Corn Ethanol and Food Prices

An honors thesis for the Department of Economics

Matthew Curtis

Contents

1 Introduction

Ethanol policy is a complicated issue. There are many environmental, political, and economic consequences of ethanol subsidy. This paper does not aim to fully analyze the costs and benefits of ethanol policy. Comparing the value of fuel independence, environmental benefits, increasing food prices, and the relative welfare of farmers is at least a cost benefit analysis problem if not a political question. Neither does this paper aim to predict the future impacts of these policies. Rather, it aims to investigate the historic link between ethanol production and food prices within the US market. The interactions between food and ethanol and food markets are complicated and suffer from numerous identification problems. However, if ethanol policy is to be considered in a rational manner, it is useful to try to attempt to estimate its effects on food prices.

Ethanol has been diverting an increasingly large percentage of the corn crop from food use to fuel production (see Graph 1). This ethanol boom has been supported by numerous government policies, including several key ones starting in 2005. This rapid If corn's supply is perfectly elastic, we expect to see an increase only in corn quantity. If corn's supply is perfectly inelastic, we expect to see an increase in corn price. If it is somewhere in the middle, we expect to see an increase in both (see Graph 2).

This paper attempts to evaluate the impact on food prices by the development of the corn ethanol industry as well as various ethanol promoting policies. There are many possible approaches to analyzing ethanol's effects on food prices. As outlined in the Literature Review, there have been many various attempts to model the effect. This paper aims to analyze the effects by constructing a model of supply and demand for several foodstuffs and ethanol based on historical data. It uses three stage least squares estimators to estimate this model and find the relevant price elasticities. This paper will discuss the relevant literature, give an overview of relevant data, explain the theoretical model it uses, and present its results. Finally, it will discuss possible implications of the results.

2 Background

In the recent search for renewable energy sources, ethanol has emerged as a front runner. It has many desirable traits as a fuel. Ethanol is a liquid fuel that can be easily used by combustion engines. Standard petroleum burning combustion engines can handle a mixture of up to 15 percent corn ethanol by volume. Since ethanol is less energy dense than petroleum, exceeding this blend ratio requires specialized flex fuel engines, which are being produced at an increasing rate. Ethanol can be produced from various crops, such as sugar cane or corn. Chemically, plant sugars such as glucose can be fermented to produce ethyl alcohol, otherwise known as ethanol. Converting plant material into a liquid fuel is desirable for many reasons. The carbon content of the plant material is mainly absorbed from the atmosphere, so the combustion of plant materials is carbon neutral. Ethanol fuel's only carbon footprint is that of the farming and manufacturing techniques, which while significant is still perhaps an improvement over fossil fuels. Politically, having fuel that can be produced from farm products would decrease dependence on foreign oil imports, especially in countries with massive agricultural sectors such as the United States or Brazil. It would also increase the demand for agricultural goods, increasing the welfare of farmers and pleasing powerful farm lobbies. Ethanol production has undergone a boom in the last decade, with significant political support.

The two largest ethanol producing nations are currently the United States and Brazil. Brazil is producing ethanol from sugar cane, distilling sucrose into ethanol. This is fairly efficient, although it is still heavily promoted by various government incentives. In the United States, the vast majority of ethanol is produced from various sugars extracted from corn. Compared to cane sugar, corn has a larger carbon footprint and is less cost effective to produce. However, the United States government has strongly subsidized its production through various laws and regulations. The United States has also been trying to develop cellulosic ethanol, produced from cellulose which can be extracted from non-food crops such as switchgrass, but these technologies are in their infancy and not yet competitive.

Corn ethanol can be produced in two different ways. Dry milling involves the grinding of entire corn kernels into meal which is then converted into dextrose. The side product, stillage, is useable as livestock feed. Wet milling uses sulfuric acid to separate corn slurry into oil, gluten, and starch. The starch can be converted into ethanol, sweeteners such as high fructose corn syrup, or sold as corn starch. Corn gluten and oil are sold as secondary products. Both production techniques require energy (often supplied from natural gas generators) water, enzymes, ammonia, and yeast. As of 2000, 60% of plants were wet milling. (McAloon et al. 2000). Despite producing less useful byproducts and having smaller capacity, dry milling plants are less capital intensive and thus a lot of the growth in capacity has been through the production of dry milling plants.

