocks or events on volatilities (conditional variances). Matrix G depicts the extent that current levels of conditional variances are related to past variances.

3.3. Data

The data set consists of monthly spot fuel price series of Brazil anhydrous ethanol, U.S. ethanol, and U.S. conventional gasoline from May 1998 to March 2007. The Brazil anhydrous ethanol prices were collected from USDA Foreign Agricultural Service and U.S. ethanol prices were obtained from the Renewable Fuel News and matched with U.S. conventional gasoline prices from the Energy Information Administration.

Prices for Brazilian and U.S. ethanol were adjusted to reflect differences in fuel efficiency, transportation costs, and the ethanol fuel subsidy. For fuel efficiency, ethanol has approximately two-thirds the energy content of petroleum gasoline (Stoft, 2006). An added transportation cost of 14 cents/gallon was applied to the Brazilian ethanol price, reflecting the cost of ocean shipping, along with the U.S. tariff of 54 cents/gallon (Severinghaus, 2005). Finally, Brazilian and U.S. ethanol prices were adjusted for the subsidy which varied over the time interval.

The price series for Brazilian and U.S. ethanol along with gasoline are plotted in Figure 3.1. The gasoline price series has experienced a gradual upward trend with a small downturn during the 2001 recession and general increased volatility during the last couple of years. In contrast, the U.S. ethanol price series, relative to gasoline, has tended to be relatively more volatile over the life of the series with larger price swings during and after the 2001 recession. The Brazilian ethanol price series prior to 2005 appears to be more volatile than both the U.S. ethanol and gasoline price series. Corresponding to Figure 3.1, Table 3.1 lists the summary statistics for the three price series, p_B, p_E, and p_G. Gasoline has the lowest mean, variance, minimum, and maximum values relative to the Brazilian and U.S. ethanol prices. Brazilian ethanol has a higher mean price, minimum, and maximum than U.S. ethanol, but a lower overall variance. The kurtosis statistics are all less than three indicating possible platykurtic distributions. This is supported by the Jarque-Bera test statistic which rejects normality. Series with skewness and kurtosis may result from variances evolving with time. A MGARCH (1, 1) used for forecasting these evolving variances can then be employed for determining the forecast optimal portfolio (Moreno, Marco, and Olmeda, 2005; Hlouskova, Schmidheiny, and Wagner, 2004).

Employing the Dickey-Fuller test, the three price series, p_B, p_E, and p_G, are tested for the presence of a unit root. For all three series, the test failed to reject the null hypothesis of a unit root at a 10% significant level, indicating nonstationary price series. However, first differencing the series results in rejecting the null hypothesis of a unit root at the 1% significance level, so to achieve stationary, all the price series were first differenced.

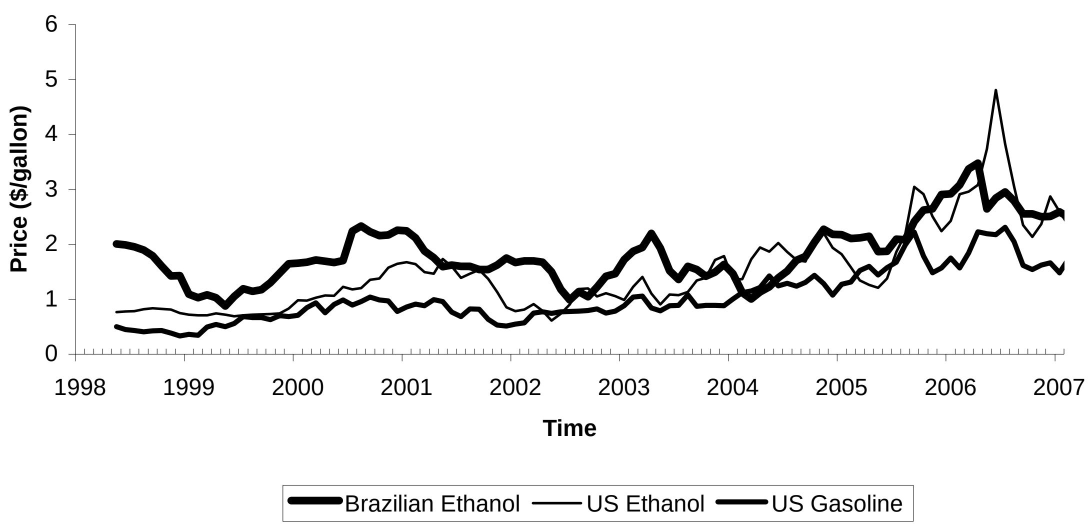

Figure 3.1. Brazilian and United States ethanol and gasoline price series

Table 3.1. Summary statistics

Price Series	Mean	Variance	Skewness	Kurtosis	Jarque-Bera[a]	Min.	Max.
Ethanol							
Brazil	1.844	0.318	0.616	−0.010	6.771** (0.034)	0.872	3.476
US	1.519	0.626	1.449	2.492	65.108* (0.000)	0.614	4.806
Gasoline	1.048	0.239	0.820	−0.072	12.028* (0.002)	0.333	2.308

[a] P-values in parentheses.
* and ** indicate significance at the 1% and 5% level, respectively.

3.4. Results

The MGARCH(1, 1) model was employed for estimating the matrices C, A, and G in calculating the time-varying conditional covariance matrix H_t, (Eq. 3.3). The resulting series of volatility (variance) and covariance are plotted in Figure 3.2 and Figure 3.3, respectively. Generally, prior to 2005 the volatility of fuel prices was low, indicating possible little efficiency to be gained from portfolio selection. However, as illustrated in these figures, the recent marked increase in volatility of these fuel prices suggests a portfolio of fuels could yield a large reduction in volatility.

Efficient portfolio frontiers, Figure 3.4, for years 2000, 2005, and 2006 were derived based on (Eq. 3.1) and (Eq. 3.2) along with selected frontier points listed in Table 3.2. For all three years, gasoline alone, not blended with ethanol, is on the frontiers with the lowest price and highest volatility. The relative higher prices for Brazilian and U.S. ethanol account for gasoline's frontier minimum price. The tradeoff between volatility and price is observed given the negative sloping convex efficiency frontiers. Reducing fuel volatility is possible by increasing the percentage of Brazilian and U.S. ethanol used in the U.S. fuel market. Such a reduction in volatility is achieved by a greater percentage increase in Brazilian ethanol compared with U.S. ethanol. In particular, for 2006, initial reduction in volatility is achieved without U.S. ethanol.

As illustrated in Figure 3.4, actual portfolios for years 2000 and 2005 are on the efficiency frontier. These yearly portfolios are comprised of over 97% gasoline. However, with higher volatility in 2006, the actual portfolio slightly deviates from the efficiency frontier, indicating alternative portfolios are more efficient in reducing fuel prices and volatility. Current U.S. policy is consistent with a portfolio toward the minimum-price highest-volatility extreme point on the frontiers. Only a slight reduction in volatility results from the current policy. In contrast, a large reduction in volatility is possible by diversifying into ethanol. The minimum variance portfolios would comprise a greater balance in diversification with a larger percentage of ethanol coming from Brazil than from U.S. production.

