THE RENEWABLE FUEL STANDARD AND ETHANOL PRICING: A SENSITIVITY ANALYSIS

A Thesis

by

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ABSTRACT

Volatile oil prices and political uncertainty surrounding uninterrupted oil supplies has pressured the U.S. Congress and economists to search for substitutes. In response, the U.S. has enacted policies to directly support the production and use of biofuel. The current Renewable Fuel Standard (RFS) requires 36 billion gallons of renewable fuel use by 2022. A large proportion of the mandate is to consist of corn-based ethanol. Most ethanol is consumed in the U.S. as a 10 percent blend of ethanol and gasoline. In 2014, it is projected oil refineries will hit the blend wall (BW). In short, oil refineries are required to blend more ethanol into gasoline than is allowed by the Environmental Protection Agency (EPA). As a consequence, the EPA will need to either reduce the Renewable Fuel Standard for 2014, or permit additional ethanol blends to be sold.

Overall, the purpose of the study was to analyze the economic impact of changing energy policy on ethanol markets. A structural, supply and demand model was developed. Four equations were estimated, and residuals were simulated to estimate probability distributions for monthly ethanol prices and total demand. Alternative scenarios were developed to estimate how the RFS, the BW, and corn prices affect ethanol markets.

The parameter estimates indicated the major determinants of ethanol demand were the RFS and the BW. The results showed the RFS and the BW positively affected the price of ethanol and demand. The base scenario estimated average ethanol price to be \$1.89/gal. When the RFS was reduced by 10.59 percent, ethanol prices were

estimated to decline \$0.29/gal, compared to the base scenario. Total demand declined 600 million gallons. If the BW was increased to 15 percent, the price of ethanol increased approximately \$1.10/gal from the base scenario. Total demand increased 1.4 billion gallons in response. Ethanol prices were found to be insensitive to corn prices.

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1. INTRODUCTION

1.1 General Overview

The rise in world oil prices and political uncertainty regarding uninterrupted oil supplies has compelled political figures and economists to search for substitutes. In the United States, suggestions have been made for alternative fuel sources, such as solar and hydrogen power, yet these have only been implemented on a small scale and have largely failed to gain widespread acceptance. In response, the U.S. Congress enacted both state and federal policies which aim to directly support and promote the production and use of biofuels for transportation, in particular, corn-based ethanol. Policy measures include tax credits given to blenders who mix ethanol with gasoline, an import tariff to protect domestic producers, research grants to promote the development of new biofuel technology, and perhaps the most prominent, minimum usage requirements to guarantee a market for biofuel which is completely unrelated to its costs. This minimum usage requirement is known as the Renewable Fuel Standard (RFS). As a result, ethanol production and use has grown more than 150 percent since 2006 (EIA 2013a).

Originally, the tax credit and import tariff were the most noteworthy of federal support programs. Since the establishment of the RFS in 2005 and its expansion in 2007, Congress has required biofuel use. It is possible the RFS will play a dominant role in the development and promotion of biofuel use in the future.

The RFS program has had its share of controversy. Supporters of the RFS claim it improves U.S. energy security by reducing reliance on imported oil, and reduces gasoline prices at the pump (EIA 2013a; Pouliot and Babcock 2014). Critics of RFS argue the expanded mandate has driven up livestock feed prices by allocating corn for ethanol production (Elobeid et al. 2007).

1.2 Statement of the Problem

The rapid expansion of U.S. corn ethanol production has motivated questions regarding its long-term sustainability and unintended consequences in other markets. Energy policy in the U.S. can affect corn and ethanol markets in several ways. Because of this, there has been considerable political pressure to negotiate an overhaul of the RFS program from livestock producers and petroleum manufacturers. In 2012, the National Chicken Council petitioned the Environmental Protection Agency (EPA) to waive all or a substantial part of the corn-based ethanol mandate, citing the RFS has harmed major agricultural markets in this U.S. because the RFS has directly affected the supply and cost of feed (Formica 2012). The American Petroleum Institute in August of 2013 also filed a petition to partially waive the 2014 RFS mandate, citing the economic implications of hitting the ethanol blend wall (BW) could significantly increase the cost of fuel and result in fuel supply shortages in the United States (Greco and Moskowitz 2013). In response, the EPA released it proposed standards and volumes for renewable fuels for 2014, which have been substantially reduced from their statutory standards. Overall, the EPA slashes the implied corn ethanol mandate by 10.59 percent to 11.73 billion gallons (EPA 2013b).

The issue with the RFS program is the required mandate for 2014 is likely to cause U.S. gasoline consumption to hit the ethanol BW. Once the average ethanol blend in the U.S. approaches or exceeds 10 percent by volume, the EPA will need to either reduce the RFS for 2014 or permit additional ethanol blends, such as E15 or E20, to be sold. This paper will address the economic impact of policy on ethanol markets by investigating how the RFS influences ethanol demand, as well as the implications of relaxing the BW to allow the sale of higher ethanol blends in gasoline.

1.3 Objective

The primary objective of this paper is to analyze the economic impacts of changes in energy policy on ethanol markets. Monte Carlo simulation will be applied to calculate stochastic monthly ethanol prices and total demand. The results should assist decision-makers in estimating how changes in energy policy affect ethanol markets.

This paper begins with a background on energy policy in the United States, which examines the current state of energy policy, as well as the history of ethanol use in the United States. The BW is discussed, in addition to the characteristics of the Renewable Identification Number system (RIN) that makes implementation of the RFS possible. The literature review emphasizes already completed research related to ethanol pricing and policy analysis. Section 4 explains risk and simulation, presents the economic theory behind the RFS and the BW and will discuss the general framework of the model and explain how it works. Chapter 5 analyzes the regression parameters and presents the results of the simulation.

2. BACKGROUND

2.1 MTBE (*Methyl tertiary butyl ether)*

The Clean Air Act Amendments of 1990 require areas of the U.S. with poor air quality to blend chemical additives called "oxygenates" into gasoline to improve combustion and mitigate tailpipe emissions (EPA 2013a). The amendments created two programs which required the use of oxygenates, but the reformulated gasoline (RFG) program was the more significant of the two. The RFG program required areas with severe ozone pollution problems to use RFG. RFG was required to contain at least 2 percent oxygen by weight and blenders were permitted to use a variety of additives which contained oxygen to meet this requirement (McCarthy and Tiemann 2006).

Methyl tertiary butyl ether (MTBE) was the most widely used oxygenate. Its use grew rapidly in the 1980's in response to a need for an octane enhancer due to the phase-out of lead in gasoline. Unfortunately, its use began to raise environmental concerns when it was detected in drinking water supplies and reservoirs across the country. A report issued in November 1998 by the University of California recommended a gradual phase-out of MTBE from gasoline in California. MTBE was phased-out in favor of ethanol in 2003 (McCarthy and Tiemann 2006). Liability concerns led to a nationwide ban. When compared to other gasoline components, MTBE is more soluble in water, has a lower taste and odor threshold, and often requires more expensive and complicated techniques of environmental remediation (McCarthy and Tiemann 2006). Typically, MTBE is released into ground water through leaky underground storage facilities.

In 2005, petroleum companies announced their intent to remove MTBE from gasoline. The decision was fueled primarily by State bans due to water contamination issues and perceived liability exposure after the oxygenate requirement was eliminated from RFG by the Energy Policy Act of 2005 (Shore 2006).

The elimination of MTBE from gasoline stimulated demand for other oxygenates. Oxygenates that could replace MTBE include other ethers, such as ethyl tertiary butyl ether (ETBE), and alcohols, such as ethanol (McCarthy and Tiemann, 2006). The RFS was instated at the same time the MTBE requirement was removed. In response, blenders switched from MTBE to ethanol. Ethanol is considered to pose less environmental threats compared to MTBE. An article, based on the California ethanol review focused specifically on groundwater contamination risks by various formulations of gasoline (Powers et al. 2001). The authors concluded that there is an increase in risk of groundwater contamination by RFG when using either MTBE or ethanol to oxygenate fuel, but that risk decreases for ethanol after five years. Because ethanol will degrade in the ground over time, it is considered the practical option to meet the oxygenate requirement in gasoline.

2.2 Ethanol

Alternative transportation fuels, particularly corn-based ethanol, is considered by policy-makers as a likely solution to issues surrounding excessive dependence of foreign oil and global warming. Federal energy policy has played a significant part in the development of the U.S. biofuels industry. Energy policies in the U.S. consist of several policy measures for ethanol, (a) including minimum alternative fuel requirements, (b) blending tax credits, (c) an import tariff, (d) loans and (e) research grants. Since the 1980s, domestic ethanol producers have been protected by an import tariff, mainly intended to curb sugarcane imports from Brazil (UNICA 2011). Blenders have also received a tax credit for each gallon of ethanol mixed into gasoline. The import tariff and tax credit expired at the end of 2011.

The RFS is one of the more prominent forms of federal policy support. The RFS mandates each year a minimum volume of biofuels that is to be blended in the national transportation fuel supply. The RFS was first established in 2005 when Congress enacted the Energy Policy Act (GPO 2005). This became known as RFS1. RFS1 required a minimum of 4 billion gallons of renewable fuel in 2006, and that minimum volume was set to rise to 7.5 billion gallons by 2012 (GPO 2005).