Since around 2000, corn ethanol production has been undergoing a period of massive expansion (see Graph 3). This so called ethanol boom has resulted in nearly exponential growth in output of ethanol and the construction of many new ethanol processing plants. However, except for a brief interlude around 2007-2008, ethanol has been more expensive than gasoline when it has been adjusted for its energy content (one gallon of ethanol has roughly 80% of the energy content of a gallon of gasoline). (See Graph 4). This growth would not be possible without the aid of the federal and local government subsidy.

The US Government has passed several pieces of legislation and tax codes designed to promote the production of corn ethanol. The Renewable Fuels Standards Program (RFS), introduced by the 2005 Farm Act and expanded by the 2007 Energy Independence and Security Act of 2007, the RFS Program mandates that certain minimum quantities of corn ethanol, cellulosic ethanol, and advanced biofuels are blended with gasoline each year. The Volumetric Ethanol Excise Tax Credit (VEETC) gives an IRS tax credit to firms that blend pure ethanol with gasoline of 0.45 dollars per gallon. It expired in 2011. The Small Ethanol Producer Tax Credit was a 0.10 dollars per gallon tax incentive applied to the first 15 million gallons of ethanol produced by distillers who produce less than 60 million gallons of ethanol per year, with the stipulation that it be sold for use as fuel. This subsidy also expired in 2011. The Ethanol Infrastructure Grants and Loans Guarantee is a program that offers grants to firms investing in ethanol fuel related infrastructure provided through the Rural Energy for America program. A 2.5 percent ad valorem tariff is applied to fuel ethanol by US Customs and Border Protection, which has successfully discouraged large scale imports. Congress banned the chemical MTBE in 2005, which had previously been used extensively as an oxygenating agent to increase the octane number of gasoline. Ethanol serves as a substitute oxygenator. Also, every single state has at least some degree of their own incentive programs. Finally, while not directly related to ethanol, the US government heavily subsidizes the production of corn, which increases the availability of raw resources for ethanol production.

Unfortunately, ethanol has its drawbacks. While it has a lower carbon footprint than gasoline, it still has a significant carbon footprint due to the energy intensive methods of farming and refining associated with its production. Ethanol is also expensive to produce, and it has historically been more expensive per energy unit than gasoline. As noted above, ethanol has lower energy density than the gasoline equivalent, so it must be consumed in larger volumes if used as a fuel by itself. Ethanol is water soluble, making transportation via pipeline technically difficult. Existing infrastructure is not properly suited for ethanol use.

However, the most concerning drawback to fuel ethanol is its reliance on food crops as raw ingredients. Ethanol production diverts agricultural resources from food production to ethanol production, potentially raising food prices (see Graph 5). Ethanol is linked to food prices through the production of corn. As US ethanol requires corn to produce, an increase in ethanol production is an increase in the demand for corn. This will in effect increase both the quantity supplied and price of corn. The exact effects are not immediately clear, as the elasticity of supply will dictate how much the increase in demand will raise prices and how much it will increase the quantity produced. Indirectly, factors that increase ethanol production will affect corn demand, such as gasoline prices (as ethanol is a substitute for gasoline) and ethanol subsidies. Since ethanol demand is an increasingly large proportion of the total demand for corn (see Graph 2), this is a real concern. The effects on the corn market will have wider consequences. Corn is used to produce many food products and is fed to animals raised as meat. Corn is also a substitute for many crops, such as soy. Finally, an increase in the production of corn will consume agricultural factors of production, possibly raising the price of other crops. An increase in corn demand that increases the price of corn affects other food prices as an increase in costs of production or an increase in the price of a substitute good. The degree by which the price of corn affects the price of other foodstuffs is of course dependent on the structure of the markets for the foodstuffs, but at least some increase is expected. Food security is a pressing issue, leading to negative welfare effects for the poor and political instability. If ethanol production significantly increases food prices, the benefits of ethanol use may be outweighed by the resulting negative effects. It is also worth noting that by increasing the demand for corn ethanol increases the significant negative externalities associated with farming, such as fertilizer run off and aquifer depletion.

