THE NEW NORMAL: A POLICY ANALYSIS OF THE US RENEWABLE FUEL STANDARD

TRISTAN HANON, WASHINGTON STATE UNIVERSITY[†]

Abstract

The cause of the rise in food prices throughout the 2000s has been difficult to ascertain, but the effects have been devastating to many of the poorest countries in the world. The Renewable Fuel Standard (RFS) mandates a certain level of alternative fuels to be blended into gasoline annually. The level increases each year. During the global food crisis of 2008 US ethanol policies were blamed for their possible role in rapidly rising food prices. This article examines whether and how the RFS has affected corn prices and global food prices. It seeks to identify what role, if any, the RFS had in the global food crisis in order to determine how to possibly moderate such a crisis in the future. A simple experiment is simulated which compares corn price to two control commodities. Economic models for estimating price are then developed for corn and a food price index. The variables in these models include corn production, soybean price, the RFS mandate level, corn input prices, per capita income, a food price index, grain production, wheat price, and barley price from 2003 through 2012. Findings indicate that the RFS has certainly caused an increase in corn prices but has had an indeterminate impact on global food prices.

Individuals living in the poorest countries of the world spend the majority of their income on food. In the summer of 2008, rising food costs led to riots plaguing the streets in many of these nations (Bourne 2009). This period was a sign that food production is beginning to feel the strain of a growing world population. Many have claimed that US policies related to alternative fuel production, and specifically the production of corn-based ethanol, were to blame for rising food prices (Leff 2012). Since the early 2000s corn ethanol was alternatively vilified and praised in the popular press, but after the start of the global food crisis no report seemed complete without a claim that US ethanol policies were to blame.

Over the course of the past forty years corn ethanol has progressed as a fuel source in the United States. Two factors led to the increase in ethanol production. First, the 1973 oil embargo led to increased fuel prices in the US, making ethanol more competitive as an alternative fuel to gasoline, although briefly (Solomon, Barnes, and Halvorsen 2007). Although oil prices quickly dropped in the 1980s following the end of the embargo, the ethanol subsidies and tax exemptions stayed in place. In the late 1990s, ethanol was promoted as a fuel additive to raise the octane rating of gasoline and began to receive its first government support, including subsidies and tax exemptions (Solomon, Barnes, and Halvorsen 2007). After leaded gasoline was phased out in the 1980s methyl tertiary butyl ether (MTBE) was used as an additive to raise octane ratings. Groundwater contamination discovered in the early 2000s led to the banning of MTBE as a fuel additive in 2005. Corn ethanol replaced MTBE, leading to further policies in support of its production and more attention on ethanol's potential as a renewable fuel.

[†] *Editor's Note*: Hanon's paper won first place in the 2014 SS-AAEA Undergraduate Paper Competition.

The Renewable Fuel Standard (RFS1) was introduced in 2005 through the Energy Policy Act (EPAct). The policy mandated the volume of ethanol to be blended with gasoline annually through 2012. Shortly afterwards, the policy was expanded through the Energy Independence and Security Act of 2007 (EISA). This second iteration of the Renewable Fuel Standard (RFS2) set blending levels through 2022. Although the policy focused exclusively on corn ethanol through 2009, RFS2 expanded the mandate to other advanced renewable fuels (Schnepf and Yacobucci 2013). The RFS2 mandate states that 9 billion gallons of renewable fuels were to be blended with gasoline in 2008, increasing stepwise to 36 billion gallons in 2022 (Solomon, Barnes, and Halvorsen 2007).

The corn ethanol market has been heavily researched since the 1970s. The focus of that research shifted as corn prices rose rapidly between 2005 and 2008 and the world felt the pressure of the global food crisis. The corn market became the target of intense investigation, with a focus on the impact of ethanol production upon corn prices. Some of the research since the global food crisis focused on RFS1 and the initial policies associated with ethanol production, but RFS2 has been studied less because prices began to level. This article studies the impacts of RFS2, focusing on more data and a longer view of the policy.

Literature Review

Luchansky and Monks (2009) estimate supply and demand models for the US ethanol market between 1997 and 2006. Their research provides a useful overview of ethanol prices and demand prior to the start of the food crisis in 2007. The authors evaluate elasticities generated from their supply-and-demand models. To generate simultaneous supply-and-demand models they use a two-stage least squares approach. The banning of MTBE as a fuel additive was one of the leading causes of the increases in corn ethanol production in the early 2000s. However, this shock has ended and its effect has been incorporated into the normal market; hence it will not be considered in the updated model here.

The work of Luchansky and Monks updates an earlier study by Rask (1998) which similarly estimates supply and demand equations for the ethanol market. Rask uses data from 1984 to 1993 to generate elasticities and to draw conclusions about the state of the fuel ethanol market towards the end of the twentieth century, providing a framework for future research. Rask argues that due to the inelastic own-price of ethanol, any demand shock, such as policies attempting to increase demand, will have a greater effect on ethanol prices than production levels in the long run. This finding was also supported in the research by Luchansky and Monks, which showed that in the time period researched there was a switch from corn prices driving ethanol production to ethanol production driving corn prices.

Anderson and Coble (2010) argue that expectations in price discovery have a role in keeping corn prices high. They argue that the RFS can be seen as an indirect support for corn prices due to its impact on price discovery. The study models price discovery in the corn market considering the change in expectations due to the RFS mandate, utilizing conceptual and empirical models to determine the effects of the RFS upon the elasticity of demand for corn. The experiment shows that in the instance of a supply shock the presence of the RFS mandate results in higher equilibrium prices and quantities of corn than in an otherwise unaffected market. The closer the level of production is to the mandate, the greater the impact of a supply shock will be.