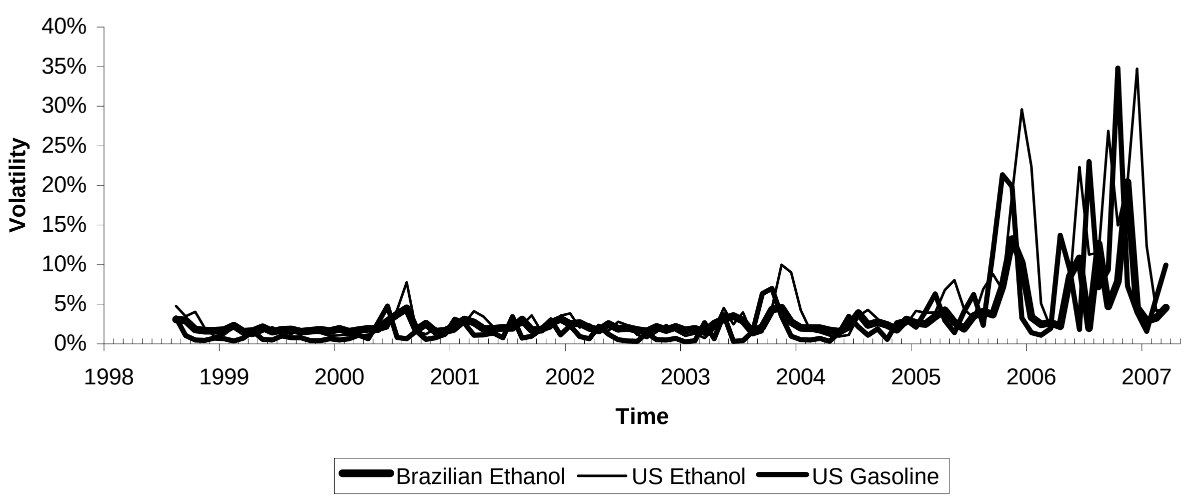

Figure 3.2. Estimated time-varying conditional variance

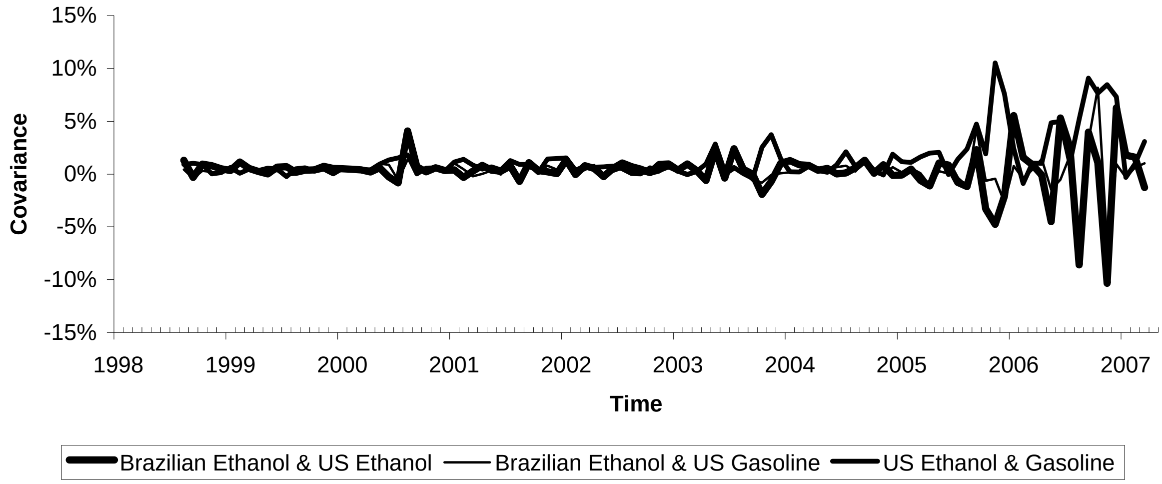

Figure 3.3. Estimated time-varying conditional covariance

Table 3.2. Selected frontier points

Year	Price ($/gal)	Regulated Market				Free-Market			
		Volatility	Weight			Volatility	Weight		
			Ethanol		Gasoline		Ethanol		Gasoline
			Brazil	US	US		Brazil	US	US
2000									
	0.9	0.013	0	0.02	0.98	0.008	0.01	0	0.99
	1.0	0.011	0.05	0.16	0.79	0.007	0.10	0	0.90
	1.1	0.010	0.13	0.21	0.66	0.006	0.18	0.01	0.81
	1.2	0.001	0.23	0.19	0.58	0.006	0.11	0.16	0.73
2005									
	1.6	0.070	0	0.01	0.99	0.050	0	0	1
	1.7	0.054	0.09	0.08	0.83	0.040	0.14	0	0.86
	1.8	0.038	0.22	0.13	0.65	0.031	0.31	0	0.69
	1.9	0.028	0.36	0.17	0.47	0.026	0.48	0	0.52
	2.0	0.024	0.49	0.22	0.29	0.025	0.59	0.02	0.39
2006									
	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

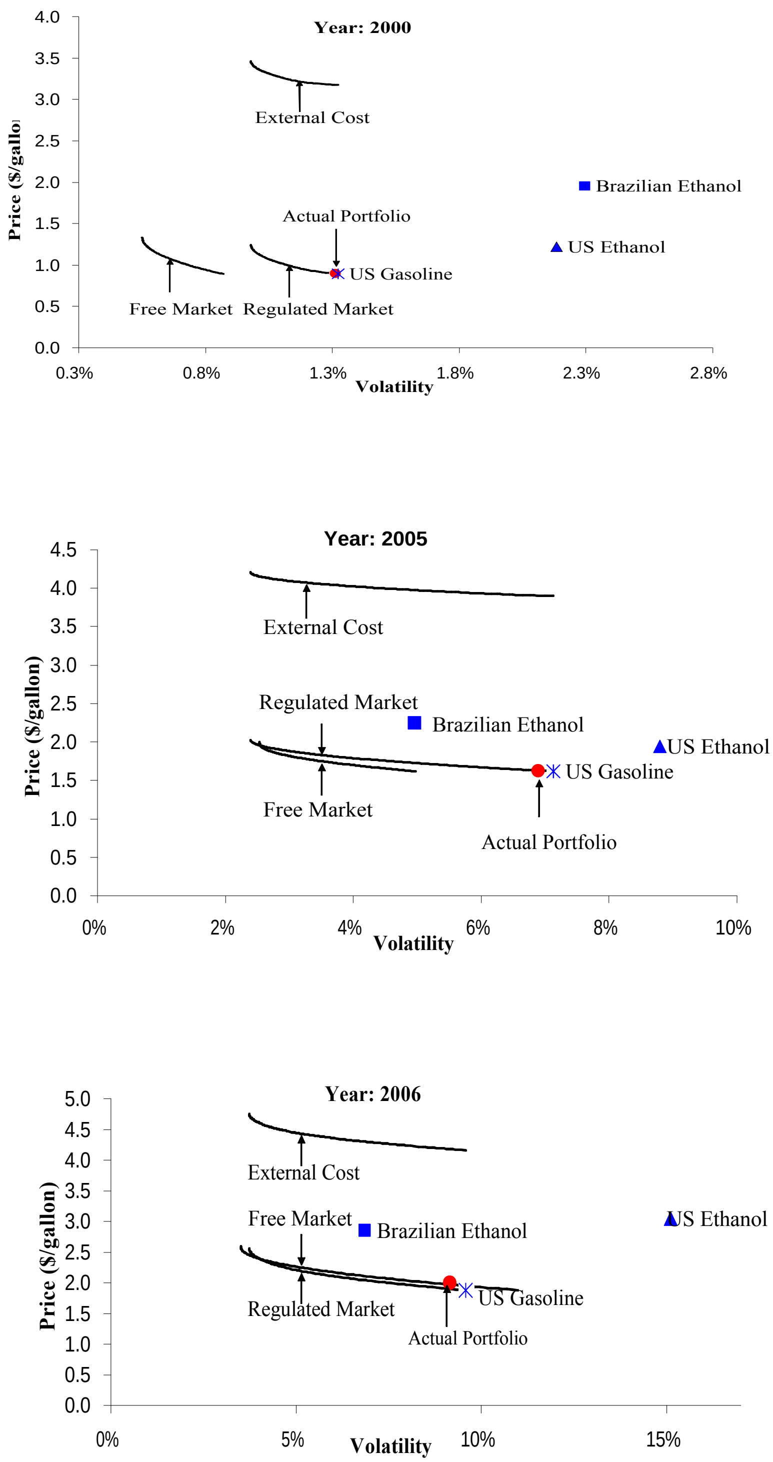

Figure 3.4. Portfolio frontiers for years 2000, 2005, and 2006

3.4.1. Free-Market Ethanol

In an effort to avoid possible economic downturns and to placate public anguish over escalating gasoline prices, policymakers are investigating options designed to reduce gasoline prices. One such option is the United States – Brazil Energy Cooperation Pact of 2007 bill introduced by Senator Richard Lugar of Indiana. The bill would eliminate the 54¢ per gallon import tariff on ethanol. Senator Lugar has called for a study on the effects of removing this trade barrier (Lugar, 2007).

Investigating the removal of this tariff in conjunction with eliminating the federal ethanol subsidy, assuming American tax payers would not support subsiding foreign ethanol production, results in the free-market portfolios also illustrated in Figure 3.4, along with selected frontier points listed in Table 3.2. Removing the U.S. ethanol subsidy and allowing duty-free Brazilian ethanol to enter the United States, results in U.S. ethanol entering into the efficient portfolio only for very low volatility levels with high fuel prices. For year 2000, volatility is markedly reduced with less ethanol in the efficient portfolios and Brazilian ethanol replacing U.S. ethanol. This reduction in volatility results from the inverse in changes in variances between Brazilian ethanol and U.S. gasoline and their negative covariance. In contrast, for the more volatile 2005 and 2006 years, there is not a marked reduction in volatility. The inverse in changes in variances between Brazilian ethanol and U.S. gasoline are not apparent in these years. Thus, in these more volatile years moving toward a free-market 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 one should be cautious in 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.

3.4.2. Ethanol Externalities

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 3.3). Air quality, congestion, and accident costs are estimated at $2.10 and do not vary with fuel type, while oil dependency cost associated only with gasoline is estimated at $0.12. Employing a total lifecycle analysis, EPA (2007) has estimated greenhouse gas emissions from ethanol are reduced approximately 20% with corn-based ethanol compared with petroleum gasoline emissions. Brazilian ethanol, chiefly produced with sugarcane, has the potential for a larger emission reduction. However, as indicated in Table 3.3, 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 external costs yields a new set of expected prices and associated variance/covariance matrices. As illustrated in Figure 3.4, incorporating the external costs results in essentially an upward vertically parallel shift in the efficiency frontiers. The lack of a marked variation in external costs among the three fuel types accounts for this parallel shift.

Table 3.3. External costs (cents/gallon)

External Costs	Ethanol		Gasoline
	Brazil	United States	
Fuel Related Costs			
Greenhouse Gases	4.8¢	4.8¢	6.0¢
Oil Dependency	0	0	12
Mileage Related Costs			
Local Air Quality	42	42	42
Congestion	105	105	105
Accidents	63	63	63
Total	214.8	214.8	228

3.5. Conclusion

Results indicate the current U.S. vehicle-fuel policies generally 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 external costs of vehicle fuels (local air quality, congestion, and accidents) 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 U.S. 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.

CHAPTER 4

ETHANOL, CORN, AND SOYBEAN PRICE RELATIONS IN A VOLATILE VEHICLE-FUELS MARKET[6]

[6] Zhang, Z., L. Lohr, C.L. Escalante, and M.E. Wetzstein. To be submitted to *Energy Economics*.

4.1. Introduction

The rapid upward shift in ethanol demand has raised concerns of ethanol's impact on the price level and volatility of agricultural commodities. Recently, the prices of corn and soybeans, the nation's two top crops in total production, doubled and then sharply declined. The popular press attributes much of this run-up in commodity prices to the swelling demand for ethanol fuel and decline to a falloff in this demand (Etter et al., 2007). Market economics predicts these high commodity prices will be mitigated by a supply response and a softening of demand (LeBlanc and Prato, 1983; Meekhof et al., 1980; Webb, 1981). In the fall of 2008, this prediction was confirmed with declines in domestic and foreign demand and higher expected crop harvests. A sharp hike in 2006 corn prices precipitated corn acreage reaching historic highs with a corresponding drop in soybean acreage yielding higher soybean prices (ERS, 2008). The recent boom in ethanol refining capacity has resulted in an ethanol economic bubble which dampened the ethanol price. This price decline in conjunction with recent declines in the demand for vehicle fuels and lack of credit availability has forced some ethanol refineries to shutdown and retarded expected entry of others (Hargreaves, 2007). These current fluid ethanol, corn, and soybean markets manifests in both the first and second moments of ethanol, corn, and soybean price distributions. Not only does ethanol potentially influence the level of corn and soybean prices but it can also impact their price volatility.

Understanding and predicting price leadership between ethanol and the corn and soybean agricultural commodities leads to better policy. Persistent changes in volatility can increase the risk exposure of agricultural producers and ethanol refiners and alter hedging decisions and incentives to invest. However, such an understanding of the linkages between ethanol and agricultural commodity prices is pertinent beyond these microeconomic decisions. By understanding the pricing relations, light is shed on the current food versus fuel debate centering around the dynamics of ethanol, corn, and soybean prices (Robinson, 2008).

Given the volatility in ethanol, corn, and soybean markets, the following questions are addressed. First, are there any long-run relationships between ethanol prices and agricultural commodity prices? Second, are there any short-run relationships between these prices? Third, are these price volatilities interrelated? Fourth, are these relationships changing over time?