Ethanol within the United States has historically been traded in what is effectively a closed market. Large scale ethanol production is a recent phenomenon, and the infrastructure required for cost effective long distance transportation has not been developed. There are also significant policy barriers to international trade of ethanol. Until recently the US Congress blocked the import of Brazilian sugar cane ethanol with a protective tariff, the high cost combined with the artificially high domestic demand produced by subsidy programs resulted in little to no exports. However, by using corn the production of ethanol has effects on the fairly integrated markets for food products. Increasing the demand for corn, ethanol will increase the quantity of domestic corn demanded and the price of corn. Since corn is a substitute for other foodstuffs, this will cause other food prices to rise, perhaps reducing exports. Also, production of corn requires resources that could be used to produce other agricultural products. There is widespread concern that ethanol production will increase the price of food in global markets. By intervening in the ethanol market, the US government policies have far reaching consequences.

3 Literature Review

The link between ethanol and food prices has been frequently discussed in politics and the media in the last few years, but is a fairly new topic for economic analysis. Several different approaches have been undertaken to estimate ethanol's effects.

One frequent approach has been to use vector autoregressive models of corn and ethanol prices. For example, Zhang et al. in their paper "Ethanol, Corn, and Soybean Price Relations in a Volatile Vehicle-Fuels Market" use Granger causality tests, a vector error correction model (VECM), and a Multivariate Generalized Autogregressive Conditional Heteroskedasticty (MGARCH) model to examine the correlation between oil, gasoline, ethanol, corn, and soy prices. Their results show short run shocks passing from fuel prices to crop prices but also predict that long run agricultural market forces will negate these shocks unless "a major increase in ethanol production shifts substantial amounts of arable land out of food production" (Zhang 322). (It is unclear whether they consider consumption of roughly 40% of the corn crop as substantial.) This approach, while mathematically complex, is in a sense the simplest, it merely looks for empirical connections between ethanol, fuel, and food prices without attempting to model the ways in which they interact.

The most straight forward mechanism by which ethanol production increases food prices is a simple supply and demand model. Ethanol requires the use of corn, which will increase the demand for corn and thus the price and quantity produced. The degree by which ethanol affects price as opposed to quantity depends on the price elasticity of the supply of corn. In the short run corn production is constrained by the available acreage, meaning that any increase in demand will result primarily in price changes. Gustafson (2002) suggests that the supply of corn for ethanol is elastic, at least in the long run. Using two focus groups of 20 North Dakota farmers, the micro level price elasticity of supply was estimated as follows: an 11 cent increase in corn prices would result in an increase in corn acreage by 5% of total harvested acreage (154,000 acres). Sugar beet growers and feed corn growers were particularly interested in expanding corn acreage. They also expressed increased interest in corn planting conditional on genetically modified and hybrid strains becoming increasingly available.

Another mechanism by which ethanol can affect price is increasing the link between food prices and fuel prices. Several studies suggest that as the number of flex fuel vehicles (and ethanol fuel usage in general) grows, the price elasticity between food and fuel prices increases. Salvo et al.(2011) studied the Brazilian economy, which has a much larger number of flex fuel vehicles than the United States. They developed a stylized model of the fuel and ethanol markets in Brazil that simulates consumer arbitrage between gasoline and ethanol, implying that an increase in flex fuel technology and ethanol arbitrage ties food price volatility closer to oil price volatility. Using both OLS and VAR models, they conclude that the empirical price data "guardedly" supports their arbitrage model. Another study by Serra et al. (2011) uses a vector error correction model (ECM) and a GARCH model to empirically analyze the connection between gasoline and food price volatilities in Brazil and comes to similar results. A separate study by Serra et al. (2011) uses a smooth transition vector error correction model (STVECM) to examine the US market for similar trends, concluding that there is a strong and increasing link between corn prices and gasoline prices and that the increasing use of ethanol is the primary cause of this link. Demonstrating the connection between fuel price volatility and food price volatility is another way to analyze how ethanol production can increase food price.