McPhail and Babcock (2012) evaluate commodity price variability due to ethanol policies, examining the RFS and the ethanol blend wall. The authors assert that the assumption of constant elasticity is not appropriate when dealing with ethanol policies, as the RFS mandate and blend wall only impact elasticity on a portion of the curve. The study uses theoretical models of the corn and gasoline markets to identify how the policies change elasticities, calculating that they reduce the price elasticity of corn and gasoline at certain points on the curve, increasing variability when impacted by supply shocks. A negative supply shock causes the RFS mandate to become binding, aggregate demand for corn becomes more inelastic, and a larger increase in price results. These findings are supported by empirical models. Within these models the elimination of the RFS results in a drop in price volatility.

Fabiosa (2012) examines the impact of ethanol subsidies and ethanol production expansion upon the corn and livestock markets. The study estimates that of the increase in corn price between 2004 and 2010, 3 percent was due to ethanol subsidies, 26 percent from market-based expansion of ethanol production, and 71 percent from other factors. If ethanol production remained at 2004 levels, corn prices in 2010 would have been 17 percent lower. This finding suggests that the RFS could have had a much greater impact on the increase in corn prices than ethanol subsidies alone, based on its influence on the expansion of ethanol production.

As ethanol production in the US doubled between 2000 and 2006 corn prices began to rise from the historic level of around $2 per bushel to $4 per bushel by 2007 (Luchansky and Monks 2009), and much higher throughout the period of study. This increase has resulted in the higher level of corn prices being considered a “new normal.” The price increase has had a number of consequences. The period under research experienced an abnormal number of events that have had an impact on global food prices, including the increase in demand for feed from developing countries like China as well as drought in Russia and Australia, and these outcomes must be considered as additional factors in the increase in price. It is the intention of this research to determine how much of that increase is due to the policies adopted by the US.

The key research question of the article concerns the magnitude of the impact of the RFS on corn prices and other food prices. The objectives of this research will be to determine if the magnitude of the impact of the RFS upon corn prices is economically significant. In addition, it will ascertain whether the RFS has had an impact on global food prices and, if so, the extent of that impact. The article will examine the claims of the popular press that the RFS had a role in the global food crisis and evaluate whether this is accurate.

Theoretical Model

The law of demand states that as consumers demand more of a given good, the price of that good will increase, ceteris paribus (Perloff 2008). In the corn ethanol industry, demand has come primarily from blenders for use as an additive to raise octane ratings. With the creation of the

RFS the quantity demanded of corn ethanol for blending was increased. According to the law of demand the price of corn ethanol must rise.

The increase in corn ethanol demand has increased the derived demand for corn. As the corn ethanol industry began to expand, so did demand for corn from that industry, causing a greater portion of corn produced to be directed toward fuel production, and taking away from other sources of demand, primarily livestock feed and high-fructose corn sweeteners. Based on the law of demand, the increase in derived demand for corn from corn ethanol producers will cause corn prices to rise. The question is, "What is the magnitude of this impact?"

The law of supply says that as the price of a good increases, producers will choose to produce a greater quantity of that good, all other factors held constant (Perloff 2008). Given the increase in corn price described above, corn producers chose to produce at a higher level, resulting in an increase in quantity supplied to the ethanol industry, which occurred in two ways. First, farmers chose to plant corn on more acreage, or chose to plant corn continuously instead of in rotation. Second, the higher price of corn-for-fuel as opposed to corn in other markets led a greater percentage of the corn produced to be directed to the ethanol market.

Corn has become more than just a staple crop in the current food system. High-fructose corn syrup is an integral component in processed foods, and the vast majority of livestock feed uses corn as its base. As indicated, the expansion of the ethanol industry has caused corn to be used at a greater rate in fuel production. Given that corn prices are rising as a result of the increase in derived demand, it stands to reason that food prices more generally may increase as well. This result is also true in the international market for corn, where the US dominated export markets prior to the establishment of the RFS. As ethanol production has expanded, corn exports from the US have fallen, leading to higher prices internationally (Zhang 2013).

In order to investigate how the RFS has impacted corn prices, a natural experiment model is used. Based on the law of demand, the RFS has impacted the derived demand for corn and raised corn prices. The natural experiment model determines by what amount corn prices have increased when compared to other control commodities as a result of the policy. The assumption of the model is that the change in price in the control commodity is representative of what would have been the change in corn price if the policy had not been enacted. Based on this assumption the control commodities represent what the price of corn would have been if the RFS had not been enacted. Wheat and barley were selected as controls. Wheat was selected because it is the primary commodity for human consumption around the world and would be representative of the price effects of corn on food grains. Barley is impacted by demand for livestock feed similar to corn and was selected in order to represent these price effects. The model allows for these price effects to be isolated and held constant and the impact of the policy to be evaluated separately. Based on these initial findings a more in-depth economic analysis is performed.

The above factors are incorporated into a corn price model to address the magnitude of the price effect of the RFS upon corn prices. A corn price discovery model with supply and demand components is estimated with corn price as the dependent variable and with independent variables that describe the expansion of the ethanol industry.

A second price model is used to estimate the effect of the RFS upon global food prices. A world food price index is the dependent variable in a similar model. Independent variables that are specific to the corn market or the US are replaced with global data as available.

Note that in this article price-dependent discovery models are used, composed of elements of both supply and demand. Often, a demand-and-supply system model with two equations would be estimated in which the demand equation includes variables representing quantity demanded, price, price of a substitute good, and income. The supply equation would be composed of variables for quantity supplied, price, and input costs. The price model used here estimates equilibrium prices rather than distinguishing separate demand and supply functions.

Based on the application of the law of demand the RFS is assumed to have had a non-negative impact on price. The primary hypothesis that will be tested is that the RFS has had an economically significant positive effect on corn prices. Economic significance will be judged to be at least a 25 percent increase in price caused by the RFS. As an extension, a secondary hypothesis tested is that the Renewable Fuel Standard has had a positive, statistically detectable, effect on food prices globally. The test will likely be more difficult due to the many factors affecting global food prices.