The federal government greatly expanded its energy policy when Congress enacted the Energy Independence and Security Act of 2007 (GPO 2007). The primary goal of the Independence and Security Act (EISA) was to improve vehicle fuel economy and reduce U.S. dependency on imported oil. EISA imposed new provisions to expand RFS1 to include diesel, in addition to gasoline. The expanded RFS1 (known as RFS2) applies to most transportation fuels intended for highway vehicles, non-road, locomotive, and marine diesel in the U.S. The expanded RFS increased the volume of renewable fuel required for blending from 9 billion gallons in 2008 to 36 billion gallons by 2022 (GPO 2007).

Table 2.1. EISA 2007 Expansion of the Renewable Fuel Standard

Year	RFS1	RFS2 Total Renewable Fuel	Advanced Biofuel	Cellulosic Biofuel	Biomass-Based Diesel	Ethanol
2006	4.00	0.00	0.00	0.00	0.00	4.00
2007	4.70	0.00	0.00	0.00	0.00	4.70
2008	5.40	9.00	0.00	0.00	0.00	9.00
2009	6.10	10.50	0.60	0.00	0.50	9.40
2010	7.40	12.95	0.95	0.10	0.65	11.35
2011	7.50	13.95	1.35	0.25	0.80	11.80
2012	0.00	15.20	2.00	0.50	1.00	12.20
2013	0.00	16.55	2.75	1.00	0.00	12.52
2014	0.00	18.15	3.75	1.75	0.00	13.12

Notes: The table reports renewable fuel volumes in billions of gallons

The table presents the expanded RFS mandate enacted by EISA. RFS2 established four distinct categories of renewable fuel; total renewable fuels, advanced biofuels from non-corn feedstock, cellulosic biofuel, and biomass-based diesel. The applicable volumes for biomass-based diesel for calendar years beyond 2012 will be determined by the EPA based on review and analysis of the RFS program during the specified years (GPO 2007). There is no specific category for corn-based ethanol, but it can be implied by subtracting out the advanced biofuel and biomass-based diesel categories. The mandate for cellulosic biofuel is assumed to be zero.

Under RFS2, the U.S. government is directly supporting biofuel production by requiring fuel blenders to incorporate minimum volumes of biofuels into their annual fuel sales, regardless of market prices (Schnepf and Yacobucci 2013). In essence, by mandating renewable fuel use through RFS, the U.S. is creating a mandatory market for biofuels by providing an indirect subsidy to reduce risk and encourage the development of biofuel plants.

2.3 Blend Wall

The Energy Policy Act of 2005 made alterations to the requirements of RFG that triggered a nationwide phase-out of MTBE starting in 2006. Since that time, the demand for ethanol as a fuel additive has risen sharply. Under current regulations, gasoline blends containing up to 10 percent ethanol by volume (E10) can be sold for use in all gasoline-powered vehicles. E85, which is a blend containing up to 85 percent ethanol by volume, may also be sold, but is sold in limited quantities and can only be used by specifically designed vehicles.

The total volume of ethanol which can be blended into gasoline is capped at 10 percent. This upper limit is called the BW. Yacobucci (2010) identifies three factors which influence the BW constraint:

- First, the Clean Air Act prohibits the sale of gasoline which contains additives at levels which exceed those approved by the EPA. For ethanol, the limit is 10 percent.
- Second, automakers have not warrantied their vehicles to operate reliably with higher blends and it is unclear whether vehicle owners would be willing to purchase the new blends without explicit approval from the manufacturer.
- Third, existing infrastructure and transportation is designed to deliver E10 blends, and it has not been determined if the existing supply chain can tolerate higher ethanol concentrations.

To address the BW issue, ethanol will either have to be blended in higher concentrations or sold as an alternative fuel for flexible fuel vehicles.

The RFS has ultimately created an untenable situation. If approval is not given to allow the sale of higher ethanol blends in gasoline, the market for E10 will become completely saturated, and ethanol producers will have few avenues for increasing sales. Their first option would be to export the excess ethanol once the BW is reached. The other option is to petition the EPA to raise the allowable limit on ethanol content in gasoline to 15 percent. Increasing the maximum allowable volume of ethanol in gasoline would increase ethanol's market potential by 50 percent.

2.4 Introduction of E15

The EPA has the authority to waive fuel requirements under certain circumstances. Waivers are the first step in making E15 readily available to consumers. Approving the sale of E15 would help boost a stagnating demand for ethanol caused by the current blend limit of 10 percent. In 2009, Growth Energy petitioned the EPA to allow the introduction of E15, a blend of gasoline which contains up to 15 percent ethanol, into commerce (EPA 2011). The following year, the EPA approved the use of E15 in vehicles specifically designed to operate on the higher blend. A positive shift in the BW will likely increase the price of ethanol. The price effect is caused by higher demand for ethanol.

An EPA approval is not the only obstacle in permitting the sale of higher ethanol blends. There is debate whether or not the existing fuel supply infrastructure can actually support higher ethanol blends (Yacobucci 2010). Most existing pipelines, tanks, and gas pumps are designed to handle E10. It is questionable fuel suppliers would be willing to sell the higher ethanol blends if there is a possibility it could damage their existing transportation system. In addition to fuel supply concerns, drivers of older vehicles will need to be convinced their vehicle will not be damaged by the higher blend.

2.5 The RIN System

The Renewable Identification Number (RIN) system was developed by the EPA to ensure compliance of the RFS mandates. A RIN is a 38-character numeric code that corresponds to a batch of ethanol fuel that is imported or produced in the U.S. RINs remain with the volume of renewable fuel throughout the entire distribution system until the ethanol is blended with gasoline. Once the ethanol has been blended, RINs can be used for compliance, traded, or held for future compliance (McPhail et al. 2011).

RINs form the basis of RFS2 compliance. The EPA developed an electronic Moderated Transaction System (EMTS) to facilitate this process by monitoring and reporting RIN transactions compliance (McPhail et al. 2011). To participate in RFS2, a person or corporation must first register with the EPA and create an account via the EPA's Central Data Exchange. After registration, an ethanol producer can electronically submit a new volume of renewable fuel produced or view the number of RINs generated or assigned. This system also facilitates the buying and selling of RINs. A seller can post the sale price of their RIN in the system, and upon acceptance by a buyer, the buyers account will automatically be increased by the number of RINs purchased.

The RIN system is instrumental to the successful implementation of RFS2. Each year, the EPA calculates a percentage standard for renewable fuel to total gasoline consumption. Obligated parties must meet their renewable volume obligation (RVO) by accumulating RINs that represent an amount of renewable fuel used as transportation fuel sold in the United States. The RVO is equal to the RFS for the calendar year *i* (in percentage terms) multiplied by the annual nonrenewable gasoline volume produced or imported by the obligated party in calendar year *i*, plus any renewable fuel deficit from the previous year (McPhail et al. 2011). An obligated party can carry over a deficit, under certain conditions, as long as the deficit is covered in full the following year. Obligated parties can retain RINs in excess of their RVO, which can be held to meet future compliance (subject to a 20 percent roll over gap), or they can be traded.

RINs are sold on spot markets because RINs are bought and sold as commodities. The actual RIN price includes the core value of the RIN, transaction costs, and/or a speculative component. In figure 2.1, the core value of a RIN is the gap between the supply price (P_s) and the demand price (P_d) at any given mandated quantity (Thompson et al. 2009). The supply curve represents the price that allows ethanol producers to cover their cost of production. Similarly, the demand curve corresponds to the price blenders are willing to pay for that volume of ethanol, absent the mandate. If market equilibrium exceeds the mandate, then the core RIN value is zero. RIN prices will be positive if the mandate (represented by the vertical RFS2 line) exceeds market equilibrium. Note that the supply price (the price producers receive) is equal to the demand price (the price blenders are willing to pay with no mandate) plus the core value of the RIN. This calculation ensures all costs are covered, assuming the mandated levels are produced, by bridging the gap between the cost of production and the price blenders are willing to pay for that quantity. In theory, the market for RINs ensures the mandated demand for ethanol will generate high enough ethanol price to allow ethanol producers to their cover cost of compliance. Because RINs represent the per-unit cost of complying with the mandate, high prices suggest a high cost of compliance to meet the mandate.

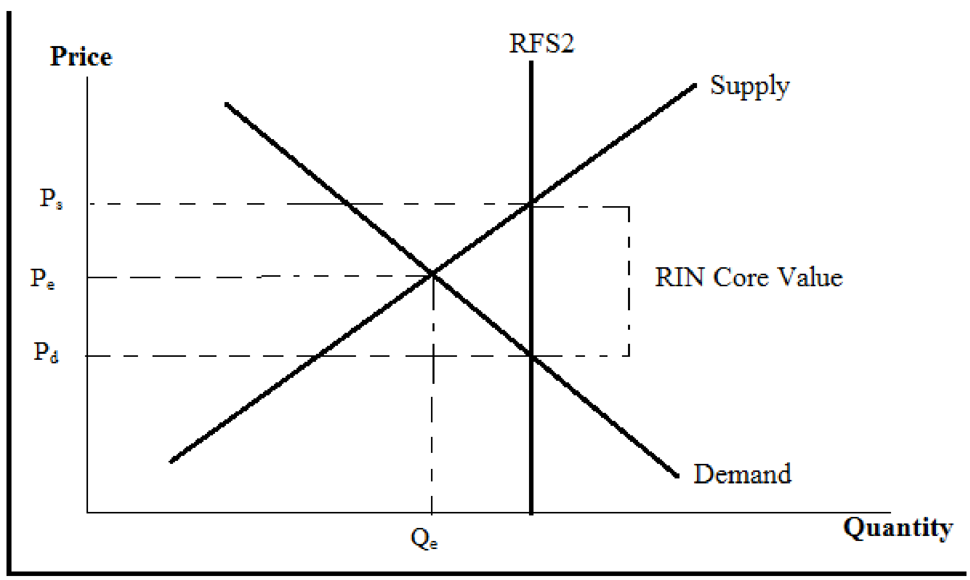
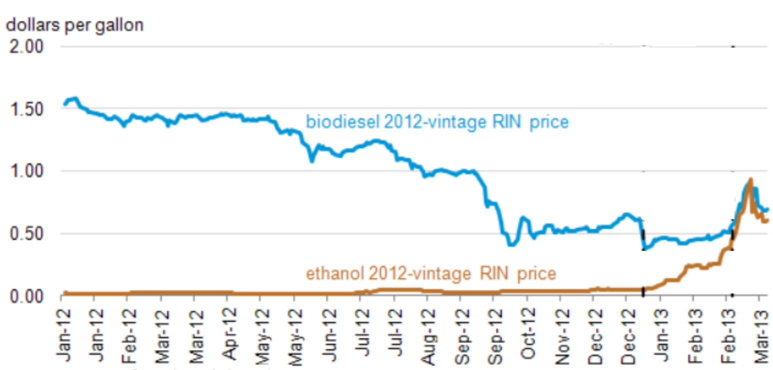