These questions are addressed with an analysis of weekly price series for U.S. ethanol, corn, soybean, petroleum-based gasoline (gasoline), and oil. The relationships among these series are investigated using cointegration, vector error corrections (VECM), and multivariate generalized autoregressive conditional heteroskedascity (MGARCH) models. The technical links among prices of corn, soybean, 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 of this study is on prices, with the acknowledgment there are other measures of volatility that are associated with consumption, production, or inventories. However, interest is in the overall market with prices as the single statistic for market conditions. As noted by Pindyck (2004), 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). A secondary effect of expanded corn acreage is an acreage reduction in its major substitute, soybeans, with a corresponding positive soybean price response. Based on this theory, the hypothesized direction of dynamic prices would flow from the price of ethanol to corn and soybean prices. 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 prices of corn and soybeans. However, if the dynamics do not support this ethanol-derived demand hypothesis, an alternative hypothesis of demand by non-ethanol (food) markets may explain prices in the corn and soybean markets.

4.2. Data

The data set includes weekly wholesale price series for U.S. ethanol, corn, soybean, 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 at three U.S. locations: Los Angeles, Houston, and New York City. Petroleum 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 (EIA, 2007a). U.S. FOB weekly West Texas Intermediate oil spot prices are also taken from the Energy Information Administration website (EIA, 2007b). U.S. weekly corn and soybean prices mated with ethanol prices are collected from USDA Agricultural Marketing Service for three U.S. locations: corn prices from Nebraska, Kansas, and Texas and soybean prices from Illinois, Indiana, and Ohio.

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 boom in ethanol refining and associated increase in ethanol price volatility. To account for this possible structural shift in the relations among these prices, analysis was conducted in terms of the pre-ethanol boom (1989-1999) and ethanol boom (2000-2007) years.

Each series is tested for the presence of a unit root. A series with a unit root is nonstationary with an infinite unconditional variance. Following Pindyck (1999), the Dickey-Fuller test and augmented Dickey-Fuller test with a time trend t are performed by estimating the models

(Eq. 4.1) $$\Delta y_t = \alpha + \beta t + \nu y_{t-1} + \varepsilon_t$$

(Eq. 4.2) $$\Delta y_t = \alpha + \beta t + \nu y_{t-1} + \sum_{j=1}^{L} \lambda_j \Delta y_{t-j} + \varepsilon_t$$

where y_t is the time-series price variable, Δ is the first differencing operation, L is the lag length, and α, β, ν, and λ are parameters. As indicated in Table 4.1, all the logarithms of the level price series fail to reject the null hypothesis of a unit root at the 1% significant level. However, all first differencing of the logarithm of the price series result in rejecting the null hypothesis at the 1% significant level, indicating stationary.

Table 4.1. Dickey-Fuller and augmented Dickey –Fuller unit root test statistics

Series	Dickey-Fuller	Augmented Dickey-Fuller				
		L = 1	L = 2	L = 4	L = 8	L= 12
Years 1989 - 1999						
Price series (P_t)						
Ethanol	-2.317	-2.880	-3.366***	-3.209***	-3.058	-3.409***
Corn	-1.293	-1.563	-1.829	-2.151	-2.823	-2.561
Soybean	-1.743	-1.726	-1.816	-2.030	-1.895	-1.831
Gasoline	-4.029*	-3.425**	-3.726**	-3.771**	-2.974	-3.099
Oil	-2.528	-2.562	-2.533	-3.209***	-3.890**	-3.321***
Log price series ($\ln P_t$)						
Ethanol	-2.341	-2.988	-3.436**	-3.218	-2.940	-3.302***
Corn	-1.329	-1.352	-1.601	-2.012	-2.338	-2.230
Soybean	-1.621	-1.625	-1.695	-1.834	-1.731	-1.576
Gasoline	-3.595**	-3.424**	-3.589**	-3.705**	-2.785	-2.941
Oil	-2.302	-2.482	-2.387	-3.058	-3.315***	-3.002
Log price change series ($p_t = 100{*}\ln(P_t/P_{t-1})$)						
Ethanol	-17.542*	-12.391*	-10.253*	-9.720*	-7.813*	-5.737*
Corn	-23.348*	-14.827*	-11.488*	-9.045*	-6.072*	-5.800*
Soybean	-22.954*	-16.322*	-13.040*	-11.231*	-7.780*	-6.507*
Gasoline	-24.855*	-16.417*	-13.053*	-10.663*	-9.017*	-6.948*
Oil	-22.542*	-16.786*	-13.040*	-9.062*	-6.973*	-6.204*
Years 2000-2007						
Price series (P_t)						
Ethanol	-1.878	-3.290***	-4.255*	-3.797**	-3.180***	-2.626
Corn	-1.743	-1.582	-1.439	-1.951	-2.034	-1.962
Soybean	-0.748	-1.643	-1.619	-1.398	-2.074	-1.988
Gasoline	-3.581**	-3.327***	-3.019	-3.907**	-3.265***	-2.967
Oil	-1.718	-2.232	-2.068	-2.054	-1.889	-1.332
Log price series ($\ln P_t$)						
Ethanol	-1.663	-2.957	-3.567**	-3.500**	-2.743	-2.513
Corn	-1.932	-1.761	-1.619	-1.978	-2.248	-2.147
Soybean	-1.193	-1.929	-1.973	-1.833	-2.319	-2.113
Gasoline	-3.143***	-3.228***	-3.273***	-3.564**	-3.110	-2.702
Oil	-2.219	-2.670	-2.488	-2.502	-2.399	-1.957
Log price change series ($p_t = 100{*}\ln(P_t/P_{t-1})$)						
Ethanol	-11.853*	-8.620*	-7.788*	-7.974*	-6.992*	-6.654*
Corn	-21.761*	-15.841*	-12.048*	-8.227*	-6.227*	-5.238*
Soybean	-15.361*	-12.109*	-10.428*	-8.871*	-5.423*	-5.702*
Gasoline	-19.939*	-14.293*	-10.935*	-9.341*	-8.676*	-6.830*
Oil	-17.528*	-15.120*	-11.096*	-9.178*	-7.535*	-6.292*

Note: *, ** and *** denote significance at a 1%, 5%, and 10% level, respectively, and L denotes the lag length.

4.3. Cointegration Estimation

Two or more price series are said to be cointegrated if the prices move together in the long-run. As discussed by Engle and Granger (1987), a linear combination of two or more non-stationary series which share the same order of integration may be stationary. If such a stationary linear combination exists, the series are said to be cointegrated and long-run equilibrium relationships exist. Although there may be short-run developments that can cause series to deviate, there is a long-run equilibrium relation represented as a linear combination, which ties the individual price series together.

As a test for the presence of cointegration among the price series, the Johansen (1991) trace test is performed. Results, presented in Table 4.2, indicate rejecting the hypotheses of zero or only one cointegration relation for the pre-boom period and no cointegration relations for the ethanol boom period. Based on these trace tests, two cointegration relations are revealed for the pre-ethanol period and one for the ethanol boom period. Searching for the possible long-run relationships among the prices, the likelihood ratio testing approach is employed. Restricted models with one or more prices not being cointegated are tested against the unrestricted model with all the prices cointegrated. Based on the χ^2 between the unrestricted and restricted models, the following cointegration relations are determined:

Pre-Ethanol Boom Period

(Eq. 4.3a) $lnP_g = 0.186 + 0.972 lnP_o,$

$(0.044) \quad (0.055)$

(Eq. 4.3b) $lnP_e = 0.114 + 0.297 lnP_c,$

$(0.66) \quad (0.069)$

Ethanol Boom Period

(Eq. 4.3c) $lnP_g = 0.082 + 0.848 lnP_o + 0.231 lnP_e,$

(0.045) (0.057) (0.080)

where P_g, P_o, P_e, and P_c are the level prices of gasoline, oil, ethanol, and corn, respectively. Coefficients in parentheses are the standard errors. All the parameter coefficients are significant at the 1% level with the exception of the intercept terms in the ethanol/corn pre-ethanol relation and the ethanol boom relation which are significant at the 10% level.

Table 4.2. Cointegration trace test

Null Hypotheses: Number of Cointegration Relations	Eigenvalue	Trace Statistic	Critical Value 95% Confidence	P-value
Pre-Ethanol Boom Period (1989 - 1999)				
0	0.097	121.383	76.813	0.000
1	0.056	64.646	53.945	0.004
2	0.027	32.761	35.070	0.089
3	0.021	17.431	20.164	0.118
4	0.010	5.699	9.142	0.223
Ethanol Boom Period (2000 - 2007)				
0	0.095	79.844	76.813	0.028
1	0.048	39.158	53.945	0.518
2	0.020	18.952	35.070	0.787
3	0.017	10.778	20.164	0.571
4	0.009	3.687	9.142	0.472

Results from (Eq. 4.3) yield two linear relations for the pre-ethanol boom and one relation for the subsequent ethanol boom periods:

Pre-Ethanol Boom Period

$$\left.\begin{array}{l}\text{Gasoline prices}\\ \text{Oil prices}\end{array}\right] \begin{array}{c}\text{cointegrated}\\ \text{relation}\end{array} \left(\begin{array}{l}\text{long - run equilibrium}\\ \text{relation}\end{array}\right)$$

$$\left.\begin{array}{l}\text{Ethanol Prices}\\ \text{Corn Prices}\end{array}\right] \begin{array}{c}\text{cointegrated}\\ \text{relation}\end{array} \left(\begin{array}{l}\text{long - run equilibrium}\\ \text{relation}\end{array}\right)$$

Ethanol Boom Period

$$\left.\begin{array}{l}\text{Gasoline Prices}\\\text{Oil Prices}\\\text{Ethanol Prices}\end{array}\right]\begin{array}{c}\text{cointegrated}\\\text{relation}\end{array}\begin{pmatrix}\text{long - run equilibrium}\\\text{relation}\end{pmatrix}$$

For the pre-ethanol boom period, the analysis indicates gasoline and oil prices exhibit one of the long-run relations with ethanol and corn prices as the other cointegrates. In contrast, results indicate no long-run relation between ethanol and corn prices in the ethanol boom period with only cointegrates among the fuel prices (gasoline, oil, and ethanol). Thus, although there was a long-run relation between ethanol and corn in the pre-ethanol boom period, this relation is not apparent in the subsequent ethanol boom period. In contrast to popular belief, ethanol and corn do not appear to currently have any long-run price relationship. However, short-run relations may exist where ethanol prices do influence corn prices and vice versa.