Empirical Models

The natural experiment model (Model 1) used here is similar to what is often called a difference-in-differences test. The idea is to compare a "treatment case" in which some event has occurred with a "control case" in which the event has not occurred. Here the event is the RFS2 policy. Two models (1a and 1b) will compare corn to barley and wheat. In each model dummy variables will indicate if the time period is before or after the passage of RFS2 and whether the commodity being tested is corn or not. An interaction variable is then generated, the variable of interest, which indicates the presence of the treatment. This variable is an interaction between the time dummy variable and the corn dummy variable, such that the resulting variable will have a value of one if the indicated data point is both corn and during the period after the passage of the RFS, and a zero if the data is not corn or is corn before the passage of the RFS.

When a price variable containing prices of both corn and the commodity being tested against is regressed on these three dummy variables, the coefficient of the interaction term represents the difference-in-differences based on the presence of the treatment. The price variable is transformed into a logarithmic form to help account for the relative difference in levels between commodity prices. This means that the calculated coefficient will be the percentage difference between corn price and the control commodity. If this calculation is significant the difference will indicate what the magnitude of the impact of the RFS has been on corn prices.

The first price model (Model 2) is a corn price model based on both supply and demand elements, estimated with corn prices modeled on corn production, soybean price, the RFS mandate, real corn input costs, and per capita income. Corn price and corn production represent price and quantity. Soybean price is used as an alternative consumption good as soybeans are the other primary feed stock for alternative fuel refiners and has an impact on the supply components as an alternative land use. Per capita income is included to complete the demand portion of the model, and real corn input costs are included to represent production costs for the supply model. Monthly time series data is used covering a period from 2003-2012. A two equation model is formulated, with the main equation expressed below:

(1a) *Corn Price* = f (*Corn Production Instrument*, *Soybean Price*, *RFS Mandate*, *Real Corn Input Costs*, *Per Capita Income*)

In this model corn production is endogenous, requiring an estimation method that can account for this issue, and three-stage least squares is used for this purpose. A model for corn production is built around lagged corn price and is used to produce an instrument that can be used to solve the endogeneity issue. The corn production model is:

(1b) *Corn Production* = f (*Lagged Corn Price*, *RFS Mandate*, *Real Corn Input Costs*)

Luchansky and Monks (2009) use a logarithmic demand model with ethanol production, real ethanol price, real corn price, real gasoline price, real MTBE price, and the total population of all MTBE-banning states. Their model uses data from 1997 to 2006, mostly prior to the institution of the RFS when MTBE was a more widely used additive. The model used in this article leaves out variables related to MTBE given that octane additive demand is now encompassed by total ethanol demand. The model also focuses on years that will allow for examination of the industry prior to and after the passage of the RFS, as well as updating the model that was developed by Luchansky and Monks.

A double-log functional form is used as it provides the best fit as well as the most statistically significant variables when compared to a linear model. A double-log model also allows for price flexibilities that do not vary with the observation values, although this does result in an assumption of constant elasticity. However, a drawback of using a logarithmic model is that it may result in an underestimation of the impact of the RFS mandate. As the RFS increases its effect is likely to become more binding, an effect consistent with Anderson and Coble's (2010) findings, and the use of a logarithm will diminish this effect, as a logarithmic curve will begin to level out as it continues. The flexibilities that are generated are used to analyze the degree to which the RFS mandate has impacted corn prices.

This model utilizes time series data and tests for both autocorrelation and multicollinearity. Luchansky and Monks utilize Newey-West standard errors in the correction of autocorrelation in their model, and this convention will be followed. However, the tests were performed on an OLS model, and Newey-West standard errors were not used in the final model.

The food price index model (Model 3) will also be calculated through three-stage least squares regression. It will use a world food price index as the dependent variable and will contain independent variables similar to the corn price model in order to maintain consistency. Monthly time series data is again used covering 2003-2012. The model is

(2a) *Food Price Index* = f (*Global Grain Production Instrument, RFS Mandate, Real Corn Input Costs, Per Capita Income*)

Similar to the corn price model both the food price index and the grain production variable are endogenous. A model is created to estimate grain production for use within the three stage least squares framework. The model is:

(2b) *Global Grain Production* = f (*Lagged Food Price Index, RFS Mandate, Real Corn Input Costs*)

The lack of a global grain input cost variable is a shortcoming of this model, as the real corn input cost variable is not a good proxy. Alternative data could not be found.

Data Description

The corn price model (Model 2) is built on six variables, with an observation period of January 2003 through December 2012. This period represents five years prior to the passage of RFS2 and five years after. The length of time is also consistent with previous evaluations of the ethanol market.

Three variables were obtained from the National Agricultural Statistics Service (NASS), data that are collected by survey. The dependent variable is Corn Price Received for which monthly data is available from 1866-2014. Corn Price is measured in dollars per bushel.

The first independent variable is Soybeans Price Received, which will be used as a substitute variable. Soybeans are a substitute for corn in production as well as in the production of biodiesel in the US. Monthly data is available for Soybean Price from 1913-2014.

Corn Production is available as annual data from 1866-2013. Corn Production is used as the quantity variable in the model. Each annual data point is duplicated for each month in the year to compare to the monthly data collected elsewhere.

The RFS Mandate variable is policy data representing the mandated level of alternative fuel blending that is set by the EPAct (RFS1) and the EISA (RFS2). The first three years of data hold zero values prior to the passage of the RFS. When transformed into logarithmic form, these zeroes are replaced with ones in order to return the proper values.

Real Corn Input is calculated from a price index established by the USDA Economic Research Service. It gives a value for costs associated with corn production annually from 1996 through 2012. The index is deflated with the Producer Price Index for grains and is used to create a monthly data set. Although this is not ideal, the variable caused significant multicollinearity when not deflated. Thus, for the integrity of the model that data set was modified.

Per Capita Income is collected from the Bureau for Economic Analysis and is available from 1959 through 2014.

The natural experiment model (Model 1) utilizes the prices of corn, wheat, and barley. The corn price variable is the same as described above. Wheat price and barley price are also collected from NASS.

The world food price index used in Model 3 is collected from the United Nations Food and Agriculture Organization (UNFAO) and consists of a weighted average of five commodity price sub-indices. The sub-indices themselves are weighted averages of the price relative to the base period of average price for the years 2002-2004. This index is available in monthly data from 1990 through 2014.