Figure 2.1. RIN Market with a Binding Mandate

Prior to 2013, there has been an excess supply of ethanol RINs (beyond what is needed to meet the overall portion of the RFS) in the market, which has kept prices relatively low, between one and four cents per gallon (see figure 2.2). Low RIN prices signal mandates do not force more consumption than is desired by blenders, which implies a low cost of compliance. During the second half of 2012, RIN prices increased slightly in response to a drought which affected U.S. corn and ethanol production. RIN prices rose drastically beginning in 2013, to over one dollar per gallon. The approaching ethanol BW and has been identified as a potential cause in the surge in RIN prices, primarily because of a limited supply of RINs, combined with surging demand from blenders to buy RINs to comply with the RFS mandate (Tracy 2013). When volumetric blending levels for RFS were set in 2007, policy makers and industry representatives did not expect the level of ethanol demand would exceed the 10 percent limit until much later. But, steadily declining gasoline demand coupled with increased fuel efficiency means the BW will be met much sooner than anticipated (EIA 2013a). If RIN prices remain high, this is a sign ethanol demand has hit the BW and obligated parties are having difficulty meeting their RVOs, which should pressure the EPA to approve higher ethanol blends. While the RIN market is cornerstone in the overall coordination of the biofuel market, it is beyond the scope of this study.



Source: Energy Information Adminstration

Figure 2.2. RIN Prices

3. REVIEW OF LITERATURE

Modeling the economic and environmental effects of biofuel policy has become increasingly complex because of the lack of market information regarding ethanol pricing (Kim et al. 2010). High crude oil prices and dependency on foreign oil supplies have incentivized the need and the development of alternative fuel sources such as ethanol and biodiesel. The incentives to provide a market for biofuels is policy driven, primarily through EISA and the Renewable Fuel Standard. Because policy interacts with the market for biofuels, particularly ethanol, it's important to have a clear understanding of the underlying market for biofuel, as well its policy implications in other markets.

Elobeid and Tokgoz (2008) evaluated the impact of removing the federal tax credit in the United States on price volatility in the U.S. and Brazil using a multi-market international ethanol model. The general structure of their model consists of production, consumption, ending stocks, and net trade equations for the United States, Brazil, and the EU. Demand for ethanol was estimated using the $.51 tax rebate refiners receive when they blend ethanol with gasoline, the required ethanol blend in percentage terms, and RFS. Supply for ethanol in the US is derived as a function of the US price for ethanol, the price of oil, policy variables, and the annual quantity of gasoline supplied. The study finds that the U.S. is effectively protecting their ethanol industry through the use of trade barriers. When the tax credit is removed, the U.S. sees higher ethanol prices and increases in imports of ethanol. With trade liberalization, they find the ethanol market to be less vulnerable to price changes due to supply and demand shocks. The model also estimated elasticities of supply and demand for ethanol. They estimate the elasticity of supply and demand to be .65 and -.43, respectively.

The BW is a major obstacle in the advancement of the ethanol industry. The BW constraint on ethanol production is partially due to existing infrastructure limitations and the availability of flex-fuel vehicles (Wisner 2009). The EPA must approve a waiver to increase the fuel-ethanol blend limit beyond 10 percent. Growth Energy, a biofuel industry advocacy group, submitted a request to allow the ethanol blend limit to be increased to 15 percent, citing enhanced energy security through increased renewable fuel consumption and lower gasoline prices (Growth Energy 2009). A partial waiver to allow fuel-ethanol blends between 10 and 15 percent ethanol by volume to be introduced into commerce was granted in November of 2010 (Jackson 2010). Zhang et.al. (2010) proposed a profit maximization model for ethanol blenders to analyze the possibility of a positive shift in the BW from 10 to 15 percent ethanol. The study found a relaxation of the BW will lead to increased ethanol consumption and less oil consumption. The demand response will likely increase the prices of ethanol and E85, while reducing the price of ethanol blended gasoline. A related biofuel model built by Tyner, Taheripour, and Hurt (2012), addressed the impact of a drought on corn and ethanol markets, and how an EPA waiver to reduce RFS might affect those markets. A drought would affect businesses and consumers who use food and fuel by increasing food prices and gasoline prices, due to higher ethanol prices caused by higher corn prices. But, the magnitude of the change will depend on the decision by the EPA to reduce the RFS. An estimation of the impact an RFS waiver will have on ethanol markets in not given.

Other studies have questioned whether corn ethanol production is economically viable without mandates. Babcock (2013) developed a simulation model for corn and ethanol markets which determined economic viability based on market supply and demand curves for corn-based ethanol. The model estimates the feasibility of the ethanol industry by calculating breakeven ethanol price, corn price, and corn production under variations in harvested acreage, yield, and gasoline price. The model was run under two different scenarios. One scenario utilized a kinked demand curve which portrayed a high willingness to pay for ethanol at volumes below the 10 percent level, and a sharp decline for volumes in excess of 10 percent. The alternative is a demand curve which is perfectly elastic at 70 percent of the energy value of gasoline. The first scenario finds if the market values ethanol as a fuel additive, the average ethanol production level ranges from 12 to 14 billion gallons when gas prices are high. The results imply the industry is viable, even if ethanol prices fall. The second scenario determined viability to be much more sensitive to gasoline prices when the market only values the energy content of ethanol and gasoline prices are high.

Thompson, Meyer, and Westhoff (2008) analyzed how RFS, crude oil prices and corn yield volatility influence the U.S. ethanol market. They used a model developed and maintained by the Food and Policy Research Institute at the University of Missouri (FAPRI) and simulated a stochastic structural model that incorporated RFS to assess how shocks to corn and oil markets affect ethanol price and use. Scenario analysis was used to estimate ethanol prices and use with and without RFS. The authors concluded that RFS makes ethanol prices more sensitive to corn yields and less sensitive to oil prices overall. They also note it is possible for ethanol use to exceed the mandate when oil prices and corn yields are high, while limiting downside adjustments when prices and yields are low.

Other researchers have focused their efforts on the long-run impact of ethanol production growth and its impact on U.S. and world agriculture. Elobeid et.al. (2007) developed an integrated multi-commodity, multi-country model which they used to estimate the long-run potential for ethanol production by calculating the corn price at which the incentive to expand ethanol production disappears. This is basically the price at which corn ethanol plants breakeven. Scenarios and sensitivity analysis was conducted to show the impact of changes in key assumptions. The authors estimated at a breakeven price of $4.05, with corn-based ethanol production reaching 31.5 billion gallons per year. To support this level of production, 95.6 million acres of corn will have to be planted. Total corn production would be approximately 15.6 billion bushels.

One drawback to the studies is they ignore risk in their forecasts. Some authors quantify market level impacts of policy variables and prices, but make no attempt to discuss the probability of those outcomes. The approach taken here will develop a model of the U.S. ethanol industry which combines the framework developed by Elobeid and Tokgoz (2008), stochastic processes, variable RFS, and exogenous corn prices to simulate monthly ethanol prices in the U.S. The model will also evaluate the economic impact of an EPA waiver to shift the BW outwards, to say E15 or E20.

4. METHODOLOGY

4.1 Simulation

In the literature review section, studies were reviewed that addressed the RFS and other policies that impact ethanol markets. Thompson, Meyer, and Westhoff (2008) incorporated stochastic components into their research. Because risk is inherent in econometric modeling, simulation is the best method for evaluating risk and the feasibility of a particular risky decision. Any variable in an econometric model which the decision-maker (DM) cannot control is considered risky. There are two types of models identified in the literature review that can be used to analyze agricultural markets. In deterministic models, the assumption is all exogenous variables do not change, and the interrelationship between variables is constant. Thus, these models provide point forecasts, and do not evaluate impacts of risk. In stochastic models, the assumption is relaxed allowing one or more of the exogenous variables to be random. The randomness creates variability in terms of input values within the model, which is used to generate probability distributions for the evaluation of risk on the output variables. We can then incorporate alternative scenarios into the analysis to measure their effects on the model probabilistically. A decision-maker could then select the best scenario based on policy goals and the likelihood of occurrence.