4.4. Vector Error Corrections Model (VECM)

4.4.1. Granger Causality Tests

The existence of these cointegrating relationships among the prices indicates there is long-run causality in at least one direction among the prices within the relations, but it does not indicate the direction of price temporal causality. Such causality can be determined with a vector error corrections model (VECM) which specifies the short-run dynamics of each price in a framework that anchors the dynamics to long-run equilibrium relationships (conintegates).

With the cointegration relations (Eq. 4.3), the Granger-type causality test models are augmented with a one period (week) lagged error correction term.

Pre-Ethanol Boom Period

(Eq. 4.4a) $$p_t = \alpha_1 ECT_{1,t-1} + \alpha_2 ECT_{2,t-1} + \sum_{i=1}^{4} \Phi_i p_{t-i} + \varepsilon_t ,$$

where p_t is a vector of percentage change in logarithm prices, α_1, α_2, and Φ_i are vectors and matrices of the parameters to be estimated. $ECT_{1,t-1}$ and $ECT_{2,t-1}$ are the lagged error correction terms from (Eq. 4.3a) and (Eq. 4.3b).

Ethanol Boom Period

(Eq. 4.4b) $$p_t = \alpha ECT_{t-1} + \sum_{i=1}^{4} \Phi_i p_{t-i} + \varepsilon_t,$$

where ECT_{t-1} is the lagged error correction term from (Eq. 4.3c).

The Final Prediction Error and Akaike's statistics are computed for determining the lag length in the VECM specifications. These statistics indicate a lag length of four for the pre-ethanol boom period and two for the ethanol boom period. Estimation of the models for alternative lag lengths yielded robust results with nearly identical estimated coefficients. For reporting consistent results, a four-lag specification is selected for both the pre-ethanol and ethanol boom periods.

Employing (Eq. 4.4) yields three tests for causality: 1. The short-run causal effects analyzed with a χ^2-statistic of the lagged explanatory variables; 2. The long-run causal effects, associated with the prices that are cointegrated, analyzed using a t-statistic on the coefficient of the lagged error-correction term; and 3. Market shock effects, associated with prices that are not cointegrated, also analyzed using the t-statistic of the lagged error-correction term.

Results from estimating (Eq. 4.4) are presented in appendix Tables A4.1 and A4.2 for the pre-ethanol boom and ethanol boom periods, respectively. The associated Granger causality statistics are listed in appendix Tables A4.3 and A4.4. Based on these results, causalities among the price series for the pre-ethanol and ethanol boom periods are listed in Table 4.3.

Table 4.3. Granger causality test[a]

Causality	Pre-Ethanol Boom (1989-1999)			Ethanol Boom (2000-2007)			Causality Reverse	
	Short-Run	Long-Run[b]	Market Shock	Short-Run	Long-Run[c]	Market Shock	Short-Run	Long-Run / Market Shock
1	Ethanol and Gasoline Prices							
	$p_g \rightarrow p_e$		$p_e \rightarrow p_g$	$p_g \rightarrow p_e$	$p_g \leftrightarrow p_e$		No	No
2	Gasoline and Oil Prices							
	$p_g \rightarrow p_o$	$p_g \leftrightarrow p_o$		$p_g \rightarrow p_o$	$p_o \rightarrow p_g$		No	No
3	Ethanol and Oil Prices							
	$p_e \rightarrow p_o$				$p_o \rightarrow p_e$			
4	Corn and Oil Prices							
	$p_c \rightarrow p_o$					$p_o \rightarrow p_c$		
5	Ethanol and Soybean Prices							
	$p_s \rightarrow p_e$			$p_e \rightarrow p_s$			Yes	
6	Corn and Soybean Prices							
	$p_c \rightarrow p_s$			$p_c \rightarrow p_s$			No	
7	Gasoline and Corn prices							
			$p_c \rightarrow p_g$			$p_g \rightarrow p_c$		Yes
8	Ethanol and Corn Prices							
		$p_c \rightarrow p_e$				$p_e \rightarrow p_c$		Yes

[a] Long-run and market shock causal effects are associated with cointegrated prices and non-cointegrated prices, respectively. The arrow, →, indicates the direction of Granger causality. Prices of ethanol, corn, soybean, gasoline, and oil, in terms of percentage change in logs, are p_e, p_c, p_s, p_g, and p_o, respectively. Exceptions are the long-run and market shock relations which are in terms of log price causing log change in price.

[b] Two long-run relations (cointegrates): 1. Relationship between gasoline and oil prices and 2. Relationship between ethanol and corn prices.

[c] Long-run relation among gasoline, oil, and ethanol prices.

In the short-run for both periods, Causalities 1 and 2 indicate that increases in the price of gasoline are driving up ethanol and oil prices while the price of corn influences soybean prices (Causality 6):

$$p_g \overset{\text{short run}}{\rightarrow} \begin{cases} p_e \\ p_o \end{cases}, \text{ for both the pre - ethanol and ethanol boom periods,}$$

$$p_c \overset{\text{short run}}{\rightarrow} p_s, \text{ for both the pre - ethanol and ethanol boom periods,}$$

where → indicates the direction of causation. This supports the microeconomic theory hypothesis of a derived demand for ethanol and oil associated with fuel production. The ever-increasing demand for gasoline within the U.S. and the existing tight world oil market underlies this ethanol and oil derived demand. As the demand for vehicle fuels increases, the input demand for ethanol and gasoline increases. In terms of corn prices influencing soybean prices, a positive corn acreage response to an own price enhancement reduces soybean acreage and associated harvest, thus driving up price.

As indicated by the pre-ethanol boom period, Causalities 2, 3, and 4, gasoline, ethanol, and corn prices determine the short-run direction of oil prices:

$$\left.\begin{matrix} p_g \\ p_e \\ p_c \end{matrix}\right\} \overset{\text{short run}}{\rightarrow} p_0, \text{ for the pre - ethanol boom periods.}$$

During this period the demand for oil appears to be driven by its use in vehicle fuels and agricultural commodity production. Also, during this pre-boom period, prices of gasoline along with soybean prices influence ethanol prices (Causalities 1 and 5):

$$\left.\begin{matrix} p_g \\ p_s \end{matrix}\right\} \overset{\text{short run}}{\rightarrow} p_e, \text{ for the pre - ethanol boom periods.}$$

This indicates that gasoline prices not only directly influence oil prices but also indirectly influence them by impacting ethanol prices which influence oil prices. Similarly, with corn prices impacting soybean prices (Causality 6), prices of corn indirectly influence ethanol prices.

The long-run causality, associated with the cointegrates, and the market shock causality, associated with the non-cointegrates, indicate the direction of causation among the cointegrates. Corn prices are influencing the prices of vehicle fuels (ethanol and gasoline) and between the two fuel prices, ethanol prices are influencing gasoline (Causalities 1, 7, and 8)

$$p_c \overset{\text{long run}}{\rightarrow} p_e, \text{ and}$$

$$\left.\begin{matrix} p_c \\ p_e \end{matrix}\right\} \overset{\text{market shock}}{\rightarrow} p_g, \text{ for the pre - ethanol boom periods.}$$

The relatively small market for ethanol during this period accounts for corn prices influencing ethanol prices, and the general economic conditions influencing the corn and ethanol markets possibly accounts for their market influence on gasoline prices.

Considering the ethanol boom period, the relationship among the agricultural commodity prices (corn and soybeans) and fuel prices (ethanol, gasoline, and oil) result in a causality reversal (Causalities 5, 7, and 8). After the year 1999, instead of gasoline, ethanol, and corn driving the demand for oil (Causalities 2, 3, and 4), a reversal occurs with oil prices now influencing gasoline, ethanol, and corn prices. Fuel prices (ethanol, oil, and gasoline) are now impacting corn prices

$$\left.\begin{matrix} p_o \\ p_g \\ p_e \end{matrix}\right\} \overset{\text{market shock}}{\rightarrow} p_c, \text{ for the ethanol boom periods.}$$

4.4.2. Variance-Decomposition

The significance of the reversal with fuel prices now directly influencing agricultural commodity prices has sparked the current food versus fuel security issue. Providing evidence on this issue, variance-decomposition and impulse response curves indicate that ethanol causes only a small short-run impact on soybean prices and any ethanol market shock on corn prices is not persistent. There is no long-run relation (cointegrate) between ethanol and corn prices.

Variance-decomposition provides information on the relative magnitude of the causation influence of one price on another. Performing variance-decomposition analysis measures the effect of shocks in each price on the current and future values of a given price. Specifically, decomposition reflects the percentage of the variance associated with each price in the VECM caused by shocks to the other prices.

The variance-decomposition statistics after five weeks are listed in Table 4.4. For the pre-ethanol boom period, the variability of the gasoline price contributes 41.4% and 17.4% of the variance of oil and ethanol prices, respectively, and the corn price variability effect on soybeans is 38%. In contrast, short-run causality for the ethanol and corn prices on oil prices are only around 1% and 2%. This variance-decomposition analysis further supports the significant positive influence of gasoline prices on oil and ethanol prices, and corn prices on soybean prices with a general minor or lack of any causality relations among the other price series.

This significant influence of gasoline prices on oil and ethanol prices as well as corn prices on soybean prices carries directly over to ethanol boom period with 54.1%, 17.3%, and 26.1% contribution, respectively. Although, for the ethanol boom period, ethanol prices are influencing soybean prices, their causation is small as only 0.2% of the price variation in soybeans is explained by ethanol price variations. At least in the short-run, ethanol prices are not exerting any significant effect on corn and soybean prices. In combination with the lack of any long-run relations between ethanol prices and agricultural commodity (corn and soybean) prices, the trade off between food and fuel (food versus fuel security issue) is not revealed by the empirical results. There appears to be a disconnection between food and fuel. The results do not support the hypothesis that much of the run-up in agricultural commodity prices is due to the swelling demand for ethanol fuel. Instead, the alternative hypothesis of demand by non-ethanol (food) markets may explain the inflation.