Global Grain Production (Model 3) is collected from the UNFAO and is available in annual data from 2003 through 2013. It is used as the quantity variable in the food price index model. Similar to corn production this variable is only available in annual data and is duplicated for each month in the year to compare to the monthly data. Each variable is summarized in Table 1 and Table 2.

Table 1. Data Description.

Variable name	Source	Date period	Data interval	Observation unit
Corn Price	USDA-NASS	2003-2012	Monthly	Dollars per bushel
Corn Production	USDA-NASS	2003-2012	Annual	Bushels
Soybeans Price	USDA-NASS	2003-2012	Monthly	Dollars per bushel
RFS Mandate	EPA/EISA	2003-2012	Annual	Billions of gallons
Real Corn Input	USDA-ERS	2003-2012	Monthly	Real dollars per planted acre
Per Capita Income	BEA	2003-2012	Monthly	Dollars
Barley Price	USDA-NASS	2003-2012	Monthly	Dollars per bushel
Wheat Price	USDA-NASS	2003-2012	Monthly	Dollars per bushel
Food Price Index	UN-FAO	2003-2012	Monthly	Weighted average of price
World Grain Production	UN-FAO	2003-2012	Annual	Million tonnes

Notes: RFS mandate levels are pulled from the EPAct of 2005 and the EISA of 2007 (Schnepf and Yacobucci 2013).

Table 2. Summary Statistics.

Variable name	Unit	Mean value	Minimum value	Maximum value
Corn Price	Dollars per bushel	3.74125	1.77	7.63
Corn Production	Bushels	11,734,434,100	10,087,292,000	13,091,862,000
Soybeans Price	Dollars per bushel	9.08008	5.23	16.20
RFS Mandate	Billions of gallons	7.09	0	15.2
Real Corn Input	Dollars per planted acre	342.513	210.824	508.384
Per Capita Income	Dollars	34482.15	28511	40689
Barley Price	Dollars per bushel	3.88033	2.26	6.54
Wheat Price	Dollars per bushel	5.36383	2.95	10.50
Food Price Index	Indexed price	160.9835	93.8885	240.0935
World Grain Production	Million tonnes	2162.423	1890.458	2353.288

Results and Discussion

The natural experiment models (Models 1a and 1b) yield results that begin to describe the impact on corn prices. The estimated differences are summarized in Table 3. Model 1a compares corn and barley, and the calculated difference shows the impact of the RFS on corn prices isolated from feed demand price effects. The result of the experiment indicates that corn prices are about 15 percent higher than barley prices as a result of the RFS. This finding supports the hypothesis that the RFS has had a positive impact on corn price and gives an idea of what the magnitude may be.

Table 3. Natural Experiment Results (Model 1)

Comparison	Estimated coefficient	Standard error	*p*-value	R^2	Number of observations
Corn vs. Barley	0.1477	0.0509	0.004	0.7184	240
Corn vs. Wheat	0.1873	0.0588	0.002	0.7157	

The experiment comparing corn prices to wheat prices (Model 1b) yields a similar result. The estimated difference calculated indicates that corn prices are 19 percent higher than wheat prices as a result of the RFS. This finding indicates that in isolation from other food price effects the RFS has increased corn prices. This result also supports the hypothesis, giving a different but also significant interpretation of the magnitude of the impact on corn prices. However, the difference between these two results does show the need for a more exact examination of the price effect.

Some consideration must be given to the assumptions of these models. The benefit of the approach used here is that it indicates what the trend in corn prices would have been if a policy had not been put into place. However, this attribute is also a shortcoming of this model, given that it assumes that the comparison commodities are not affected by the RFS. The complex interactions between commodities markets, especially livestock feed and food, mean that both wheat and barley are likely impacted by the RFS as well, due to a substitution effect. As demand for corn from the ethanol sector increases, the decrease in supply leads to a substitution in the livestock feed and human consumption markets by barley and wheat, respectively. This increase in demand would also raise the prices of barley and wheat. The estimated differences calculated in these models do not account for that increase in price, given that the approach builds in the independent assumption of no impact. Hence, while the percentage increases in corn price determined by these models are useful in determining the magnitude of the increase in corn price due to the RFS, they can only be considered a lower bound. The price models allow for a more thorough economic analysis to be carried out and a more accurate determination of the magnitude of the price effect.

The corn price model (Model 2) shows a high adjusted R^2 value, 0.9335, and all of the variables are statistically significant at the 0.05 level. Variance Inflation Factors (VIF) are calculated to determine if multicollinearity is present and a Durbin-Watson *d*-statistic is calculated in order to check for autocorrelation. These calculations were made based on an OLS regression prior to the three-stage least squares method being used. There were two variables with a VIF above ten, but neither could be removed from the model without compromising its theoretical consistency. Table 4 presents the calculated VIF values. Income is an essential part of a demand model, and the RFS Mandate is the variable being tested. The problem with collinearity in the RFS Mandate is likely the result of it being an annual variable. Within the EISA (RFS2) the mandate level is set on an annual basis, and thus holds the same value over the course of the year. Fortunately, the calculated VIFs are at an acceptable level. The calculated *d*-statistic of 0.2569 indicated that autocorrelation is present.

Table 4. Calculated VIFs for Corn Price Model (Model 2).

Independent Variable	VIF
ln Income	10.52
ln RFS Mandate	10.14
ln Soybean Price	5.02
ln Real Corn Input	2.94
ln Corn Production	1.34
Mean VIF	5.99

Because of significant autocorrelation, Newey-West standard errors are computed for the original OLS model that are robust to autocorrelation. Table 5 shows the estimated parameters.

Table 5. Corn Price Model Statistical Estimation Results (Model 2).