We use simulation as a tool to improve the decision-making process by estimating "the shapes of probability distributions for variables we cannot observe" (Richardson 2013). The presence of unknown probability distributions implies risk which complicates the decision-making process. Simulation can quantify the risk associated with selected key output variables (KOVs) by producing hundreds of possible outcomes, instead of one finite value. The results show not just what could happen, but also the likelihood of those outcomes.

The process of simulation involves solving a set of mathematical equations, which represent an economic system, given a set of input data. Typically, simulation models are used to answer "what-if" type questions. The primary goal of simulation is to imitate how the actual system would respond to changes in input variables and policy decisions. The model should cover enough detail of the real system to adequately answer the research question. The model is then solved hundreds of times using stochastic shocks to the risky variables to statistically represent most all possibilities of random values as defined by their probability distributions. The result is an empirical estimate of the risk and probability distributions for the KOVs.

The preferred method of probability sampling is the Latin Hypercube procedure because it reduces the number of iterations that must be simulated (Richardson 2008). The procedure divides the probability distribution equally into N intervals, where N is the number of iterations, and one random value is drawn from each interval. By dividing the probability distribution into N intervals, the Latin Hypercube method insures all possible random values are considered in the simulation.

The residuals from the structural econometric equations will be simulated using a normal distribution, assuming a mean of zero and a standard deviation equal to the standard deviation of the residuals. Thus, risk associated with the equations in the model will be incorporated into the estimated KOVs.

4.2 Theoretical Approach

Economic theory has the potential to investigate market consequences associated with ethanol regulation. Figure 4.1 is used to provide a graphical representation that can be used to explain the demand curve for ethanol. The so-called ethanol BW constrains growth in the ethanol industry by limiting the domestic demand for ethanol. The BW requires no more than 10 percent ethanol, E10, will be blended in the U.S. transportation fuel supply each year, which essentially creates a perfectly inelastic kink in the demand curve for ethanol at 10 percent of annual gasoline consumption. Any blends higher than E10, such as E15 or E20, will require a waiver by the EPA and a flex-fuel vehicle capable of using the higher blend. In the figure, a waiver will shift the maximum volume of ethanol which can be blended into gasoline outward from E10 to say E20.

The other policy which directly impacts the ethanol industry is RFS. Ethanol mandates under RFS create a production floor for the ethanol industry, creating long-run industry security and a minimum demand for ethanol. This creates another kink in the demand curve for ethanol (figure 4.1). The kink forces the demand for ethanol to be perfectly inelastic at the RFS level for that year. The RFS mandate level currently is less than the annual demand for ethanol as a fuel additive at Q_e.

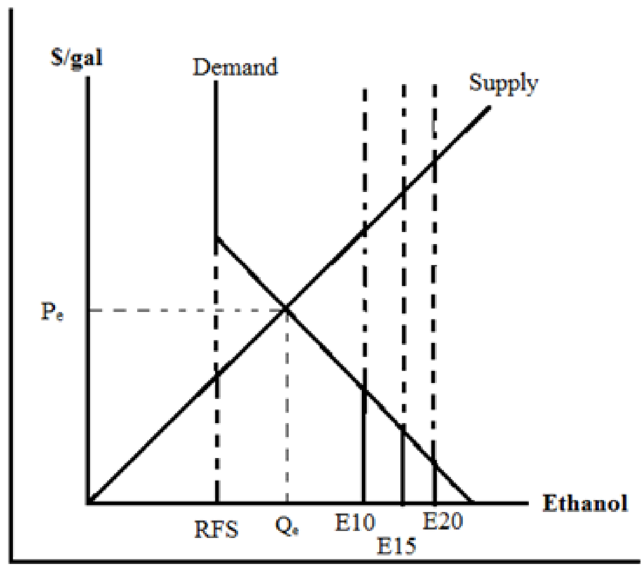


Figure 4.1. Kinked Domestic Demand Curve for Ethanol

In figure 4.1, the domestic demand curve for ethanol is segmented into pieces. Price per gallon and quantity of ethanol are on the y and x-axis, respectively. The RFS mandate is the minimum quantity demanded for ethanol, which causes the demand curve to become perfectly inelastic at that level. Demand is negatively sloping until Q_e exceeds the maximum volume of ethanol which can be blended into gasoline. E10, E15, and E20 represent the maximum percentage of ethanol by volume which can be blended into gasoline each year. Domestic demand is perfectly inelastic at quantities of ethanol beyond the maximum level. P_e and Q_e are free-market equilibrium price and quantity demanded, as long as the quantity produced is between the RFS and the BW at E10.

4.3 Data

Data were obtained from various sources and ranges from year 2006 through October 2013. Monthly corn and ethanol prices were obtained from the USDA's Economic Research Service Feed Grains Database. Ethanol prices are wholesale, rack prices in the city of Omaha, Nebraska. Monthly ethanol production, consumption, trade, and oil price data were obtained from U.S. Energy Information Administration Monthly Energy Review. All prices have been deflated using the U.S. Bureau of Labor Statistics segmented producer price index (PPI); ethanol prices were deflated using the energy related finished goods category, while oil prices were deflated using the crude materials for further processing category.

4.4 Model Development

The purpose of the model is to estimate equilibrium ethanol prices subject to changes in exogenous corn prices, the BW, and the RFS. A recursive, structural partial equilibrium framework was developed to solve for equilibrium monthly ethanol prices. The model is considered recursive in nature because ethanol blenders will make economic decisions based on last period's information and across multiple time periods. This kind of model is useful because it allows variables like supply, demand, and prices to co-vary and interact over time. For simplicity, imports are held constant at its historical average. The oil price is also constant, and was acquired from the EIA's Monthly Energy Review. Imports and oil price for the simulation are .03 billion gallons and $81.34 per barrel, respectively. Ethanol domestic, export, and end stock demand residuals were simulated to estimate probability distributions for monthly ethanol prices and quantity demanded. KOVs include monthly ethanol prices and total ethanol demand for 2014.

This first step is to estimate the structural equations using ordinary least squares linear regression. Four equations were estimated: supply, demand, demand for exports, and ending stocks.

The supply equation for ethanol is specified as the following:

$$S_t = b_0 + b_1 *S_{t-1} + b_2*Jan + b_3*Feb + b_4*Mar + b_5*Apr + b_6*May + b_7*Jun + b_8*Jul + b_9*Aug + b_{10}*Sept + b_{11}*Oct + b_{12}*Nov + b_{13}*EP_{t-1} + b_{14}*CP_{t-1} + b_{15}*DV2006/2007_t \quad (1)$$

where b_0, b_1, b_2, b_3, b_4, b_5 ,b_6,b_7, b_8,b_9, b_{10}, b_{11}, b_{12}, b_{13}, b_{14}, b_{15} are the parameters to be estimated, subscript t is measured in months, S is the supply of ethanol in billions of gallons, S_{t-1} is the supply of ethanol lagged one month (period), RFS is the Renewable Fuel Standard, Jan thru Nov are categorical dummy variables which represent a seasonal index, DV2006/2007 is dummy variable for 2006 and 2007, EP_{t-1} is the ethanol price lagged one period, CP_{t-1} is the corn price in dollars per bushel, and e_t is an error term.

Lagged supply, S_{t-1}, is used to allow ethanol producers time to adjust to changing economic conditions, such as changing RFS mandate levels. The full effects of change in price of ethanol are not felt immediately, but rather gradually over a period of time, and are estimated using a structure proposed by Nerlove (1958). Supply is a function of lagged corn and ethanol prices to make the model calculate supply in period t based on last period's prices. The categorical dummy variables for January thru November is estimating the seasonality in ethanol supply. A dummy variable for 2006/2007 is estimating a structural shift in ethanol production as a result of EISA being passed.

The domestic demand for ethanol is specified as:

$$DD_t = BW_t + b_1{*}OP_t + b_2{*}RFS_t + b_3{*}EP_t + e_t \qquad (2)$$

where $b_{0,}$ b_1, b_2, b_3 are the parameters to be estimated, subscript t is measured in months, D_t is the demand for ethanol in billion gallons, BW_t is a constant which represents the maximum amount of ethanol which can be blended into gasoline, OP_t is the Brent crude oil price in dollars per barrel, RFS_t is the Renewable Fuel Standard, EP_t is the ethanol price per gallon, and e_t is an error term.

Domestic demand is estimated by regressing ethanol demand on a constant term, BW, which is BW expressed in percentage terms. The BW_t variable will operate as an intercept shift when the BW is increased. The sign is expected to be positive. The sign on OP_t will be positive if we assume oil and ethanol are substitutes for fuel. RFS is expected to have to have a positive sign because each year, RFS will require more and more ethanol to be blended, thus shifting out demand.

The export demand equation is specified as:

$$\text{Exports}_t = b_0 + b_1 * \text{Exports}_{t-1} + b_2 * \text{DV1}_t + b_3 * \text{DV2}_t + b_4 * \text{EP}_t + e_t \qquad (3)$$

where b_0, b_1, b_2, b_3, b_4 are the parameters to be estimated, subscript t is measured in months, Exports_t is the demand for exports in billions of gallons, Exports_{t-1} is lagged export demand, DV1_t and DV2_2 are dummy variables. EP_t is the ethanol price, and e_t is an error term.