Table 4.4. Variance-decompositions after five periods (weeks)

Forecast Error for Log Prices of	Contributions of the Shocks in Log Prices of				
	Gasoline	Oil	Ethanol	Corn	Soybean
Pre-Ethanol Boom Period (1989-1999)					
Gasoline	0.952	0.027	0.010	0.007	0.004
Oil	0.414	0.554	0.009	0.022	0.001
Ethanol	0.174	0.032	0.791	0.002	0.001
Corn	0.004	0.007	0.004	0.973	0.012
Soybean	0.010	0.000	0.001	0.380	0.609
Ethanol Boom Period (2000-2007)					
Gasoline	0.980	0.010	0.003	0.003	0.004
Oil	0.541	0.444	0.005	0.003	0.007
Ethanol	0.173	0.001	0.818	0.006	0.002
Corn	0.006	0.003	0.018	0.968	0.005
Soybean	0.004	0.010	0.002	0.261	0.723

4.4.3. Impulse Response

One possible reason for this food versus fuel disconnection is the lack of any persistence in corn prices given a shock to its price. Such 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. As illustrated in Figure 4.1, impulse response curves for fuel price effects on corn prices indicate corn prices have little, if any, response to fuel price shocks. Within ten weeks, corn prices converge toward equilibrium from an ethanol price shock and within 15 weeks for shocks in oil and petroleum gasoline prices. This lack of corn-price persistence to an ethanol price shock indicates a rapid market response mitigating ethanol-price effects on corn prices.

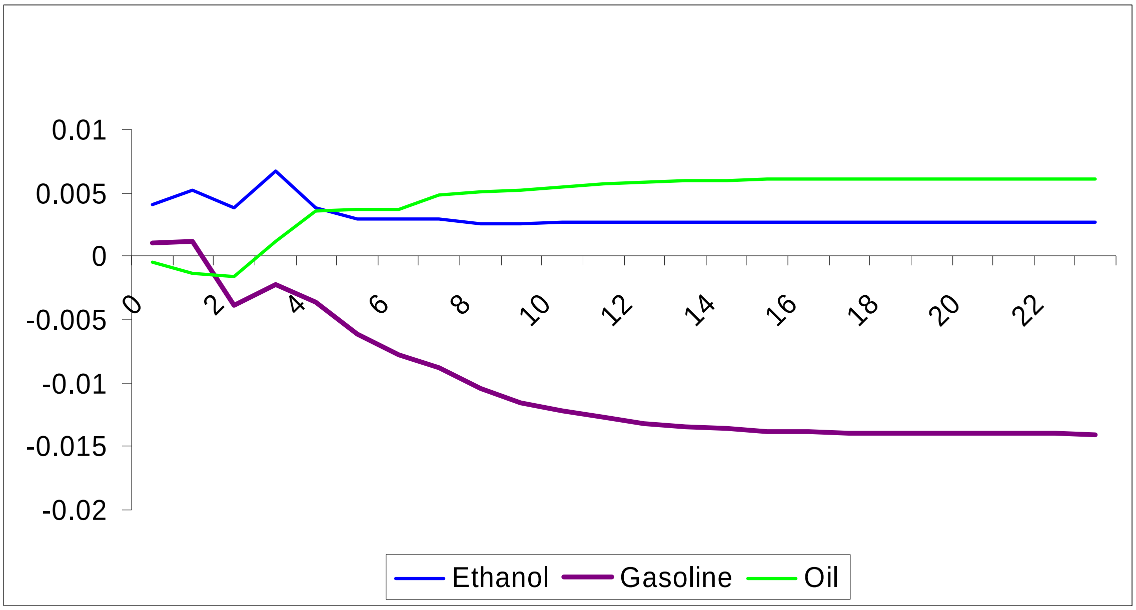

Figure 4.1. Impulse responses for ethanol, gasoline, and oil price shocks on the corn prices for the ethanol boom 2000-2007

4.5. MGARCH Estimation

Similar to the VECM, the MGARCH results in modeling price volatility yield a link between oil and gasoline price volatilities as well as a link between corn and soybean price volatilities over both the pre-ethanol and ethanol boom periods (Table 4.5). Specifically, a BEKK specification of MGARCH (1, 1) is employed which allows for dynamic correlations among the prices (Engle and Kroner, 1995). Denoting the conditional covariance matrix as H_t, an MGARCH(1,1) can be written as

(Eq. 4.5) $$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + G'H_{t-1}G,$$

where C, A, and G are 5×5 square matrices of parameters with C a lower triangular matrix and ε_{t-1} is the error term (deviations from the mean). The A matrix measures the extent that conditional variance and covariances are correlated with past squared errors and captures the effects of shocks or events on volatilities (conditional variances). Matrix G depicts the extent that current levels of conditional variances and covariances are related to the past conditional variances and covariances. This BEKK model yields dynamic variances (conditional variances which are the diagonal elements of H_t) as measures of volatilities which are functions of past and current disturbances. Results of applying the MGARCH model to the pre-ethanol and ethanol boom periods are provided in appendix tables A4.5 and A4.6.

Table 4.5. Impacts of the MGARCH model[a]

	Pre-Ethanol Boom (1989-1999)			Ethanol Boom (2000-2007)		
ARCH Effects						
	Shock		Response	Shock		Response
	$\varepsilon_{o,t}$	→	$h_{g,t+1}$	$\varepsilon_{o,t}$	→	$h_{g,t+1}$
				$\varepsilon_{g,t}$	→	$h_{o,t+1}$
				$\varepsilon_{s,t}$	→	$h_{e,t+1}$, $h_{g,t+1}$
				$\varepsilon_{c,t}$	→	$h_{s,t+1}$
GARCH Effects						
	Volatility		Influence	Volatility		Influence
	$h_{o,t}$	→	$h_{g,t+1}$	$h_{o,t}$	→	$h_{g,t+1}$
	$h_{g,t}$	→	$h_{o,t+1}$	$h_{g,t}$	→	$h_{o,t+1}$
	$h_{s,t}$	→	$h_{c,t+1}$	$h_{s,t}$	→	$h_{c,t+1}$, $h_{e,t+1}$
	$h_{c,t}$	→	$h_{s,t+1}$	$h_{c,t}$	→	$h_{s,t+1}$, $h_{o,t+1}$

[a] Shocks from a price are ε_o, ε_g, ε_s, and ε_c for oil, gasoline, soybean, and corn price shocks, respectively. Price volatilities h_g, h_o, h_e, h_s, and h_c are associated with gasoline, oil, ethanol, soybeans, and corn, respectively.

In contrast to popular beliefs, no links with ethanol volatilities influencing corn and soybean price volatilities are established with instead, during the ethanol boom period, a shock in soybean prices (ARCH effects) and soybean price volatility (GARCH effects) both impacting ethanol price volatility. A shock in soybean prices also impacts gasoline volatility, and corn price volatility impacts oil price volatility.

These impacts of agricultural commodity price volatility on energy price volatility may indicate some other underlying effect not considered in the models. Specifically, the general increase in world living standards may be impacting the price volatilities of both agricultural and energy commodity prices. Particularly in Asia, enhanced incomes are leading to increased demand for meat and dairy products, along with subsequent demand for their food inputs (corn and soybeans) and energy inputs (oil, gasoline, and ethanol).

The VECM and MGARCH results indicate that popular beliefs may be confusing the link of shocks in the fuel market (oil, gasoline, and ethanol) influencing short-run corn prices, and volatility in the agricultural commodity markets impacting fuel price volatilities as a persistent long-run ethanol influence on agricultural commodity prices. In the ethanol boom period, no long-run relationship is revealed between agricultural commodity prices and fuel prices. Any short-run relations are not persistent, with agricultural prices returning to their historic long-run trend. A positive fuel-price shock may increase agricultural commodity prices, but the lack of commodity price persistence to such a shock results in commodity prices relatively rapidly mean reverting. The flexibility of agricultural acreage and yield enhancement abilities mitigates any price shocks. The price of corn and soybeans reflects this flexibility by integrating the current as well as expected future values of yields, consumption, and inventories.

4.6. Conclusions

Results obtained in this study are consistent with economic theory. In terms of derived demand theory, our results support the notion of 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 fuel versus food security issue, results support the effect of agricultural commodity prices as market signals which restore commodity markets to their equilibriums after a demand or supply event (shock). As the results indicate, such shocks may, in the short-run, increase agricultural commodity prices, but decentralized freely operating markets will mitigate the persistence of these shocks. Results indicate in recent years there are no long-run relations among fuel (ethanol, oil and gasoline) prices and agricultural commodity (corn and soybean) prices. As specifically addressed, the recent upward direction of agricultural commodity 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 prices toward their equilibrium levels.

As the share of ethanol in our vehicle fuel mix increases, concern arises with ethanol's impacts on agricultural commodity prices. The initial analysis on ethanol's effects on corn and soybean prices indicates that while ethanol does not appear to influence the long-run equilibrium level of corn and soybean prices, fuel prices in general may potentially cause transitory short-run agricultural commodity price inflation. Such inflation may have an effect on U.S. economic growth, but the major impact is on the poor in developing countries. Consideration may then be directed toward shifting U.S. agricultural policy for mitigating such commodity-price inflation with commodity buffers for supplementing supplies in years of insufficient harvests. Such commodity buffers could blunt food price spikes caused not only by possible biofuel shocks but also by shocks associated with weather, conflicts, and terrorism.