Dependent Variable is *ln Corn Price*					
Independent Variable	Estimated Coefficient	Standard Error (Newey-West)	*p*-value	Probability > χ^2	Number of Observations
Intercept	25.2489	9.3597	0.007	0.0000	108
ln Corn Production	-1.2030	0.2359	0.000		
ln Soybean Price	0.5293	0.0503	0.000		
ln RFS Mandate	0.1062	0.0311	0.001		
ln Real Corn Input	-0.5809	0.0590	0.000		
ln Income	0.5697	0.4519	0.207		

The corn production model used to generate an instrumental variable for corn production in the corn price model has mostly statistically significant variables with all signs in the expected direction, but the R^2 for the model was low. The R^2 value is 0.1836, indicating that the model only explains a small part of the data. However, the model is significant overall and allows for a useful instrument to be estimated for use within the final model. See Table A7 in the appendix for summarized results.

The variable of primary interest in this article is the RFS Mandate. The coefficient of the RFS Mandate is positive, consistent with the theoretical model's expectation of a positive impact on corn price. The variable is also statistically significant at the 0.05 level, indicating that it can be reliably used to provide interpretations about the mandate's impact upon corn prices. The price flexibility of 0.1062 indicates that a 1 percent rise in the RFS mandate level will result in a 0.11 percent increase in corn prices. This finding supports the hypothesis and indicates that the RFS has an inelastic effect on corn price.

The RFS mandate increased 280 percent from 2006 to 2012. Based on the corn price model, this change implies that the RFS mandate caused a 30 percent increase in corn prices over the same time period. This result does not account for the full increase that corn has seen between these years, meaning that there are other factors that have impacted corn price; however, it is an important component of the price increase. This result also shows that the natural experiment model has slightly underestimated the increase in corn prices as expected based on its assumptions, meaning that it is likely that both wheat and barley have seen an impact in price as a result of the RFS. Further research could show whether or not the effect of the RFS has indeed reached beyond just the corn market, impacting the food market and the livestock feed markets as well.

Corn Production, the quantity variable in this equation, is statistically significant and the estimated coefficient is negative, making it consistent with the law of demand. The estimated price flexibility is –1.203, meaning that as corn production increases by 1 percent, corn price decreases by 1.2 percent.

The estimated coefficient of 0.5293 for Soybean Price is positive, indicating a complementary relationship between Soybean Price and Corn Price. This calculation makes sense in the context of this model given that both corn ethanol and soybean biodiesel are used to meet the mandate; however, other factors also affect both prices as complements. As soybean price increases by 1 percent, corn price will increase by 0.53 percent.

Real Corn Input Cost is the only variable with an estimated coefficient that is inconsistent with the theoretical model. The price flexibility of –0.5809 indicates that as real input costs increase by 1 percent, corn prices fall by 0.58 percent. A typical supply model would show that as input costs increase, the price of a good should increase as well. However, due to the fact that the corn input cost is a real value and the corn price is a nominal value, this interpretation is unusual. This result represents a downside of this model; however, it would have created even more issues to use the corn input costs as a nominal value.

The calculation of the food price index model (Model 3) results in a high R^2 value, 0.9311, and a model containing many statistically significant variables. Tests for multicollinearity and autocorrelation on an OLS regression of the model indicate that there is likely a problem with autocorrelation, and income again has a VIF above 10 as displayed in Table 6, leading to some concern over multicollinearity. The estimated parameters from the three-stage least squares regression are displayed in Table 7.

Table 6. Calculated VIFs for Food Price Model (Model 3).

Independent Variable	VIF
ln Income	13.28
ln RFS Mandate	9.74
ln Grain Production	6.20
ln Real Corn Input	1.75
Mean VIF	7.74

Table 7. Food Price Index Statistical Estimation Results (Model 3).

Dependent Variable is *ln Food Index*					
Independent Variable	Estimated Coefficient	Standard Error (NW)	*p*-value	Probability > χ^2	Number of Observations
Intercept	-16.7332	3.8797	0.000	0.0000	108
ln Grain Production	0.6045	0.3461	0.081		
ln RFS Mandate	0.0146	0.0215	0.498		
ln Real Corn Input	-0.3469	0.0412	0.000		
ln Income	1.8313	0.2923	0.000		

The instrumental model for global grain production performs much better than the model for corn production, with an R^2 of 0.8774 and all variables statistically significant. This result indicates that the model is a very good predictor for the data. However, the model is highly simplified, possessing only the variables necessary to meet theoretical standards. This limitation does lead to some concern over its accuracy, but the model is still useful. (See Table A11 in the appendix for summarized results.)

The estimated food price index model does not yield a statistically significant result for the effect of the RFS Mandate. The positive value suggests that the RFS does have a positive impact on food prices; however, this conclusion cannot be stated with any statistical confidence. This result is consistent with previous research into the impact of US ethanol production on world food prices. Due to the complexity of the world food market it is difficult to discern with any confidence what the impact of ethanol production has been despite the claims of the popular press. These findings lead to the formal rejection of the hypothesis that the RFS has had a measurable positive impact on food prices.

Alternative models vary in their functional forms as well as the variables included. Use of a linear model, a quantity-dependent demand equation, and different proxy variables were examined as opportunities to address problems with multicollinearity and autocorrelation and to be consistent with previous research. These alternatives introduced other issues and results that were less meaningful.

These findings support the results of previous studies, indicating that the RFS has indeed had the effect on price anticipated, and showing that the RFS has caused similar price effects to the increase in ethanol production overall. In the study by Luchansky and Monks, and the earlier study by Rask, it was determined that a policy that increased demand for corn ethanol would have a greater impact on ethanol prices than ethanol production, and that such an impact would be a driver of corn prices. This determination is consistent with the results of these models, which indicate that the RFS, a policy which the theoretical model indicates has an impact on ethanol demand, has a positive effect on corn prices. This result also supports the findings of Anderson and Coble, which indicate that the RFS keeps price expectations high due to the possibility of the mandate becoming binding and thus equilibrium prices end up at a higher level. McPhail and Babcock's findings that the RFS increases price variability are also consistent with the results of this research. These findings lend additional support to the findings of many previous studies.