Export demand is estimated using lagged export demand, and dummy variables. Lagged exports were included as an adjustment factor. DV1 was added to capture a rising trend in exports during the first half of 2010. DV2 was included because there was a record high spike in ethanol exports in 2011, which was partially due to Brazil's need to import more ethanol as a result of a shortfall in their sugarcane harvest, their primary feedstock for ethanol production. Ethanol exports increased from 10,000 barrels per day in early 2010 to 133,000 barrels per day at the end of 2011 (EIA, 2014b).
The ending stocks equation is specified as:

$$\text{Ending Stock}_t = b_0 + b_1 * \text{DV1}_t + b_2 * \text{DV2013}_t + b_3 * \text{Trend}_t + b_4 * \text{EP}_t + e_t \qquad (4)$$

where b_0, b_1, b_2, b_3, b_4 are the parameters to be estimated, subscript t is measured in months, Ending Stock_t is the demand for exports in billions of gallons, DV1 is a dummy variable, DV2013 is a dummy variable for 2013, Trend_t is a time trend, EP_t is the ethanol price, and e_t is an error term. DV1 is capturing periods of unusually high stocks at the end of the year for 2010-12.

The system of equations will solve for equilibrium ethanol prices because we have four equations and four unknowns, which are linked together through ethanol price. The three demand equations can be added together and rewritten to calculate a total demand function. The total demand equation can then be rearranged to solve for price. The recursive component is incorporated into the model by inputting the quantity supplied (which is based on last period's information) in period t to solve for equilibrium price in month t.

The next step is to implement the two constraints on the domestic demand curve for ethanol, which will kink the curve in two places, as shown in figure 4.1. There is a minimum demand for ethanol which forces the demand curve to be perfectly inelastic where the minimum required RFS level is set. Demand for ethanol for any month must be greater than or equal to the RFS level for that year divided by 12. The second kink exists because there is a maximum amount of ethanol which can be blended into gasoline as a fuel additive, which causes the demand curve beyond this point to become perfectly inelastic. The EPA has approved only E10, a blend of gasoline with up to 10 percent ethanol by volume, to be used in gasoline-powered engines. Therefore, market demand for ethanol in any month cannot exceed 10 percent ethanol by volume of total gasoline consumption divided by 12 unless the EPA approves additional blends. Residual demand beyond the mandate will be exported or accumulated as ending stocks.

Scenario analysis will be used to evaluate alternative policy options. The consequences of alternative policies can be compared by changing the level of the policy variable. Because this model addresses RFS and the possibility of incorporating higher concentrations of ethanol-blended gasoline into the transportation fuel supply, scenarios will be developed which vary the RFS, corn price, and the maximum concentration of ethanol in gasoline.

Scenarios will be simulated 500 times to approximate PDF graphs of annual ethanol prices assuming a level of RFS, ethanol concentration in gasoline, and corn price. The KOVs will be average ethanol price and total ethanol demand for year 2014. The base scenario will include the 2014 statutory mandate of 12.65 billion gallons of ethanol, a 10 percent ethanol by volume requirement, and $4.15 per bushel corn price. The base scenario corn price was obtained from the University of Missouri's Food and Agricultural Policy Research Institute U.S. Crop and Biofuel Baseline. Alternative scenarios will vary the RFS and the BW concentrations. Corn prices will vary from a mean value of $4.15 per bushel to low and high value of $3.74 and $4.57 respectively. The BW, or the maximum quantity of ethanol which can be blended into E10, E15, and E20 gasoline is calculated by multiplying the total forecasted demand for gasoline, 134.60 billion gallons (EIA 2013a), by 10, 15 and 20 percent. The maximum demand for 10, 15 and 20 percent ethanol is 13.46, 20.19, and 26.92 billion gallons. Table 4.1 summarizes 27 different scenarios to be analyzed:

Table 4.1. Scenarios to be Analyzed

Scenario	RFS	Corn Price	Blend Wall
1	13.12	3.74	13.46
2	13.12	4.15	13.46
3	13.12	4.57	13.46
4	13.12	3.74	20.19
5	13.12	4.15	20.19
6	13.12	4.57	20.19
7	13.12	3.74	26.92
8	13.12	4.15	26.92
9	13.12	4.57	26.92
10	11.73	3.74	13.46
11	11.73	4.15	13.46
12	11.73	4.57	13.46
13	11.73	3.74	20.19
14	11.73	4.15	20.19
15	11.73	4.57	20.19
16	11.73	3.74	26.92
17	11.73	4.15	26.92
18	11.73	4.57	26.92
19	14.43	3.74	13.46
20	14.43	4.15	13.46
21	14.43	4.57	13.46
22	14.43	3.74	20.19
23	14.43	4.15	20.19
24	14.43	4.57	20.19
25	14.43	3.74	26.92
26	14.43	4.15	26.92
27	14.43	4.57	26.92

The scenarios will address the objective of this paper because we want to better understand how policy influences ethanol markets. The purpose of the model is to estimate probabilistically how changes in policy variables and corn prices affect ethanol markets so policy-makers can make better decisions.

It is important to check models for completeness and accuracy. This is the final step in building the model. Verification is the process of confirming all equations in the model have been calculated appropriately and are calculating what they are supposed to. All equations are checked to ensure the variables and coefficients have been multiplied or added correctly. Model validation ensures the residuals were simulated correctly and appropriately approximate a normal distribution. The residuals were validated using statistical tests to ensure they were simulated properly.

5. RESULTS

This chapter will focus on the results of the regressions described in Section 4, and it will be divided into three parts: 1.) regression results, 2.) a section dedicated to the presentation of elasticities, and 3.) summary statistics for the 27 scenarios.

5.1 Regression Results

Ordinary least squares is the preferred method for estimating the unknown parameters in a linear regression model. The ideal model specification will be determined by comparing various measures of fit, including R^2 and F-tests. Parameter results are validated using a Student's t-test. Hypothesis tests will be used to check their validity.

The coefficient of determination, or R^2, indicates how well the data fit the regression model. R^2 is a number between 0 and 1, with 1 indicating a perfect linear relationship, and 0 indicating no fit. Selecting the appropriate independent variables can increase R^2. The R^2 for production, domestic demand, export demand, and end stock demand are .992, .994, .867, .928, respectively, which implies the equation fits the data well. The results are presented in table 5.1.

Another method used to determine model specification is the F-test. The F-test is designed to test the significance of the R^2 when multiple parameters are involved by comparing the ratio of two variances. Equation (5) presents the formula for the F-test.

$$F = \frac{(SSR_r - SSR_u)/r}{SSR_u/(n-k-1)}. \tag{5}$$

SSR_r is the sum of squared residuals (SSR) for the restricted model, SSR_u is the SSR for the unrestricted model, n is the number of observations, k is the number of independent variables in the unrestricted model, r is the number of restrictions, and n-k-1 represents the degrees of freedom.

SSR measures the amount of variance in the data that is not explained by the regression model. A small SSR suggests the model fits the data well. It is ideal to have the unrestricted model closely resemble the restricted model because it implies the unrestricted model has explanatory power. If they are different, it means the unrestricted form is not appropriately capturing the variation in the dependent variable. If SSR is larger in the restricted model, F will also be large. F is large when the restricted model makes the fit of the regression worse, which is when we should question the null hypothesis. The restricted model will almost always have a larger SSR than the unrestricted model because the restricted model does not use all of the independent variables to minimize SSR. The unrestricted model utilizes more independent variables which tend to reduce SSR. The null hypothesis is formed under the assumption all independent variables are equal to zero. The null will be rejected if the SSR of the restricted model is larger than the SSR of the unrestricted model because it is likely the unrestricted model has variables which should be included in the regression. F-test results are presented in table 5.1.

Table 5.1. Model Specification Results

	Supply	Domestic Demand	Export Demand	Demand for End Stock
R-Sqaure	0.992	0.994	0.867	0.928
F-test statistic	686.580	3837.070	66.983	290.153
P-value on F	0.000	0.000	0.000	0.000

F-test values are sufficiently large, which provide evidence in support of appropriate model specification. P-values for the F-ratio are also reported. P-values help determine the significance of the F-test statistic. A P-value is the smallest significance level at which the null hypothesis would be rejected. This means small p-values are evidence against the null, while large P-values provide little evidence for rejecting the null hypothesis.

Beta coefficients are interpreted as the expected change in the dependent variable for a one unit change in an independent variable, holding all other independent variables constant. A Student's t-test was used to determine if the coefficients are statistically different from zero. T-test measures the size of the beta coefficient in relation to its standard error. The null hypothesis assumes the beta coefficient is equal to zero. Large values imply statistical significance and rejection of the null hypothesis. Equation (6) shows the formula for the Student's t-test.

$$t = \frac{\hat{\beta}_j}{s(\hat{\beta}_j)}. \tag{6}$$

Table 5.2 shows the parameter results for the beta coefficients, t-tests, and P-values associated with each independent variable in the regression equations.