Table A4.1. Pre-Ethanol boom, 1989-1999 VECM results

	$p_{g,t}$ (Gasoline)	$p_{o,t}$ (Oil)	$p_{e,t}$ (Ethanol)	$p_{c,t}$ (Corn)	$p_{s,t}$ (Soybean)
Error Correction Term					
α_1	-0.082*(0.030)	0.093*(0.023)	0.006 (0.009)	-0.018 (0.016)	-0.001 (0.017)
α_2	-0.106*(0.029)	-0.035(0.022)	-0.039*(0.009)	-0.014(0.016)	0.018 (0.013)
Gasoline Lags					
$p_{g,t-1}$	-0.041 (0.054)	-0.010 (0.040)	0.010 (0.016)	0.050***(0.028)	0.009 (0.023)
$p_{g,t-2}$	0.037 (0.052)	0.012 (0.041)	0.030***(0.016)	-0.006 (0.030)	0.023 (0.024)
$p_{g,t-3}$	0.006 (0.049)	0.004 (0.037)	0.027***(0.016)	0.031 (0.027)	0.040 (0.023)
$p_{g,t-4}$	-0.010 (0.049)	-0.129* (0.038)	-0.014 (0.015)	-0.033 (0.027)	-0.017 (0.022)
Oil Lags					
$p_{o,t-1}$	0.055 (0.066)	0.077 (0.050)	0.013 (0.020)	-0.073**(0.035)	-0.003 (0.027)
$p_{o,t-2}$	0.025 (0.066)	-0.027 (0.049)	0.021 (0.020)	-0.028 (0.035)	-0.001 (0.333)
$p_{o,t-3}$	0.069 (0.064)	0.018 (0.049)	0.006 (0.018)	-0.053 (0.034)	-0.007 (0.030)
$p_{o,t-4}$	0.048 (0.063)	0.221* 0.048)	0.017 (0.019)	0.015 (0.035)	0.006 (0.028)
Ethanol Lags					
$p_{e,t-1}$	-0.116 (0.144)	-0.155 (0.109)	0.229*(0.044)	-0.085 (0.076)	-0.086 (0.063)
$p_{e,t-2}$	0.168 (0.147)	0.025 (0.112)	0.075***(0.045)	0.174**(0.078)	0.071 (0.065)
$p_{e,t-3}$	0.019 (0.147)	0.150 (0.110)	0.114**(0.044)	0.026 (0.078)	-0.010 (0.066)
$p_{e,t-4}$	-0.156 (0.139)	-0.306*(0.105)	-0.115*(0.042)	-0.007 (0.074)	-0.011 (0.064)
Corn Lags					
$p_{c,t-1}$	-0.157***(0.084)	-0.131**(0.064)	-0.026 (0.026)	-0.005 (0.045)	0.285*(0.037)
$p_{c,t-2}$	0.027 (0.091)	-0.152**(0.068)	-0.024 (0.027)	0.120**(0.048)	0.115*(0.039)
$p_{c,t-3}$	0.044 (0.091)	-0.028 (0.068)	0.008 (0.028)	0.101**(0.048)	0.065 (0.040)
$p_{c,t-4}$	-0.122 (0.090)	-0.082 (0.068)	-0.032 (0.027)	0.129*(0.048)	0.050 (0.040)
Soybean Lags					
$p_{s,t-1}$	-0.039 (0.101)	0.070 (0.076)	-0.027 (0.031)	-0.052 (0.053)	-0.112**(0.044)
$p_{s,t-2}$	-0.069 (0.101)	-0.030 (0.075)	0.057***(0.031)	-0.062 (0.054)	-0.049 (0.045)
$p_{s,t-3}$	-0.072 (0.100)	0.048 (0.076)	-0.031 (0.030)	-0.055 (0.053)	-0.005 (0.041)
$p_{s,t-4}$	-0.175***(0.095)	-0.070 (0.071)	0.019 (0.029)	-0.108**(0.050)	0.001 (0.040)

Note: Standard errors are in parentheses and *, **, and *** denote significance at the 1%, 5% and 10% level, respectively. Prices of ethanol, corn, soybean, gasoline, and oil, in terms of percentage change, are p_e, p_c, p_s, p_g, and p_o, respectively.

Table A4.2. Ethanol boom, 2000-2007 VECM results

	$p_{g,t}$ (Gasoline)	$p_{o,t}$ (Oil)	$p_{e,t}$ (Ethanol)	$p_{c,t}$ (Corn)	$p_{s,t}$ (Soybean)
Error Correction Term					
α	-0.144*(0.040)	0.013 (0.024)	0.039**(0.018)	-0.045***(0.023)	0.012 (0.018)
Gasoline Lags					
$p_{g,t-1}$	0.094 (0.065)	0.109*(0.039)	0.079*(0.030)	0.052 (0.038)	-0.042(0.029)
$p_{g,t-2}$	0.117***(0.065)	0.092**(0.040)	-0.025 (0.030)	-0.020 (0.039)	-0.028 (0.029)
$p_{g,t-3}$	0.105 (0.065)	0.062 (0.040)	0.027 (0.029)	0.035 (0.038)	-0.019 (0.029)
$p_{g,t-4}$	0.058 (0.063)	-0.004 (0.040)	-0.015 (0.029)	-0.025 (0.038)	-0.060**(0.028)
Oil Lags					
$p_{o,t-1}$	0.045 (0.102)	0.072 (0.062)	0.017 (0.047)	-0.075 (0.059)	0.014 (0.047)
$p_{o,t-2}$	-0.129 (0.101)	-0.206*(0.061)	0.061 (0.046)	-0.056 (0.059)	-0.002 (0.043)
$p_{o,t-3}$	0.026 (0.099)	0.035 (0.060)	-0.025 (0.046)	0.053 (0.058)	0.061 (0.045)
$p_{o,t-4}$	-0.088 (0.096)	-0.071 (0.058)	0.101**(0.044)	0.031 (0.056)	0.029 (0.042)
Ethanol Lags					
$p_{e,t-1}$	-0.190***(0.108)	-0.033 (0.066)	0.356*(0.050)	0.035 (0.063)	-0.126*(0.048)
$p_{e,t-2}$	0.012 (0.118)	-0.108 (0.071)	0.158*(0.054)	-0.054 (0.069)	0.116**(0.052)
$p_{e,t-3}$	0.124 (0.118)	0.120***(0.072)	0.042 (0.054)	0.058 (0.069)	0.033 (0.052)
$p_{e,t-4}$	-0.011 (0.106)	-0.009 (0.064)	-0.053 (0.049)	-0.145**(0.063)	-0.052 (0.048)
Corn Lags					
$p_{c,t-1}$	-0.121 (0.091)	-0.005 (0.058)	0.013 (0.042)	-0.102***(0.053)	0.075***(0.041)
$p_{c,t-2}$	0.044 (0.091)	0.002 (0.048)	0.077**(0.042)	-0.083 (0.054)	0.002 (0.047)
$p_{c,t-3}$	0.116 (0.091)	0.023 (0.056)	0.053 (0.042)	0.010 (0.053)	0.153*(0.040)
$p_{c,t-4}$	-0.099 (0.090)	-0.049 (0.055)	0.027 (0.041)	0.089***(0.052)	0.119*(0.040)
Soybean Lags					
$p_{s,t-1}$	-0.073 (0.118)	-0.078 (0.072)	-0.063 (0.054)	0.062 (0.069)	0.239*(0.053)
$p_{s,t-2}$	-0.118 (0.122)	-0.112 (0.074)	0.008 (0.058)	0.022 (0.072)	0.013 (0.056)
$p_{s,t-3}$	0.006 (0.128)	0.060 (0.073)	0.032 (0.056)	-0.013 (0.070)	-0.074 (0.054)
$p_{s,t-4}$	0.181 (0.115)	0.103 (0.069)	0.058 (0.053)	0.082 (0.067)	-0.070 (0.051)

Note: Standard errors are in parentheses and *, **, and *** denote significance at the 1%, 5% and 10% level, respectively. Prices of ethanol, corn, soybean, gasoline, and oil, in terms of percentage change, are p_e, p_c, p_s, p_g, and p_o, respectively.

Table A4.3. Granger causality test statistics for the pre-ethanol boom 1989–1999

Direction of Causality[a]	Short-run (χ^2 statistics)	Long-run[b] (t-statistics)	Market Shock[c] (t-statistics)
Ethanol and Corn Prices			
$p_e \rightarrow p_c$	6.43	-0.897	
$p_c \rightarrow p_e$	3.24	-4.532*	
Ethanol and Gasoline Prices			
$p_e \rightarrow p_g$	3.32		-3.697*
$p_g \rightarrow p_e$	8.21***		0.687
Ethanol and Oil Prices			
$p_e \rightarrow p_o$	12.08**		-1.622
$p_o \rightarrow p_e$	2.54		0.687
Ethanol and Soybean Prices			
$p_e \rightarrow p_s$	2.89		1.425
$p_s \rightarrow p_e$	9.70**		–
Gasoline and Oil Prices			
$p_g \rightarrow p_o$	11.70**	4.089*	
$p_o \rightarrow p_g$	2.10	-2.727*	
Gasoline and Corn Prices			
$p_g \rightarrow p_c$	6.81		-1.096
$p_c \rightarrow p_g$	5.88		-3.697*
Gasoline and Soybean Prices			
$p_g \rightarrow p_s$	4.51		-0.058
$p_s \rightarrow p_g$	3.96		–
Oil and Corn Prices			
$p_o \rightarrow p_c$	6.54		-1.096
$p_c \rightarrow p_o$	9.39***		-1.622
Oil and Soybean Prices			
$p_o \rightarrow p_s$	0.09		-0.058
$p_s \rightarrow p_o$	2.23		–
Corn and Soybean Prices			
$p_c \rightarrow p_s$	64.85*		0.018
$p_s \rightarrow p_c$	7.27		–

Note: *, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively.
[a] The arrow, →, indicates the direction of Granger causality. Prices of ethanol, corn, soybean, gasoline, and oil, in terms of percentage change, are p_e, p_c, p_s, p_g, and p_o, respectively.
[b] Long-run causal effect is associated with cointegrated prices. Two long-run relations (cointegrates): 1. Relationship between petroleum gasoline and oil prices and 2. Relationship between ethanol and corn prices.
[c] Market shock causal effects is associated with non-cointegarted prices.

Table A4.4. Granger causality test statistics for the ethanol boom 2000–2007

Direction of Causality[a]	Short-run (χ^2 statistics)	Long-run[b] (t-statistics)	Market Shock[c] (t-statistics)
Ethanol and Corn Prices			
$p_e \rightarrow p_c$	6.70		-1.939***
$p_c \rightarrow p_e$	4.29		–
Ethanol and Gasoline Prices			
$p_e \rightarrow p_g$	3.84	-3.629*	
$p_g \rightarrow p_e$	10.02**	2.168*	
Ethanol and Oil Prices			
$p_e \rightarrow p_o$	4.25	0.547	
$p_o \rightarrow p_e$	6.21	2.168**	
Ethanol and Soybean Prices			
$p_e \rightarrow p_s$	9.67**		0.664
$p_s \rightarrow p_e$	3.54		–
Gasoline and Oil Prices			
$p_g \rightarrow p_o$	11.72**	0.547	
$p_o \rightarrow p_g$	2.98	-3.629*	
Gasoline and Corn Prices			
$p_g \rightarrow p_c$	4.69		-1.939***
$p_c \rightarrow p_g$	4.86		–
Gasoline and Soybean Prices			
$p_g \rightarrow p_s$	5.85		0.664
$p_s \rightarrow p_g$	4.20		–
Oil and Corn Prices			
$p_o \rightarrow p_c$	4.16		-1.939***
$p_c \rightarrow p_o$	0.93		–
Oil and Soybean Prices			
$p_o \rightarrow p_s$	2.29		0.664
$p_s \rightarrow p_o$	6.90		–
Corn and Soybean Prices			
$p_c \rightarrow p_s$	21.55*		–
$p_s \rightarrow p_c$	2.05		–

Note: *, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively.
[a] The arrow, →, indicates the direction of Granger causality. Prices of ethanol, corn, soybean, gasoline, and oil, in terms of percentage change, are p_e, p_c, p_s, p_g, and p_o, respectively.
[b] Long-run causal effect is associated with cointegrated prices. One long-run relations (cointegrates): Relationship among gasoline, oil, and ethanol prices
[c] Market shock causal effects is associated with non-cointegarted prices.