Conclusion

This article set out to determine the impact of the renewable fuel standard upon corn prices and food prices. The theoretical model supported expectations that the RFS did have a positive impact on corn and food prices. The possible magnitude of this impact was examined with the estimation of empirical models. The results support the hypothesis that corn prices were increased by the RFS; however, the impact on global food prices is more ambiguous.

The simple experiment models (Models 1a and 1b) provide a basic understanding of the policy's effects on the corn market. It allows for the analysis of this policy to be examined with a relatively simply model and presented in a simple way. The results show that when price effects of the food and livestock markets are controlled a policy effect is seen. Based on the findings of the other models it can also be seen that the increase in price identified by the simple experiment is only a lower bound because of unaccounted general equilibrium effects, as it is likely that wheat and barley prices have also been impacted by the RFS.

The key findings relate to the magnitude of the impact upon corn prices. The estimation of the corn price model (Model 2) indicates that corn prices increase 1.06 percent for every 10 percent increase in the RFS mandate. This result suggests that the RFS caused corn prices to increase 30 percent between 2006 and 2012, the period under study that was affected by the mandate. Not only is this consistent with the positive impact anticipated by the theoretical model, but it supports the definition of economic significance set out in the hypothesis. In the period of time studied corn prices increased 163 percent with higher peaks in between. Clearly, other factors were involved in the increase in corn price; however, this finding shows that the RFS was a significant contributor to that increase. This hypothesis could benefit from further research into the corn market and the significance of specific changes in price.

The hypothesis regarding the impact of the RFS upon food prices was rejected statistically based on the results of the food price model (Model 3). Although the model was a good fit to the data and yielded statistically significant variables, the RFS mandate variable was not significant. Studies attempting to analyze the increases in global food prices have found that the market is too complex to attribute the increase to any single factor. This complexity has been the issue in determining whether the claims of the popular press about the impact of US ethanol policies are accurate. The market is simply too complex to identify the impact of these policies with confidence. The findings of this article are consistent with other research attempting to examine the global food market. The model could be improved if more global data were used instead of US data and with these changes it is possible that a more confident result could be found.

This research could be improved if it incorporated a more complete understanding of the interplay between the corn market and the broader global food market. The interactions between these markets are complex, and the findings of these models leave out some aspects of the markets that are more difficult to model. Future research could attempt to construct a broad-based model of these interactions, which would be very useful to any study attempting to answer questions related to the impact of corn prices upon food prices.

The findings of this analysis lead to the conclusion that the claims of the popular press cannot be supported. The RFS has played a role in the increase in corn prices, but the same cannot be said about its role in the global food crisis. These findings nevertheless suggest that the policy should be reevaluated. Although the RFS has not caused the full increase in the price of corn, it has been a contributor. Other factors at play in this price increase, such as the droughts in Russia and Australia and increased demand in China, are temporary shocks. While their effects are significant, these are unavoidable events. The RFS is a policy, and thus its effect has been put in place by human action. This effect will at least last throughout the policy's life and therefore the policy should be reevaluated.

Research on the ethanol market has diminished since the passage of the RFS in 2007, and much of the literature surrounding the mandate could only estimate the impact it would have after implementation. This article has allowed for a longer-term view of the RFS and to estimate the effects that it has had on the corn market. The findings show that there is an opportunity to examine this policy in the light of rising food prices and a growing world population. It is critical to plan for reevaluation of any policy to avoid unintended impacts.

References

Anderson, J.D., and K.H. Coble. 2010. Impact of Renewable Fuels Standard Ethanol Mandates on the Corn Market. *Agribusiness* 49-63.

Bourne, J.K. 2009. The End of Plenty: Special Report, The Global Food Crisis. *National Geographic*, June: 29-59.

Bureau of Labor Statistics. 2014. Databases, Tables & Calculators by Subject. January. Available at: http://data.bls.gov/cgi-bin/surveymost.

Energy Information Administration. 2014. *Total Energy: Monthly Energy Review*. January 30. Available at: http://www.eia.gov/totalenergy/data/monthly/#renewable.

Fabiosa, J.F. 2012. The Long-run Impacts of Ethanol Subsidies and Ethanol Expansion on the US Corn and Pig Sectors. *EuroChoices* 29-35.

Food and Agriculture Organization. 2014. *FAO Food Price Index.* March 20. Available at: http://www.fao.org/worldfoodsituation/foodpricesindex/en/.

Hubbert, M.K. 1949. Energy from Fossil Fuels. *Science* 103-109.

Leff, J. 2012. Easing US ethanol mandate would help prevent food crisis-UN. *Reuters*, August 9.

Luchansky, M.S., and J. Monks. 2009. Supply and Demand Elasticities in the U.S. Ethanol Fuel Market. *Energy Economics* 403-10.

McPhail, L.L., and B.A. Babcock. 2012. Impact of US Biofuel Policy on US Corn and Gasoline Price Variability. *Energy* 505-513.

National Agricultural Statistics Service. 2014. *Quick Stats 2.0.* January. Available at: http://quickstats.nass.usda.gov/.

Perloff, J.M. 2008. *Microeconomics: Theory and Applications with Calculus.* Boston: Pearson Education.

Rask, K.N. 1998. Clean Air and Renewable Fuels: The Market for Fuel Ethanol in the US from 1984 to 1993. *Energy Economics* 325-45.

Roberts, M.J., and W. Schlenker. 2013. Identifying Supply and Demand Elasticities of Agricultural Commodities: Implications for the US Ethanol Mandate. *American Economic Review* 2265-95.

Schnepf, R., and B.D. Yacobucci. 2013. *Renewable Fuel Standard (RFS): Overview and Issues.* Washington, DC: Congressional Research Service.

Solomon, B.D., J.R. Barnes, and K.E. Halvorsen. 2007. Grain and Cellulosic Ethanol: History, Economics, and Energy Policy. *Biomass and Bioenergy* 416-425.

Zhang, M. 2013. US Risks Losing Status As World's Top Exporter Of Corn Due To The Ethanol Mandate. *International Business Times*, February 8.