Table 5.2. Parameter Results for Regression Equations

	Beta	Standard Error	t-test	p-value
Supply				
Intercept	0.00910	0.030	0.307	0.760
Lagged Production	**0.96117**	0.017	55.536	0.000
Lagged Corn Price	-0.00106	0.003	-0.351	0.727
Jan	**-0.03165**	0.014	-2.325	0.023
Feb	**-0.09631**	0.014	-7.007	0.000
Mar	**0.04896**	0.014	3.541	0.001
Apr	**-0.06066**	0.014	-4.436	0.000
May	0.01819	0.014	1.332	0.187
Jun	**-0.05197**	0.014	-3.834	0.000
Jul	-0.01504	0.014	-1.105	0.272
Aug	-0.01835	0.014	-1.349	0.181
Sep	**-0.06787**	0.014	-5.004	0.000
Oct	0.01324	0.014	0.976	0.332
Nov	-0.02318	0.014	-1.652	0.103
DV EISA	**0.03231**	0.013	2.394	0.019
Lagged Ethanol Price	0.01549	0.010	1.573	0.120
Domestic Demand				
BW (Intercept)	**2.50239**	0.644	3.886	0.000
Crude Oil Price	0.00110	0.001	1.911	0.059
RFS	**0.80807**	0.048	16.853	0.000
Ethanol Price	-0.03679	0.022	-1.638	0.105
Export Demand				
Intercept	**0.06923**	0.020	3.539	0.001
Lagged Export Demand	**0.31266**	0.067	4.699	0.000
DV1	**-0.02855**	0.008	-3.800	0.000
DV2	**0.07067**	0.007	10.439	0.000
Ethanol Price	-0.01406	0.009	-1.653	0.106
Demand For End Stock				
Intercept	**0.28991**	0.048	6.058	0.000
DV1	**0.10268**	0.015	7.008	0.000
DV 2013	**0.22802**	0.024	9.509	0.000
Trend	**0.00595**	0.000	23.651	0.000
Ethanol price	**-0.06825**	0.014	-4.962	0.000

Notes: Bold values indicate statistical significance at the 95 percent confidence level.

The second column in the table corresponds to the estimated coefficient for each independent variable. The value of the coefficient measures the size of the marginal effect the independent variable has on the dependent variable, and the sign gives the direction of change. Signs are correct on all beta coefficients.

The production equation results show corn price has a negative impact on ethanol production. Seasonal variability is also a significant factor in determining ethanol production. Ethanol price has a positive, but insignificant effect on supply. Negative signs on the betas for Jan, Feb, Apr, Jun, and Sept indicate ethanol production in those months is less than average production across all of the observed data. A positive sign for Mar indicates production in March is on average higher than average.

The results for the domestic demand equation indicate the RFS is a significant aspect in determining demand for ethanol. Its sign is positive which is expected. A positive sign on the beta for BW shows a positive relationship between shifts in the BW and domestic demand. The beta for the price of crude oil is slightly positive, which means crude oil prices have a relatively minor impact on demand for ethanol. The sign on ethanol price is negative, but insignificant. The negative sign on ethanol price in the export demand equation is expected, but it’s insignificant. Finally, all betas in the end stock equation are significant.

5.2 Estimates of Elasticities

Elasticities measure how responsive dependent variables are to changes in explanatory variables. The formula to calculate the elasticity of demand (e_d) with respect to price is shown below.

$$e_{d,p} = \frac{\partial Q_d}{\partial P} \cdot \frac{P}{Q_d}. \tag{7}$$

In words, the elasticity of demand is equal to the first derivative of demand with respect to price multiplied by the historical average price (P) and divided by the historical average demand (Q_d). The numerator is interpreted as a percentage change in quantity demanded, and the denominator is a percentage change in price. An elastic demand implies small changes in price will result in large changes in demand, while inelastic demand elasticity indicates large changes in price will have to occur to create significant fluctuations in demand.

Table 5.3. Elasticity Estimates

	Supply	Domestic Demand	Export Demand	Demand For End Stock
Corn Price	-0.007	0	0	0
Oil Price	0	0.102	0	0
RFS	0	0.712	0	0
BW	0	0.285	0	0
Ethanol Price	0.042	-0.099	-0.509	-0.251

Table 5.3 shows the elasticity estimates for the four structural equations. Corn price was found to have little effect on production, based on its very inelastic elasticity. Supply will increase approximately .42 percent, if ethanol price rises by 10 percent. This is expected because in the historical data, ethanol production is steadily increasing

over time, while corn prices fluctuate rather significantly, from $3/bushel in 2006 to $7/bushel in 2012, and then begin to decline in 2013. The elasticity of supply with respect to ethanol price is .04, which implies virtually no supply response to changes in ethanol price. This can be explained because there is a minimum demand for oxygenates, and in the short-run, ethanol producers will not adjust their output due to capacity issues. The elasticity of demand with respect to RFS is 0.712, which implies demand is relatively inelastic. This means if RFS increases by 10 percent, demand for ethanol will expand by 7.12 percent. It is also important to note the elasticity of demand with respect to the BW. Its elasticity is 0.285, which means a 10 percent increase the in blend wall will increase demand for domestic ethanol by 2.85 percent. Notice, domestic demand for ethanol is more sensitive to changes in the RFS and the BW. The elasticities of domestic, export, and stock demand can be added together to estimate total elasticity of demand for ethanol. The model approximates total demand elasticity to be -.859.

5.3 Simulation Results

Residuals for domestic, export, and end stock demand were simulated assuming a multivariate distribution, with a mean of zero and standard deviation equal to the standard deviation of the residuals associated with each demand equation. The normal distribution was applied to the model to simulate monthly ethanol prices and total demand for ethanol in 2014. 27 scenarios were analyzed using stochastic residuals, which were simulated for 500 iterations.

In reference to table 4.1, scenario 2 will be considered the base scenario. This scenario is considered the base because it is most likely to occur given current projections for RFS, corn price, and the BW. The base scenario consists of 13.12 BN gallon RFS, $4.15 corn prices, and the BW equal to 10 percent. Summary statistics for scenario 2 are presented in table 5.4.

Table 5.4. Summary Statistics for the Base Scenario

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average Ethanol Price	Total Ethanol Demand
Mean ($/gal)	2.51	2.83	2.37	2.23	1.73	1.57	1.41	1.31	1.62	1.67	1.76	1.69	1.89	14.118
StDev ($/gal)	0.77	0.81	0.86	0.86	0.83	0.85	0.83	0.85	0.90	0.86	0.87	0.91	0.14	0.020
CV	30.57	28.68	36.31	38.34	47.72	54.00	59.19	65.03	55.28	51.37	49.10	54.06	7.64	0.140
Min ($/gal)	0.57	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.46	14.048
Max ($/gal)	4.69	5.16	4.81	5.07	4.25	3.90	4.07	3.56	4.56	4.12	4.42	3.95	2.35	14.164

Notes: Prices are in real terms. Ethanol demand is in billions of gallons.

Table 5.4 shows the mean and standard deviation of ethanol prices for each month, average ethanol price, and total ethanol demand for 2014. Standard deviation is provided as an estimate of risk about the mean. The table also reports minimum and maximum values for each KOV. The average ethanol price in 2014 is estimated to be $1.89/gal. Standard deviation for average ethanol price (.14) is relatively small, implying a tight probability distribution about the mean. Average domestic demand for ethanol in 2014 is estimated to be 14.12 billion gallons.

An alternative method for analyzing risky KOVs is to visually inspect the simulation results with probability density functions (PDF). PDFs are useful because they graphically depict the estimate of risk by graphing the simulated KOVs over many iterations. PDF graphs are presented in figures 5.1 and 5.2 for average annual ethanol price and total demand for ethanol in 2014.

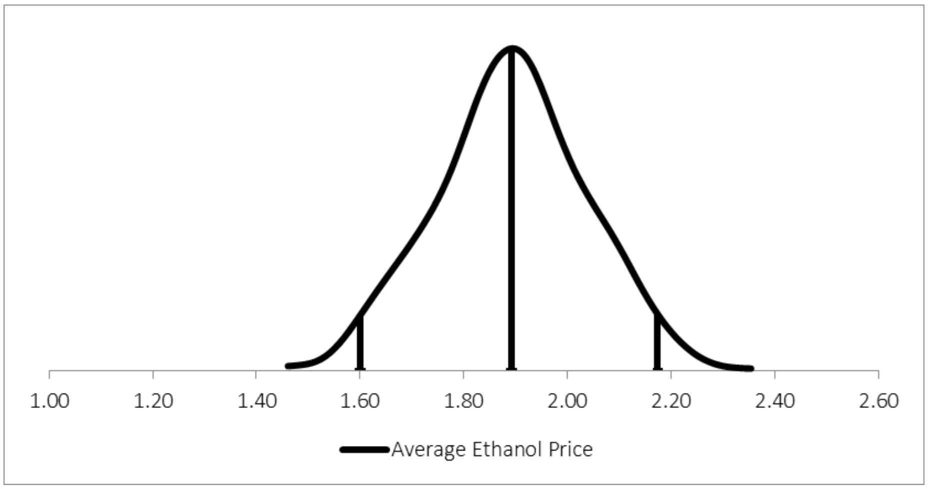


Figure 5.1. PDF Graph of Average Ethanol Price in 2014

Figure 5.1 shows the PDF graph for annual ethanol price in 2014. Price is on the x-axis. The mean and 95 percent confidence intervals for the forecast are depicted as vertical lines. Risk is shown as the horizontal distance from the mean. The graph indicates average ethanol price is likely to be between \$1.60 and \$2.20 per gallon, at the 95 percent confidence level.