At the other extreme from VAR style approaches is the creation of an entirely theoretical model for ethanol production. Charkravorty et al.'s 2012 paper "Do Biofuel Mandates Raise Food Prices?" creates such a model. They create a model of transportation demand, food demand, oil production, ethanol production, and agricultural production to examine the effects of EU and US biofuel mandates. Key features of the model include endogenous land allocation; classification of land by high, medium, or low quality; creation of Cobb-Douglass demand functions for 5 markets: US, Europe, high income countries, medium income countries, and low income countries; exogenous oil stocks and the use of a Hotelling model; income sensitive dietary preferences; and the use of elasticities empirically found by other studies. In their model, biofuel mandates increase the production of biofuels, increase land scarcity, increase food prices, increase CO2 emissions due to increased cultivation, reduce exports from mandate nations, and decrease net world welfare. They tested the predictive accuracy of the model, reporting that the "difference between observed and projected values is systemically less than 10%" (Charkravorty et al. 4). This model was used to predict significant future increases in food prices,the welfare effects for each region, the changes in CO2 emissions, the changes in acreage of land under cultivation, and the changes in export levels due to the production and mandate of biofuels. The approach is an ambitious attempt to model the global dynamics of biofuel production. It makes a lot of simplifying assumptions that allow an impressively inclusive model with a very large scale.

Somewhere in between VAR modeling and the construction of theoretical global models are attempts to model the supply and demand system for corn.

3.1 Models of Supply and Demand: Two-stage least squares

This paper attempts to model supply and demand systems, which have multiple endogenous variables. Due to problems of endogeneity, structural equations such as a supply and demand system cannot be consistently estimated by OLS. Traditionally, supply and demand has frequently been estimated by two-stage least squares (2SLS). Two-stage least squares is a an estimation technique that accounts for endogenous variables. In the first stage the endogenous variables are regressed on all the exogenous variables (the reduced form equations). In the second stage, the predicted values of the endogenous variables are used to estimate the structural equations. This method is an application of instrumental variables, using the exogenous variables as instruments for the endogenous variables. For 2SLS to work, the order and rank conditions must be met. These can be combined into the following rank order condition: if there are m equations and m endogenous variables, the structural equation is identified if there is at least one non-zero determinant of order (M-1)(M-1) that can be constructed from the coefficients of the variables excluded from that particular equation but included in other equations. In other words, there must be at least one independent exogenous variable for each right hand side endogenous variable (but not the same as the exclusion restriction).

2SLS is frequently applied to supply and demand systems. An informative example is that provided by Epple and McCallum in their 2005 paper "Simultaneous Equation Econometrics: The Missing Example." In this paper, the two construct a model of the supply and demand for broiler chickens, treating price and quantity as endogenous and using supply and demand as their two structural equations. They use supply-shifting exogenous variables as instruments when estimating the demand equation and use demand-shifting exogenous variables when estimating the supply equations. The demand shifters are GDP and the price of supplementary goods (beef). Time as a proxy of technological progress and the price of corn were included as exogenous supply shifters. They treated exports as exogenous and proxied them with beef, veal, and pork exports. Their also specify their equations as first order autogregressive due to a high Durbin-Watson statistic and results with signs that were unexpected.