Appendix

Natural Experiment Models (Models 1a and 1b):

Table A1. STATA OLS Output with Wheat as Control.

```
      Source |       SS       df       MS              Number of obs =     240
-------------+------------------------------           F(  3,   236) =  201.55
       Model |  31.3729759     3  10.4576586           Prob > F      =  0.0000
    Residual |  12.2454244   236  .051887392           R-squared     =  0.7193
-------------+------------------------------           Adj R-squared =  0.7157
       Total |  43.6184004   239  .182503767           Root MSE      =  .22779

------------------------------------------------------------------------------
   lnPriceCW |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          DT |   .5082907   .0415882    12.22   0.000     .4263591    .5902222
       DPCOR |   -.483244   .0415882   -11.62   0.000    -.5651755   -.4013124
      TreatX |   .1872888   .0588146     3.18   0.002     .0714201    .3031576
       _cons |   1.367513   .0294073    46.50   0.000     1.309579    1.425447
------------------------------------------------------------------------------
```

Table A2. STATA OLS Output with Barley as Control.

```
      Source |       SS       df       MS              Number of obs =     240
-------------+------------------------------           F(  3,   236) =  204.25
       Model |  23.8495403     3  7.94984676           Prob > F      =  0.0000
    Residual |  9.18561621   236  .038922103           R-squared     =  0.7219
-------------+------------------------------           Adj R-squared =  0.7184
       Total |  33.0351565   239  .138222412           Root MSE      =  .19729

------------------------------------------------------------------------------
   lnPriceCB |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          DT |   .5478925   .0360195    15.21   0.000     .4769317    .6188533
       DPCOR |  -.1478963   .0360195    -4.11   0.000    -.2188571   -.0769355
      TreatX |    .147687   .0509392     2.90   0.004     .0473333    .2480407
       _cons |   1.032165   .0254696    40.53   0.000     .9819883    1.082342
------------------------------------------------------------------------------
```

Corn Price Model (Model 2):

Table A3. STATA Output of Linear OLS Regression.

```
      Source |       SS       df       MS              Number of obs =     120
-------------+------------------------------           F(  5,   114) =  520.90
       Model |  290.857505     5  58.1715009           Prob > F      =  0.0000
    Residual |  12.7310078   114  .111675507           R-squared     =  0.9581
-------------+------------------------------           Adj R-squared =  0.9562
       Total |  303.588512   119  2.55116397           Root MSE      =  .33418

--------------------------------------------------------------------------------
     CornPrice |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
CornProduction |  -2.19e-10   3.38e-11    -6.49   0.000    -2.86e-10   -1.52e-10
  SoybeanPrice |   .2561857   .0270638     9.47   0.000     .2025725    .3097989
    RFSMandate |   .0215771   .0171953     1.25   0.212    -.0124867    .0556409
        Income |   .0001543   .0000303     5.09   0.000     .0000943    .0002143
 RealCornInput |  -.0052132   .0006622    -7.87   0.000     -.006525   -.0039014
         _cons |   .2983806   1.084217     0.28   0.784    -1.849445    2.446206
--------------------------------------------------------------------------------
```

Table A4. STATA Output of Double-Log Regression.

```
      Source |       SS       df       MS              Number of obs =     120
-------------+------------------------------           F(  5,   114) =  634.36
       Model |  20.0446017     5  4.00892034           Prob > F      =  0.0000
    Residual |  .720437651   114  .006319629           R-squared     =  0.9653
-------------+------------------------------           Adj R-squared =  0.9638
       Total |  20.7650393   119  .174496129           Root MSE      =   .0795

----------------------------------------------------------------------------------
     lnCornPrice |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-----------------+----------------------------------------------------------------
lnCornProduction |  -.2490265   .0970591    -2.57   0.012    -.4412999   -.0567532
  lnSoybeanPrice |   .5366868   .0495782    10.83   0.000     .4384727    .6349009
    lnRFSMandate |   .0707195    .021135     3.35   0.001     .0288513    .1125877
 lnRealCornInput |  -.5609288   .0512967   -10.93   0.000    -.6625472   -.4593103
        lnIncome |   .7589338   .2644545     2.87   0.005     .2350514    1.282816
           _cons |   1.071333   3.555477     0.30   0.764     -5.97204    8.114706
----------------------------------------------------------------------------------
```

Table A5. STATA Output of Double-Log Regression with Newey-West Standard Errors.

```
Regression with Newey-West standard errors          Number of obs  =       120
maximum lag: 1                                      F(  5,    114)  =    399.56
                                                    Prob > F        =    0.0000

---------------------------------------------------------------------------------
                 |             Newey-West
     lnCornPrice |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-----------------+---------------------------------------------------------------
lnCornProduction |  -.2490265   .1337636    -1.86   0.065    -.5140112    .0159582
  lnSoybeanPrice |   .5366868   .0605219     8.87   0.000     .4167933    .6565802
    lnRFSMandate |   .0707195   .0257054     2.75   0.007     .0197973    .1216417
 lnRealCornInput |  -.5609288   .0759568    -7.38   0.000    -.7113986    -.410459
        lnIncome |   .7589338   .3316383     2.29   0.024     .1019609    1.415907
           _cons |   1.071333    5.11921     0.21   0.835    -9.069783    11.21245
---------------------------------------------------------------------------------
```