Table A4.5. MGARCH(1,1) results for the pre-ethanol boom 1989-1999

	$h_{11,t+1}$ (gasoline)	$h_{22,t+1}$ (oil)	$h_{33,t+1}$ (ethanol)	$h_{44,t+1}$ (corn)	$h_{55,t+1}$ (soybean)
Constant					
	0.000 (0.000)	0.000*(0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
ARCH terms					
$\varepsilon_{1,t}^2$	0.059*(0.018)	0.008 (0.005)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
$\varepsilon_{2,t}^2$	0.082*(0.030)	0.001 (0.004)	0.000 (0.000)	0.000 (0.001)	0.000 (0.000)
$\varepsilon_{3,t}^2$	0.000 (0.002)	0.003 (0.009)	0.181*(0.047)	0.000 (0.001)	0.000 (0.002)
$\varepsilon_{4,t}^2$	0.003 (0.006)	0.006 (0.007)	0.000 (0.001)	0.106*(0.023)	0.005 (0.005)
$\varepsilon_{5,t}^2$	0.003 (0.007)	0.003 (0.005)	0.001 (0.001)	0.019 (0.017)	0.063* (0.022)
$\varepsilon_{1,t}\varepsilon_{2,t}$	-0.139*(0.033)	0.006 (0.011)	0.000 (0.000)	0.000 (0.001)	0.000 (0.001)
$\varepsilon_{1,t}\varepsilon_{3,t}$	-0.003 (0.060)	0.010 (0.015)	-0.001 (0.013)	0.000 (0.001)	0.000 (0.001)
$\varepsilon_{1,t}\varepsilon_{4,t}$	0.025**(0.013)	-0.014 (0.009)	0.000 (0.001)	0.004 (0.013)	-0.002 (0.003)
$\varepsilon_{1,t}\varepsilon_{5,t}$	-0.027 (0.035)	0.009 (0.009)	0.000 (0.001)	-0.002 (0.006)	-0.005 (0.010)
$\varepsilon_{2,t}\varepsilon_{3,t}$	0.004 (0.070)	0.004 (0.013)	0.028***(0.016)	0.000 (0.003)	0.000 (0.001)
$\varepsilon_{2,t}\varepsilon_{4,t}$	-0.030 (0.033)	-0.005 (0.010)	0.000 (0.001)	0.013 (0.023)	0.000 (0.004)
$\varepsilon_{2,t}\varepsilon_{5,t}$	0.031 (0.041)	0.003 (0.007)	0.000 (0.001)	-0.006 (0.010)	-0.001 (0.014)
$\varepsilon_{3,t}\varepsilon_{4,t}$	-0.001 (0.013)	-0.009 (0.014)	-0.015 (0.017)	0.003 (0.043)	-0.002 (0.008)
$\varepsilon_{3,t}\varepsilon_{5,t}$	0.001 (0.013)	0.006 (0.010)	0.023 (0.023)	-0.001 (0.018)	-0.007 (0.028)
$\varepsilon_{4,t}\varepsilon_{5,t}$	-0.006 (0.009)	-0.008 (0.009)	-0.001 (0.001)	-0.089**(0.042)	0.037***(0.019)
GARCH terms					
$h_{11,t}$	0.548*(0.025)	0.066*(0.008)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
$h_{22,t}$	0.202*(0.022)	1.242*(0.035)	0.000 (0.000)	0.000 (0.000)	0.001 (0.001)
$h_{33,t}$	0.001 (0.006)	0.008(0.011)	0.722*(0.058)	0.000 (0.000)	0.000 (0.000)
$h_{44,t}$	0.000 (0.002)	0.014(0.012)	0.000 (0.000)	0.677*(0.034)	0.048*(0.013)
$h_{55,t}$	0.001 (0.005)	0.021(0.014)	0.000 (0.001)	0.105*(0.025)	0.793*(0.071)
$h_{12,t}$	0.666*(0.039)	-0.571*(0.035)	0.000 (0.000)	0.000 (0.000)	0.000 (0.001)
$h_{13,t}$	0.047 (0.134)	-0.045 (0.033)	-0.021 (0.016)	0.000 (0.001)	0.000 (0.000)
$h_{14,t}$	0.025 (0.094)	-0.061**(0.027)	0.000 (0.000)	0.015 (0.028)	-0.001 (0.008)
$h_{15,t}$	-0.050 (0.116)	0.074*(0.026)	-0.001 (0.001)	0.006 (0.011)	0.003 (0.033)
$h_{23,t}$	0.029 (0.082)	0.194 (0.142)	0.028 (0.020)	0.000 (0.000)	0.000 (0.002)
$h_{24,t}$	0.015 (0.057)	0.264**(0.116)	0.000 (0.001)	-0.005 (0.040)	-0.012 (0.011)
$h_{25,t}$	-0.031 (0.070)	-0.322*(0.111)	0.001 (0.001)	-0.002 (0.016)	0.050 (0.044)
$h_{34,t}$	0.001 (0.005)	0.021 (0.018)	-0.009 (0.031)	-0.002 (0.086)	-0.002 (0.016)
$h_{35,t}$	-0.002 (0.008)	-0.025 (0.020)	0.035 (0.052)	-0.001 (0.034)	0.009 (0.066)
$h_{45,t}$	-0.001 (0.005)	-0.034 (0.019)	0.000 (0.001)	0.532*(0.065)	-0.392*(0.054)

Note: Standard errors are in parenthesis and *, **, and *** denote significant at 1%, 5%, and 10% level, respectively. h_{11}, h_{22}, h_{33}, h_{44}, and h_{55} denote volatilities of gasoline, oil, ethanol, corn, and soybean, respectively, and ε_1, ε_2, ε_3, ε_4, and ε_5 denote shocks in percentage change prices of gasoline, oil, ethanol, corn, and soybean, respectively.

Table A4.6. MGARCH(1,1) results for the ethanol boom 2000-2007

	$h_{11,t+1}$ (gasoline)	$h_{22,t+1}$ (oil)	$h_{33,t+1}$ (ethanol)	$h_{44,t+1}$ (corn)	$h_{55,t+1}$ (soybean)
Constant					
	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
ARCH terms					
$\epsilon_{1,t}^2$	0.076*(0.027)	0.013**(0.006)	0.004 (0.004)	0.000 (0.001)	0.002 (0.002)
$\epsilon_{2,t}^2$	0.107**(0.049)	0.001 (0.003)	0.001 (0.002)	0.014 (0.012)	0.003 (0.004)
$\epsilon_{3,t}^2$	0.009 (0.016)	0.003 (0.005)	0.221*(0.062)	0.009 (0.012)	0.000 (0.002)
$\epsilon_{4,t}^2$	0.001 (0.003)	0.001 (0.002)	0.006 (0.006)	0.068*(0.024)	0.023***(0.012)
$\epsilon_{5,t}^2$	0.051*(0.017)	0.009 (0.010)	0.036***(0.020)	0.003 (0.007)	0.115*(0.031)
$\epsilon_{1,t}\epsilon_{2,t}$	-0.180*(0.052)	-0.008 (0.010)	0.004 (0.006)	-0.004 (0.007)	-0.005 (0.004)
$\epsilon_{1,t}\epsilon_{3,t}$	-0.053 (0.046)	-0.012 (0.011)	-0.063**(0.026)	0.003 (0.006)	0.002 (0.005)
$\epsilon_{1,t}\epsilon_{4,t}$	0.014 (0.013)	0.007 (0.010)	-0.011***(0.006)	-0.009 (0.015)	-0.014***(0.008)
$\epsilon_{1,t}\epsilon_{5,t}$	-0.124**(0.053)	-0.022***(0.013)	0.025 (0.012)	-0.002 (0.004)	0.032**(0.016)
$\epsilon_{2,t}\epsilon_{3,t}$	0.063 (0.055)	0.004 (0.008)	0.034 (0.043)	-0.022 (0.018)	-0.002 (0.006)
$\epsilon_{2,t}\epsilon_{4,t}$	-0.017 (0.042)	-0.002 (0.004)	-0.004 (0.007)	0.062**(0.029)	0.017 (0.012)
$\epsilon_{2,t}\epsilon_{5,t}$	0.147**(0.066)	0.007 (0.009)	0.010 (0.017)	0.014 (0.016)	-0.038 (0.025)
$\epsilon_{3,t}\epsilon_{4,t}$	-0.005 (0.013)	-0.003 (0.005)	0.075**(0.034)	-0.049 (0.034)	-0.005 (0.016)
$\epsilon_{3,t}\epsilon_{5,t}$	0.043 (0.041)	0.010 (0.011)	-0.179*(0.056)	-0.011 (0.014)	0.011 (0.036)
$\epsilon_{4,t}\epsilon_{5,t}$	-0.012 (0.029)	-0.006 (0.008)	-0.030***(0.016)	0.030 (0.033)	-0.103*(0.030)
GARCH terms					
$h_{11,t}$	0.347*(0.029)	0.562*(0.044)	0.000 (0.002)	0.013 (0.009)	0.000 (0.000)
$h_{22,t}$	0.534*(0.066)	0.382*(0.040)	0.006 (0.012)	0.038 (0.032)	0.008 (0.013)
$h_{33,t}$	0.000 (0.002)	0.005 (0.012)	0.535*(0.087)	0.016 (0.013)	0.000 (0.000)
$h_{44,t}$	0.001 (0.003)	0.014*(0.005)	0.000 (0.001)	0.875*(0.066)	0.097*(0.019)
$h_{55,t}$	0.095 (0.060)	0.001 (0.008)	0.083**(0.032)	0.188*(0.057)	0.387*(0.077)
$h_{12,t}$	0.861*(0.065)	-0.927*(0.060)	-0.003 (0.007)	-0.044***(0.023)	-0.001 (0.006)
$h_{13,t}$	-0.012 (0.091)	-0.105 (0.130)	0.032 (0.056)	-0.028***(0.015)	0.000 (0.001)
$h_{14,t}$	0.031 (0.070)	0.177*(0.032)	-0.001 (0.002)	-0.210*(0.072)	0.003 (0.021)
$h_{15,t}$	0.363*(0.116)	0.055 (0.169)	0.013 (0.022)	0.097*(0.036)	0.006 (0.042)
$h_{23,t}$	-0.015 (0.113)	0.087 (0.107)	-0.109 (0.118)	0.049***(0.029)	-0.001 (0.009)
$h_{24,t}$	0.038 (0.088)	-0.146*(0.027)	0.003 (0.006)	0.363**(0.153)	-0.057 (0.044)
$h_{25,t}$	0.451*(0.145)	-0.045 (0.140)	-0.043 (0.047)	-0.169**(0.075)	-0.114 (0.088)
$h_{34,t}$	-0.001 (0.004)	-0.017 (0.021)	-0.025 (0.057)	0.236**(0.100)	0.002 (0.031)
$h_{35,t}$	-0.006 (0.048)	-0.005 (0.017)	0.422*(0.088)	-0.110**(0.049)	0.004 (0.062)
$h_{45,t}$	0.016 (0.037)	0.009 (0.027)	-0.010 (0.023)	-0.811**(0.127)	0.386*(0.055)