The pioneering use of 2SLS for ethanol markets was Keven N. Rask's 1998 paper "Clean air and renewable fuels: the market for fuelethanol in the US from 1984 to 1993". Writing in the early days of the ethanol boom, his paper is the first real attempt to model the ethanol fuel market. His model is both time series and cross-sectional by state, but avoids fixed effects by state as he believed that there was little differences in ethanol fuel markets between states. His model includes a separate demand curve for ethanol as a straight fuel and ethanol as a fuel supplement. His supply shifters for supply are corn prices and the price of ethanol co-products, specifically corn gluten. He also uses a time trend as a proxy for technological progress. His demand shifters are the number of registered cars in a state and the distance to an ethanol producing state as a proxy for transportation cost. He also included state level subsidy variables. His model reports an estimate of the elasticity between the quantity of ethanol and the price corn of 3.03 and the elasticity between the quantity of ethanol and the price of gasoline to be 2.13. He reports an estimated own price elasticity of supply for ethanol to be a very small 0.37, suggesting significant "over-subsidization" and that supply shocks are mostly felt though changes in price. Finally, the own price elasticity for demand was 0.75.

3.2 Models of Supply and Demand: Three-stage least squares

Three stage least squares is a method for estimating simultaneous equations developed by Arnold Zellner and H. Theil in 1962. While two stage least squares uses two rounds of OLS estimation to "purify" endogenous variables, three stage least squares goes further and estimates each equation simultaneously. It accounts for the correlation of the disturbances of the different structural equations, and parallels the difference between a SUR (seemingly unrelated regressions) model and regular OLS. Mechanically, 3SLS is the Generalized Least Squares version of 2SLS. The procedure is to find 2SLS estimates and then using the 2SLS results, estimate the cross-equations variance and covariance similar to SUR estimation, and then finally estimate the equations by generalized least squares. As it uses 2SLS, 3SLS must fulfill the rank and order conditions. Because it uses additional information about the correlation between the error terms, 3SLS is more efficient than 2SLS.

Three stage least squares is often used for studies of agricultural demand as agricultural goods often have several endogenous submarkets. For example, Roy and Edwin (1975) used both 2SLS and 3SLS to study the US sorghum market, splitting sorghum demand into exports, feeds, and storage. Their model was yearly and managed to obtain significant results despite a small number of observations. They also reported that their 3SLS estimations had smaller errors and more accuracy than the 2SLS ones.

A model for corn demand was developed by Fortenbery et al. (2008). They decided to focus solely on the corn market and divided corn production into three categories: feed, export, and FAI (food, alcohol, and industrial). They assumed that the price of corn was determined by supply and by demand in each of the three submarkets. As they wished to find the effect of ethanol production, an endogenous variable, on corn price, another endogenous variable, they decided to use the three stage least squares estimator. Their model used five endogenous variables for corn: feed, FAI, exports, price, and supply. As their model was quarterly, supply relied on not just production but also beginning and ending stocks. They treated ethanol production as an exogenous shifter of FAI demand. Other exogenous variables of note were the US dollar index as a proxy for the US exchange rate and global wheat production as exogenous shifter of exports, soybean price as an exogenous substitute for feed corn, and a time variable as a proxy for technological progress in ethanol production. They conclude that a 1% increase in ethanol production caused a 0.16% increase in corn price on average ceteris paribus.

4 Data

This paper looks at several different agricultural markets: corn, soy, wheat, and pork. It also considers the ethanol market, a subset of the corn market.

The data used for this model can be divided into the following categories by market: endogenous price and quantity, exogenous demand shifters, and exogenous supply shifters. Due to the recent emergence of the ethanol market, pricing data for ethanol was only available since 1982. Since agricultural products are produced in a yearly crop cycle, yearly data was the smallest frequency that made sense for many variables. Unfortunately, this only leaves 28 observations, which is a problem.

All price data were originally obtained in nominal values. Real prices were calculated by using the Core Personal Consumption Expenditures deflator provided by the St. Louis Federal Reserve.

See Table 1 for summary statistics.

4.1 Corn

4.1.1 Endogenous variables

Quantity (in millions of bushels) was obtained from the USDA ERS Feed Grains Database. Price (in dollars per bushel) was obtained from the USDA ERS Commodity Costs and Returns Database.