Table A6. STATA Output of Three-Stage Least Squares Regression.

```
----------------------------------------------------------------------
Equation          Obs  Parms        RMSE    "R-sq"       chi2        P
----------------------------------------------------------------------
lnCornPrice       108      5    .1065906    0.9335    2368.45   0.0000
lnCornProd~n      108      4    .0677491    0.1836      50.38   0.0000
----------------------------------------------------------------------

---------------------------------------------------------------------------------
                 |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----------------+---------------------------------------------------------------
lnCornPrice      |
lnCornProduction |   -1.20298   .2359481    -5.10   0.000     -1.66543     -.74053
  lnSoybeanPrice |   .5293251    .050252    10.53   0.000     .4308329    .6278172
    lnRFSMandate |   .1061769   .0311463     3.41   0.001     .0451313    .1672225
 lnRealCornInput |   -.580853    .058951    -9.85   0.000    -.6963948   -.4653112
        lnIncome |   .5696744   .4518611     1.26   0.207    -.3159571    1.455306
           _cons |   25.24886   9.359742     2.70   0.007     6.904102    43.59362
-----------------+---------------------------------------------------------------
lnCornProduction |
       CornPrice |
             L1. |  -.0670034   .0105439    -6.35   0.000     -.087669   -.0463378
            L12. |   .0051053   .0081804     0.62   0.533     -.010928    .0211387
                 |
     RFSMandate |   .0109291   .0024888     4.39   0.000     .0060512     .015807
  RealCornInput |  -.0007641   .0001401    -5.45   0.000    -.0010388   -.0004895
           _cons |   23.61057   .0712063   331.58   0.000     23.47101    23.75013
---------------------------------------------------------------------------------
Endogenous variables:  lnCornPrice lnCornProduction
Exogenous variables:   lnSoybeanPrice lnRFSMandate lnRealCornInput lnIncome
     L.CornPrice L12.CornPrice RFSMandate RealCornInput
-----------------------------------------------------------------------------
```

Table A7. Corn Production Instrumental Model Results.

Dependent Variable is *ln Corn Production*					
Independent Variable	Estimated Coefficient	Standard Error (NW)	*p*-value	Probability > χ^2	Number of Observations
Intercept	23.6106	0.0712	0.000	0.0000	108
Corn Price (Lag 1)	-0.0670	0.0105	0.000		
Corn Price (Lag12)	0.0051	0.0081	0.533		
RFS Mandate	0.0109	0.0025	0.000		
Real Corn Input	-0.0008	0.0001	0.000		

Food Price Model (Model 3):

Table A8. STATA Output of Double-Log Regression.

```
      Source |       SS       df       MS              Number of obs =     120
-------------+------------------------------           F(  4,   115) =  588.38
       Model |  9.60724869     4  2.40181217           Prob > F      =  0.0000
    Residual |  .469438254   115  .004082072           R-squared     =  0.9534
-------------+------------------------------           Adj R-squared =  0.9518
       Total |  10.0766869   119  .084678042           Root MSE      =  .06389
------------------------------------------------------------------------------------
      lnFoodIndex |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
------------------+-----------------------------------------------------------------
lnGrainProduction |   1.286832   .2135064     6.03   0.000     .8639171    1.709747
    lnRFSMandate |   .0031318   .0166437     0.19   0.851    -.0298361    .0360998
  lnRealCornInput |  -.3288578   .0318034   -10.34   0.000    -.3918542   -.2658614
         lnIncome |   1.553263   .2388228     6.50   0.000     1.080201    2.026326
            _cons |  -19.15633   2.271437    -8.43   0.000    -23.65561   -14.65705
------------------------------------------------------------------------------------
```

Table A9. STATA Output of Double-Log Regression with Newey-West Standard Errors.

```
Regression with Newey-West standard errors          Number of obs  =       120
maximum lag: 1                                      F(  4,   115)  =    554.83
                                                    Prob > F       =    0.0000
------------------------------------------------------------------------------------
                  |             Newey-West
      lnFoodIndex |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
------------------+-----------------------------------------------------------------
lnGrainProduction |   1.286832   .2638913     4.88   0.000     .7641144     1.80955
     lnRFSMandate |   .0031318   .0208822     0.15   0.881    -.0382317    .0444954
  lnRealCornInput |  -.3288578    .038089    -8.63   0.000    -.4043049   -.2534107
         lnIncome |   1.553263   .3512436     4.42   0.000     .8575175    2.249009
            _cons |  -19.15633   2.310996    -8.29   0.000    -23.73397   -14.57869
------------------------------------------------------------------------------------
```

Table A10. STATA Output of Three-Stage Least Squares Regression.

```
----------------------------------------------------------------------
Equation          Obs  Parms        RMSE    "R-sq"       chi2        P
----------------------------------------------------------------------
lnFoodIndex       108      4    .0680384    0.9311    1530.46   0.0000
lnGrainPro~n      108      3    .0191421    0.8774     794.46   0.0000
-----------------------------------------------------------------------------------
                  |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------+----------------------------------------------------------------
lnFoodIndex       |
lnGrainProduction |   .6045169   .3461311     1.75   0.081    -.0738876    1.282921
     lnRFSMandate |   .0145753   .0215007     0.68   0.498    -.0275653    .0567159
  lnRealCornInput |  -.3469274   .0412162    -8.42   0.000    -.4277097   -.2661451
         lnIncome |   1.831344   .2923033     6.27   0.000      1.25844    2.404248
            _cons |  -16.73322   3.879734    -4.31   0.000    -24.33736   -9.129081
------------------+----------------------------------------------------------------
lnGrainProduction |
        FoodIndex |
             L12. |   .0002369    .000085     2.79   0.005     .0000704    .0004034
                  |
       RFSMandate |   .0063663   .0007873     8.09   0.000     .0048232    .0079095
    RealCornInput |  -.0001457   .0000279    -5.22   0.000    -.0002004    -.000091
            _cons |   7.652483   .0143035   535.01   0.000     7.624449    7.680518
-----------------------------------------------------------------------------------
Endogenous variables:  lnFoodIndex lnGrainProduction
Exogenous variables:   lnRFSMandate lnRealCornInput lnIncome L12.FoodIndex
     RFSMandate RealCornInput
------------------------------------------------------------------------------
```

Table A11. Global Grain Production Instrumental Model Results.

Dependent Variable is *ln Grain Production*					
Independent Variable	Estimated Coefficient	Standard Error (NW)	*p*-value	Probability $> \chi^2$	Number of Observations
Intercept	7.6525	0.0143	0.000	0.0000	108
Food Index (Lag 12)	0.0002	0.0001	0.005		
RFS Mandate	0.0064	0.0008	0.000		
Real Corn Input	–0.0001	0.0000	0.000		