Note: Standard errors are in parenthesis and *, **, and *** denote significant at 1%, 5%, and 10% level, respectively. h_{11}, h_{22}, h_{33}, h_{44}, and h_{55} denote volatilities of gasoline, oil, ethanol, corn, and soybean, respectively, and ϵ_1, ϵ_2, ϵ_3, ϵ_4, and ϵ_5 denote shocks in percentage change prices of gasoline, oil, ethanol, corn, and soybean, respectively.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1. Summary and Conclusions

This study investigates three related issues on building empirical time series models for the U.S. ethanol market. The primary objectives involve investigating the competitive structure of the U.S. ethanol fuel market, evaluating current U.S. transportation fuel policies, and addressing the food versus fuel security debate.

U.S. ethanol producers have enjoyed subsidies and protective tariffs on imports ever since the Energy Tax Act of 1978 exempted 10% ethanol/gasoline blend from the federal excise tax. Despite these subsidies and tariffs, until early 2000, the U.S. ethanol fuel industry was unable to expand from the corn-producing Midwest regional market. Ethanol ran into competition with the oil industry's own additive, MTBE. Only after MTBE was found to contaminate groundwater, leading many states banning MTBE and suddenly creating a two-billion-gallon market for ethanol, did the demand for ethanol expand nationally.

Limit pricing on the part of MTBE refiners is one hypothesis that may explain this lack of ethanol entry into the fuel-additive market. As a test of this hypothesis, a six-variable SVAR model of supply and demand is developed. The results support the hypothesis of limit-pricing behavior on the part of MTBE refiners, i.e., the price of MTBE exhibits matching responses to any shocks in the price of ethanol, and suggest the U.S. corn-based ethanol industry is vulnerable to limit-price competition, which could reoccur. The dependence of the corn-based ethanol price on supply determinants limits U.S. ethanol refiners' ability to price compete with sugar-cane-based ethanol refiners. Without federal support, U.S. ethanol refiners may find it difficult to compete with cheaper sugar cane-based ethanol, chiefly from Brazil.

Since the turn of the 21st century, the volatility in gasoline prices causing price "spikes" has become increasingly common. 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. 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. Since 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 portfolio composed of U.S. and Brazilian ethanol along with petroleum fuel is constructed.

Employing MGARCH model to solve the constant variance covariance problem by allowing the volatility to vary with time, the efficient fuel portfolio frontier is estimated. Policy analysis is then investigated by deriving the set of efficient portfolios when considering the tariff in conjunction with the federal ethanol subsidy as well as time-varying volatility. Results indicate that the current U.S. vehicle-fuel policies yield an efficient portfolio of alternative fuels on the efficiency frontier. However, these policies are generally minimizing the expected gasoline prices, but at the expense of high fuel-price volatility. Results led to the discovery that shifting policies toward encouraging the use of more ethanol, fuel-price volatility can be reduced with an associated overall higher gasoline price. When accounting for vehicle-fuel external costs (local air quality, congestion, and accidents), this higher gasoline price may be socially desirable.

Higher gasoline prices reduce driving which improves air quality and reduces congestion and accidents. This win-win result of reducing both price volatility and environmental effects, by encouraging the increased use of biofuels, can yield major benefits in our drive toward stable and sustainable fuels.

However, food versus fuel security has recently emerged as another potential major external cost of biofuels. In 2007, the prices of corn and soybeans, the nation's two top crops in total acres, doubled. The popular press attributes much of this run-up in commodity prices to the swelling demand for ethanol fuel. However, to date, there have been limited attempts to use economic tools and models to examine the impact of the ethanol fuel price on commodity prices.

Employing cointegration analysis, VECM, and MGARCH models, long-run equilibrium and short-run dynamic relations between U.S. energy (oil, gasoline, and ethanol) prices and U.S. agricultural commodity (corn and soybean) prices, as well as price volatility relations among these markets, are investigated. By understanding the pricing relations, light is shed on the current food versus fuel debate centering around the dynamics of ethanol, corn, and soybean prices. Results support economic theory of agricultural commodity prices as market signals which restore commodity markets to their equilibria after a demand or supply event (shock). A positive energy-price shock may increase agricultural commodity prices, but the lack of commodity price persistence to such a shock results in commodity prices relatively rapidly mean reverting. The flexibility of agricultural acreage and yield enhancement abilities mitigates any price shocks. The prices of corn and soybean reflect this flexibility by integrating the current as well as expected future values of yields, consumption, and inventories. In terms of price volatility, results indicate that agricultural commodity price volatility impacts energy price volatility. Specifically, a shock in soybean prices and soybean-price volatility both impact ethanol-price volatility, a shock in soybean prices also impacts gasoline-price volatility, and corn-price volatility impacts oil-price volatility.

In summary, this study makes two primary contributions to the energy economics literature. First, the study contributes to the current literatures on energy economics with three empirical investigations on the U.S. ethanol fuel market which will help us understand how to develop sustainable and renewable fuels in the future. The study reveals that diversifying the U.S. fuel supply with ethanol can reduce fuel price volatility which provides a new explanation of benefits of fuel ethanol. Most of the research and attention on ethanol is aimed at its potential to replace gasoline which is difficult to achieve given the higher production cost of ethanol at current technology. Our results address another critical question: does adding ethanol to the U.S. fuel supply reduce exposure to gasoline fuel price shocks? Second, the study extends the multiple time series methods to the application of energy economics. Through these methods, dynamic interrelationships between a number of variables are investigated not only in their first moments but also in their second moments, avoiding the identification problem of simultaneous-equations models. For example, initial cointegrating analysis of ethanol, corn and soybeans prices lead to a new analysis direction to addressing the food versus fuel issue. Recently, several papers (Ferris and Joshi, 2004, von Lampe, 2006, Tokgoz and Elobeid, 2006, Elobeid and Hart, 2007; Tokgoz et al., 2007; Elobeid et al., 2007) employ a large modeling system of supply and demand for different sectors to analyze the effects of ethanol expansion in the agricultural and food sectors. The disadvantage of their methods is that most of parameters can only be surveyed from the literature, or obtained from consensus of expert opinions which are imprecise. However, the cointegration and VECM model can avoid this disadvantage by letting the data reveal the dynamic relations among these variables.

5.2. Policy Implications

Based on the results of the analysis from these three papers, consideration should be given to governmental policies that promote an increasing share of ethanol in our vehicle-fuel portfolio and also providing a buffer in the form of agricultural commodity surpluses. Such policies would take the form of providing incentives for the adoption of alternative flex-fuel vehicles and supply of blended ethanol fuels. 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. 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, and the U.S. corn-based ethanol refiners will find it difficult to compete with lower priced sugar-cane-refined ethanol, chiefly from Brazil.

As the share of ethanol on our vehicle fuel mix increases, concern arises with ethanol's impacts on agricultural commodity prices. The initial analysis on ethanol's effects on corn and soybean prices indicates that while ethanol does not appear to influence the long-run equilibrium level of corn and soybean prices, fuel prices in general may potentially cause transitory short-run agricultural commodity price inflation. Such inflation may benefit farmers as producers of energy crops and reduce government payments for agricultural programs, but the major impact is on the poor in developing countries. The poor, usually net food buyers, are adversely affected by government mandates for higher ethanol use since higher food prices reduce their purchasing power for other goods and services. Consideration may then be directed toward shifting U.S. agricultural policy for mitigating such commodity price inflation with commodity buffers for supplementing supplies in years of insufficient harvests. Such commodity buffers could blunt food price spikes caused not only by possible biofuel shocks but also shocks associated with weather, conflicts, and terrorism.

5.3. Suggestions for Future Research

Possible extensions to this study can be made in several directions. First, future research is warranted in extending the U.S. data to the world level data. Since U.S. corn accounts for about 40% of global production and roughly 70% of world trade, an increase in the demand for U.S. corn used in ethanol production would have an impact not only in domestic markets but also in the global arena. Consideration of the causation among world biofuel and agricultural commodities prices, would shed light on the relationship of biofuels with agricultural commodities, and then address the food versus fuel issue.

Second, the analysis can be extended, in a general equilibrium framework, to 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. It is estimated that if the entire U.S. vehicle fleet is replaced with plug-in hybrids, the nation's oil consumption would decrease by 70%, completely eliminating the demand for imports. In the future, as the internal combustion engine shrinks as a vehicle power source, biofuel gasoline blends may be used to fuel it.

Third, VECM results could be improved by incorporating economic theory. This study used statistical tests to determinate the numbers of long-run relations (cointegration) in the system and then tested Granger causality directions. However, since Granger causality tests and VECM results are based upon the selected numbers of cointegration relations, results can only be drawn from these particular numbers of cointegration relations. If economic theory suggests the numbers of long-run relations, this information can be incorporated into the models, and the analysis would then be more robust. Current economic theory does not provide a satisfying answer for this issue.

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