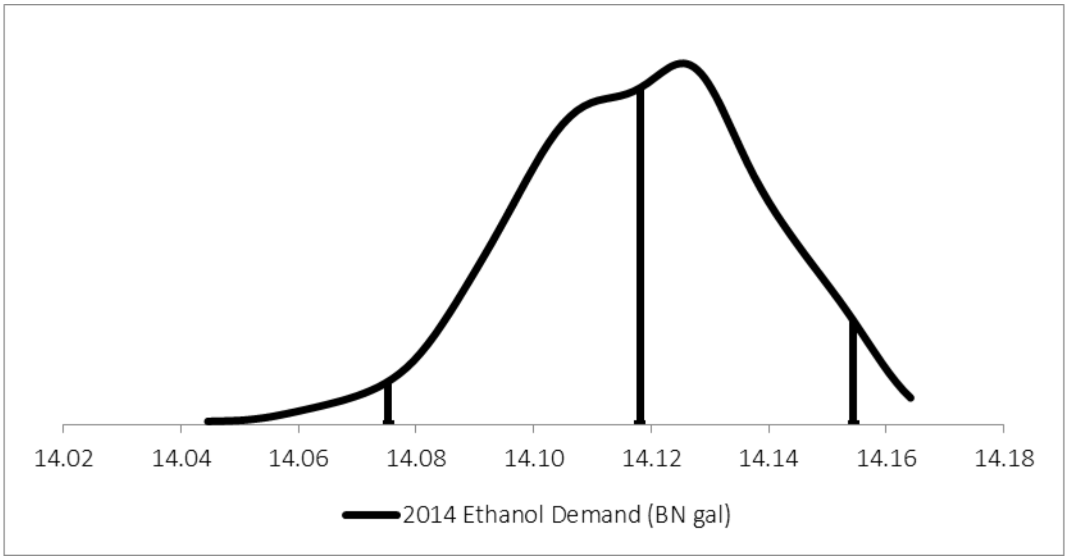


Figure 5.2. PDF Graph of Total Demand for Ethanol in 2014

Figure 5.2 is the PDF representation of total domestic ethanol demand. The graph shows a fairly wide dispersion of quantity demanded about its mean, suggesting demand is risky. With 95 percent confidence, ethanol demand is estimated to be between roughly 14.08 and 14.16 billion gallons.

The model was run for 27 different scenarios to simulate monthly ethanol prices. However, the KOVs reported below are average annual price and annual demand. Annual KOVs are reported to make comparisons across scenarios easier. The tables report KOV summary statistics for each scenario.

Table 5.5. Summary Statistics for 13.12 RFS

	Average Ethanol Price	Total Ethanol Demand		Average Ethanol Price	Total Ethanol Demand		Average Ethanol Price	Total Ethanol Demand
Blend Wall (E10) = 13.46	Corn Price = $3.74			Corn Price = $4.15			Corn Price = $4.57	
Scenario 1			**Scenario 2**			**Scenario 3**		
Mean ($/gal)	1.86	14.121	Mean ($/gal)	1.89	14.118	Mean ($/gal)	1.92	14.116
StDev ($/gal)	0.14	0.020	StDev ($/gal)	0.14	0.020	StDev ($/gal)	0.14	0.020
CV	7.67	0.141	CV	7.54	0.143	CV	7.40	0.145
Min ($/gal)	1.41	14.049	Min ($/gal)	1.44	14.047	Min ($/gal)	1.47	14.046
Max ($/gal)	2.22	14.166	Max ($/gal)	2.25	14.165	Max ($/gal)	2.28	14.163
Blend Wall (E15) = 20.19								
Scenario 4			**Scenario 5**			**Scenario 6**		
Mean ($/gal)	2.96	15.526	Mean ($/gal)	2.99	15.516	Mean ($/gal)	3.01	15.505
StDev ($/gal)	0.10	0.045	StDev ($/gal)	0.10	0.045	StDev ($/gal)	0.10	0.045
CV	3.25	0.291	CV	3.23	0.292	CV	3.21	0.292
Min ($/gal)	2.69	15.376	Min ($/gal)	2.71	15.365	Min ($/gal)	2.73	15.355
Max ($/gal)	3.28	15.656	Max ($/gal)	3.31	15.646	Max ($/gal)	3.33	15.635
Blend Wall (E20) = 26.92								
Scenario 7			**Scenario 8**			**Scenario 9**		
Mean ($/gal)	3.75	16.652	Mean ($/gal)	3.77	16.641	Mean ($/gal)	3.80	16.630
StDev ($/gal)	0.10	0.045	StDev ($/gal)	0.10	0.045	StDev ($/gal)	0.10	0.045
CV	2.57	0.272	CV	2.56	0.272	CV	2.54	0.272
Min ($/gal)	3.47	16.502	Min ($/gal)	3.50	16.491	Min ($/gal)	3.52	16.480
Max ($/gal)	4.07	16.782	Max ($/gal)	4.09	16.771	Max ($/gal)	4.12	16.760

Notes: Prices are in real terms. Ethanol demand is in billions of gallons.

The best method of scenario evaluation is to compare the scenarios 9 at a time. Each group of 9 scenarios has a different RFS level. For example, the first group of 9 scenarios is calculated using an RFS of 13.12 billion gallons, the second group has an RFS level of 11.73 billion gallons, and the third group has an RFS of 14.43 billion gallons. The three rows within each group are calculated with a BW of 10, 15, and 20 percent, respectively. Corn prices increase by 10 percent across each row. In Table 5.5, row 1, RFS and the BW are held constant and corn price is allowed to increase. Comparing across the row, ethanol is not very sensitive to rising corn prices. A 10 percent increase in the price of corn only increases the price of ethanol roughly $0.03/gal. Ethanol demand decreases approximately 30 million gallons in response to higher corn prices. The price of ethanol is not sensitive to variable corn prices, as seen by constant standard deviation across the row. In row 2 and 3, the assumptions are the same as row 1, except the BW is increased to 15 and 20 percent. Scenarios 2 and 5 can be compared to determine how much a BW increase to 15 percent will increase average ethanol price. This can be done because the RFS and corn price assumptions are the same. It is estimated the mean annual price of ethanol will increase from $1.89/gal to $2.99/gal. Ethanol demand increased roughly 1.4 billion gallons, as expected. The price increase is anticipated because an increase in the BW will allow more ethanol to be blended, thus pushing demand outward. Each group of 9 scenarios can be compared in a similar fashion.

Table 5.6. Summary Statistics for 11.73 RFS

	Average Ethanol Price	Total Ethanol Demand		Average Ethanol Price	Total Ethanol Demand		Average Ethanol Price	Total Ethanol Demand
Blend Wall (E10) = 13.46	Corn Price = $3.74			Corn Price = $4.15			Corn Price = $4.57	
Scenario 10			**Scenario 11**			**Scenario 12**		
Mean ($/gal)	1.58	13.555	Mean ($/gal)	1.60	13.545	Mean ($/gal)	1.63	13.534
StDev ($/gal)	0.11	0.049	StDev ($/gal)	0.11	0.049	StDev ($/gal)	0.11	0.049
CV	6.74	0.360	CV	6.64	0.361	CV	6.55	0.362
Min ($/gal)	1.28	13.429	Min ($/gal)	1.30	13.419	Min ($/gal)	1.32	13.408
Max ($/gal)	1.86	13.700	Max ($/gal)	1.88	13.690	Max ($/gal)	1.91	13.680
Blend Wall (E15) = 20.19								
Scenario 13			**Scenario 14**			**Scenario 15**		
Mean ($/gal)	2.37	14.684	Mean ($/gal)	2.40	14.673	Mean ($/gal)	2.42	14.662
StDev ($/gal)	0.11	0.050	StDev ($/gal)	0.11	0.050	StDev ($/gal)	0.11	0.050
CV	4.46	0.338	CV	4.42	0.339	CV	4.38	0.339
Min ($/gal)	2.07	14.555	Min ($/gal)	2.09	14.545	Min ($/gal)	2.11	14.534
Max ($/gal)	2.65	14.828	Max ($/gal)	2.67	14.817	Max ($/gal)	2.69	14.807
Blend Wall (E20) = 26.92								
Scenario 16			**Scenario 17**			**Scenario 18**		
Mean ($/gal)	3.16	15.810	Mean ($/gal)	3.18	15.799	Mean ($/gal)	3.21	15.788
StDev ($/gal)	0.11	0.050	StDev ($/gal)	0.11	0.050	StDev ($/gal)	0.11	0.050
CV	3.36	0.315	CV	3.33	0.315	CV	3.31	0.316
Min ($/gal)	2.86	15.681	Min ($/gal)	2.88	15.670	Min ($/gal)	2.90	15.659
Max ($/gal)	3.44	15.954	Max ($/gal)	3.46	15.943	Max ($/gal)	3.48	15.932

Notes: Prices are in real terms. Ethanol demand is in billions of gallons.

Table 5.6 shows the results of scenarios 10 through 18. For these scenarios, RFS was reduced to its proposed RFS level of 11.73 billion gallons. Scenarios 2 and 11 can be compared together to analyze the effect of a reduction in the RFS. The comparison can be done because scenarios 2 and 11 were calculated using the same exogenous corn price and BW constraint, but a different RFS. If RFS is reduced, the mean ethanol price per gallon is estimated to decrease \$0.29/gal. Demand fell 600 million gallons in response to the reduction in the RFS. Reducing RFS increases demand risk slightly, but reduces price risk by \$0.03/gal. Scenarios 11 and 14 can be compared to determine the effect of a reduction in RFS and an increase in the BW to 15 percent. Under these conditions, an increase in the BW will expand demand for ethanol as expected by 1.1 billion gallons, and increase the price of ethanol from \$1.60/gal to \$2.40/gal, or \$0.80/gal.