Quantities for each subcategory of demand were obtained from the USDA ERS Feed

Grains Database.

4.1.2 Exogenous variables

The production costs for corn were used as exogenous supply shifters. Using the USDA ERS Commodity Costs and Returns Database, the yearly average costs per bushel for producing corn were calculated for several different factors of production.

Another exogenous supply shifter used was the governmental subsidy, using the Environmental Working Group's calculation based on USDA data.

US population, US GDP per captia, provided by the World Bank, were included as exogenous demand shifters to account for income and number of consumers.

World population and GDP per capita, provide by the World Bank, and the global price of wheat, provided by the IMF, were used as proxies for global demand for US export.

The price of sugar was obtained from the USDA Sugar and Sweeteners section and was treated as an exogenous demand shifter for corn sweetener demand.

The details of various governmental incentive programs are included as demand shifters for corn used to produce ethanol. The mandated level of ethanol mixing mandated by the Renewable Fuel Standards program was obtained from the EPA. Gasoline pump prices provided by the Nebraska ethanol board were used as a demand shifter for the demand for corn for ethanol. Gasoline quantity consumed, provided by the Energy Department, was also used as a demand shifter.

Real interest rate was used as a demand shifter for corn storage. It was acquired from the World Bank database.

4.2 Soy

4.2.1 Endogenous variables

Quantity (in millions of bushels) was obtained from the USDA Oil Crops Yearbook Data. Price (in dollars per bushel) was obtained from the USDA ERS Commodity Costs and Returns Database.

4.2.2 Exogenous variables

The production costs for soy were used as exogenous supply shifters. Using the USDA ERS Commodity Costs and Returns Database, the yearly average costs per bushel for producing soy were calculated for several different factors of production.

US population, US GDP per captia, US population, World GDP per capita, world population, and global wheat price were included as exogenous demand shifters. GDP and population were obtained from the World Bank. The global price of wheat provided by the IMF.

4.3 Wheat

4.3.1 Endogenous variables

Quantity (in millions of bushels) was obtained from the USDA Wheat Yearbook Data. Price (in dollars per bushel) was obtained from the USDA ERS Commodity Costs and Returns Database.

4.3.2 Exogenous variables

The production costs for wheat were used as exogenous supply shifters. Using the USDA ERS Commodity Costs and Returns Database, the yearly average costs per bushel for producing wheat were calculated for several different factors of production.

US population, US GDP per captia, US population, World GDP per capita, world population, and global wheat price were included as exogenous demand shifters. GDP and population were obtained from the World Bank. The global price of wheat provided by the IMF.

4.4 Pork

4.4.1 Endogenous variables

Quantity (in millions of lbs) and price (in dollars per pound) were obtained from the USDA ERS Meat Statistics database.

4.4.2 Exogenous variables

The production costs for pork were used as exogenous supply shifters. Using the USDA ERS Commodity Costs and Returns Database, the yearly average costs per pound for producing pork were calculated for several different factors of production.

US population, US GDP per captia, US population, World GDP per capita, world population, and global wheat price were included as exogenous demand shifters. GDP and population were obtained from the World Bank. The global price of wheat provided by the IMF.

5 Model

This paper aims to model the US markets for ethanol, corn, soy, wheat, and pork. The following assumptions are made regarding the interactions of the markets: 1. Corn is a substitute good for wheat and soy. 2. Corn and soy are factors of production for pork and ethanol 3. Wheat is a substitute good for soy. 4. Oil and fuel prices are exogenous. Ethanol production is relatively small compared to oil, and thus does not have a large impact on oil prices.

Because supply and demand are simultaneous equations, there is a parameter identification issue. In both models, simultaneous equations are used to allow for several variables to be endogenous. 3SLS estimation is used because there is good reason to assume that error terms are correlated (the simultaneous equations are all agricultural supply or demand models.)