Table 5.7. Summary Statistics for 14.32 RFS

	Average Ethanol Price	Total Ethanol Demand		Average Ethanol Price	Total Ethanol Demand		Average Ethanol Price	Total Ethanol Demand
Blend Wall (E15) = 20.19	Corn Price = \$3.74			Corn Price = \$4.15			Corn Price = \$4.57	
Scenario 22			**Scenario 23**			**Scenario 24**		
Mean (\$/gal)	3.41	16.381	Mean (\$/gal)	3.43	16.373	Mean (\$/gal)	3.45	16.364
StDev (\$/gal)	0.10	0.048	StDev (\$/gal)	0.10	0.048	StDev (\$/gal)	0.10	0.048
CV	2.89	0.291	CV	2.88	0.292	CV	2.87	0.293
Min (\$/gal)	3.11	16.257	Min (\$/gal)	3.12	16.248	Min (\$/gal)	3.14	16.239
Max (\$/gal)	3.70	16.547	Max (\$/gal)	3.72	16.539	Max (\$/gal)	3.74	16.530
Blend Wall (E20) = 26.92								
Scenario 25			**Scenario 26**			**Scenario 27**		
Mean (\$/gal)	4.31	17.448	Mean (\$/gal)	4.33	17.438	Mean (\$/gal)	4.35	17.427
StDev (\$/gal)	0.10	0.045	StDev (\$/gal)	0.10	0.045	StDev (\$/gal)	0.09	0.044
CV	2.21	0.256	CV	2.20	0.255	CV	2.18	0.255
Min (\$/gal)	4.00	17.322	Min (\$/gal)	4.03	17.312	Min (\$/gal)	4.05	17.301
Max (\$/gal)	4.57	17.591	Max (\$/gal)	4.60	17.580	Max (\$/gal)	4.62	17.570

Notes: Prices are in real terms. Ethanol demand is in billions of gallons.

Table 5.7 presents the results of the last 6 scenarios. All scenarios in this table have increased the RFS mandate level to 14.32 billion gallons. Scenarios 19 through 21 are not reported because it is doubtful they will occur. For instance, scenario 20 is questionable because the RFS mandate will exceed the BW. This is highly unlikely because RFS each year will always be less than the BW. However, we can compare the base scenario (scenario 2) to scenario 23. When compared to the base scenario, a 10 percent increase in RFS to 14.32 billion gallons and a BW increase to 15 percent, will cause ethanol price to rise from $1.89/gal to $3.43/gal. Demand is estimated to increase nearly 2.2 billion gallons as a result of increasing the BW to E15 and the RFS to 14.32 billion gallons. Price risk decreases $.04/gal when compared to the base scenario. If we compare scenario 23 and 26, it is possible demand will expand even further as the BW is increased to 20 percent.

5.4 Model Validation

The model was validated to ensure risk has been properly incorporated into the model. The residuals from the 3 demand equations were simulated using a normal distribution, with a mean equal to zero and a standard deviation equal to the standard deviation of the residuals from its respective OLS regression. The actual and simulated residual values are presented in Table 5.8.

Table 5.8. Actual and Simulated Values for Residuals

Actual Residual Values			
	Domestic Demand	Export Demand	End Stock Demand
Mean	0	0	0
Standard Deviation	0.070	0.012	0.050
Simulated Residuals			
	Domestic Demand	Export Demand	End Stock Demand
Mean	-7.7E-06	-5.8E-06	-3.2E-05
Standard Deviation	0.050	0.012	0.070

Statistical tests can be used to validate stochastic variables. Because the residuals are univariate probability distributions, Student's-t tests and F-tests are appropriate for testing the means and standard deviations, respectively. The null hypothesis for the Student's-t test assumes the actual mean and the simulated mean are equal. If the simulated mean of the residual is not statistically equal to its actual mean, the test with reject the null hypothesis. The F-test will determine if the variance was properly reproduced. The null hypothesis will be rejected if the 2 standard deviations are not statistically equal to one another. Table 5.9 shows the results of the validation tests.

Table 5.9. Validation Test Results for the Simulated Residuals

Distribution Comparison of Sim. DD Residuals & Actual DD Residuals				
Confidence Level		95.00%		
	Test Value	Critical Value	P-Value	
2 Sample t Test	0.00	2.27	0.997	*Fail to Reject the Ho that the Means are Equal*
F Test	1.01	1.28	0.457	*Fail to Reject the Ho that the Variances are Equal*
Distribution Comparison of Sim. Export Residuals & Actual Export Residuals				
Confidence Level		95.00%		
	Test Value	Critical Value	P-Value	
2 Sample t Test	0.00	2.31	0.998	*Fail to Reject the Ho that the Means are Equal*
F Test	1.02	1.40	0.432	*Fail to Reject the Ho that the Variances are Equal*
Distribution Comparison of Sim. End Stock Residuals & Actual End Stock Residuals				
Confidence Level		95.00%		
	Test Value	Critical Value	P-Value	
2 Sample t Test	-0.14	2.27	0.886	*Fail to Reject the Ho that the Means are Equal*
F Test	1.01	1.32	0.500	*Fail to Reject the Ho that the Variances are Equal*

Table 5.9 presents the results of the validation tests. The test statistic and critical P-values are provided for each test. If the calculated test statistic is less than its critical value, then the test will fail to reject the null hypothesis that the mean and standard

deviation are statistically different. Table 5.9 shows the historical mean and standard deviation of residuals for each equation have been statistically reproduced at an alpha level equal to .05.

6. SUMMARY AND CONCLUSIONS

Federal energy policy continues to play a role in the development of the biofuels industry. Volatile world oil prices and political uncertainty has compelled political figures to search for practical alternatives to reduce U.S. dependence on imported oil. Ethanol has been identified as a viable option. There have been various policy measures put in place to support biofuel production, some of which have expired. One of the more profound forms of federal policy support is the RFS. The RFS requires annual minimum usage volumes of biofuel for blending and has greatly expanded ethanol production and use, which has raised questions regarding its long-term sustainability and potential unintended consequences in corn and livestock markets. The issue with the RFS program is the required mandate for 2014 will likely cause gasoline consumption to hit the ethanol BW. If the average ethanol blend exceeds 10 percent, the cost of fuel could increase, resulting in economic harm to consumers and possibly fuel shortages. To avoid the ethanol BW, the EPA may need to reduce RFS or increase the BW by allowing the sale of higher ethanol blends, such as E15 or E20.

The objective of this paper is to analyze the economic impacts of energy policy on the ethanol market. Monte Carlo simulation was used to estimate stochastic monthly ethanol prices and total demand. Scenario analysis was used to estimate how RFS affects ethanol demand, as well as the possibility of allowing the sale of higher ethanol blends. The results can be used to assist decision-makers in making better decisions regarding energy policy.

A recursive, structural partial equilibrium model was developed to simulate monthly ethanol prices and total demand. Econometric equations were estimated for supply, domestic, export and ending stock demand. The model was designed to provide a probabilistic projection of monthly ethanol prices and total demand for ethanol in 2014. It addressed both the RFS and the BW, both of which heavily influence the demand for ethanol. The model is able to forecast ethanol prices and demand for a 12-month horizon. The differences in the scenario KOVs were used to compare the consequences of alternative policy options. The residuals from the 3 demand equations were simulated to estimate probability distributions for monthly ethanol prices and total demand. The model was validated using statistical tests to ensure the residuals were properly simulated.

The results of 27 scenarios show how sensitive ethanol markets are to exogenous changes in RFS, the BW, and corn prices. Elasticities were estimated to measure how sensitive the structural equations are to changes in the independent variables. The elasticity of supply with respect to corn price was found to be very inelastic (-.007). The own-price elasticity of supply is .042, which implies a 10 percent increase in the price of ethanol will expand production by .042 percent. The elasticity of demand with respect to RFS and the BW are 0.712 and 0.285, respectively. The total own-price elasticity of demand for ethanol is -0.859. A base scenario was chosen to compare various policy alternatives. The base scenario consisted of a 13.12 billion gallon RFS, 10 percent BW, and $4.15 corn price. The simulation estimated the average 2014 price of ethanol to be between $1.60 and $2.20 per gallon. The expected price is $1.89/gal. Total demand is expected to be 14.12 billion gallons, but it will vary between 14.08 and 14.16 billion gallons. Ethanol prices were found to be insensitive to corn prices. Increasing corn prices 10 percent per bushel increased the average price of ethanol roughly $0.03/gal. Total demand was reduced 30 million gallons in response to increasing corn prices by $0.42 per bushel. The RFS was determined to play a substantial role in determining the demand for ethanol. When RFS is reduced from 13.12 to 11.73 billion gallons, ethanol prices fell $0.29/gal when compared to the base scenario. Demand declined approximately 600 million gallons. The BW was found to significantly increase ethanol prices and total demand. If the BW is increased to 15 percent, prices were estimated to increase $1.10/gal from the base scenario to $2.99/gal. Ethanol demand increased about 1.4 billion gallons. Overall, the results show RFS and the BW positively affect ethanol pricing and demand.

The current debate surrounding incentives to promote biofuel production is driven largely by the desire of Congress to reduce reliance on imported oil. The EPA has considered reducing the biofuel mandates for 2014 because oil and gas companies are concerned it would be difficult to consume the targeted mandate for ethanol, given current EPA regulations and infrastructure issues. High compliance costs, or high prices of the ethanol credits known as RINs, reflect difficulty in meeting the mandate. The cost of compliance falls on gasoline refineries who must comply with the RFS mandate. This link implies any increases in the cost of RINs will reduce the volume of gasoline supplied by refineries. Those costs are ultimately passed on to the consumer as higher gasoline prices. Unless gasoline consumptions begins to rise again, the results of the study should indicate to Congress the ethanol mandate is a broken policy and is in need of a revamp.

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