Because of the interaction between markets, the price and quantity of corn, wheat, soy, pork, and ethanol are considered to be endogenous. For soy and wheat, we are interested in how an increase in the price of corn effects the demand for these goods, and thus the demand equations must be modeled. For pork, we are interested how the price of corn affects the supply of pork, and the supply equation must be modeled. An overall supply and demand model for corn is estimated using the same supply and demand shifters used in the first model.

For corn, this paper is concerned with how ethanol policy increases the demand for corn, so the demand equation for corn for ethanol must be estimated.

Corn's primary products are feed, starch, oil, and seed. Seed corn is a tiny percentage of corn usage. Corn oil data is unavailable through the USDA ERS. Starch is used for several purposes: production of sweeteners, production of various other foodstuffs, and production of ethanol. Because of the limitations of the data, this model will assume corn can be used for ethanol, eners, or animal feed. It can also be exported to a foreign country or stored.

3SLS is used to estimate the effects of various subcategories of demand for corn on the price for corn. The demand for corn is split into several categories.

This model assumes constant elasticities of supply and demand. By using the natural logarithm of each variable we can linearize each equation in such a way that the regression coefficients are elasticities.

Corn for ethanol demand:

$Q_{cornforethanol} = \beta_0 + \beta_1 P_c + \beta_2 time + \beta_3 rfs + \beta_4 Q_{gasoline} + \epsilon$ (1)

The demand for corn to be used for ethanol is a function of the price of corn, technological progress proxied by a linear time trend, and the RFS mandate quantity.

Corn for feed demand:

$Q_{cornforfeed} = \beta_0 + \beta_1 P_c + \beta_2 Q_p + \beta_3 P_{soy} \epsilon$ (2)

The demand for corn to be used for feed is a function of the price of corn, the quantity of pork produced, and soy prices.

Corn for export demand:

$Q_{cornforexport} = \beta_0 + \beta_1 P_c + \beta_2 P_{globalwheat} + \beta_3 WorldGDPpercapita + \beta_4 Worldpop + \epsilon$

(3)

The demand for corn to be exported is a function of the price of corn, global food price levels proxied by global wheat price, world population, and average world GDP per capita.

Corn for sweetener demand:

$Q_{cornforsweeteners} = \beta_0 + \beta_1 P_c + \beta_2 P_{sugar} + \beta_3 USpop + \beta_4 USGDPpercapita + \epsilon$ (4)

The demand for corn to be used for sweeteners is a function of the price of corn, the price of cane sugar, US population, and US GDP.

Corn supply: $Q_c = \beta_0 + \beta_1 P_c + \beta_2 costs_c + \beta_3 P_{c,t-1} + \epsilon$ (5)

Corn supply is a function of the price of corn, the average per unit costs of producing corn, and the lagged price of corn.

Pork demand: $Q_p = \beta_0 + \beta_1 P_p + \beta_2 USpop + \beta_3 USGDPpercapita \beta_4 P_{globalwheat} + \beta_5 WorldGDPpercapita + \beta_6 Worldpop + \epsilon$ (6)

Pork demand is a function of the price of pork, US population, US GDP per capita, world population, average world GDP per capita, and global food price levels proxied by global wheat price, world population.

Pork supply: $Q_p = \beta_0 + \beta_1 P_p + \beta_2 P_c + \beta_3 costs_p + \beta_4 P_{p,t-1} + \epsilon$ (7)

Soy demand: $Q_s = \beta_0 + \beta_1 P_s + \beta_2 P_c + \beta_3 USpop + \beta_5 USGDPpercapita \beta_6 P_{globalwheat} + \beta_7 WorldGDPpercapita + \beta_7 Worldpop + \epsilon$ (8)

Soy demand is a function of the price of soy, the price of corn, US population, US GDP per capita, world population, average world GDP per capita, and global food price levels proxied by global wheat price, world population.

Soy supply: $Q_s = \beta_0 + \beta_1 P_s + \beta_2 costs_s + \beta_3 P_{s,t-1} + \epsilon$ (9)

Corn supply is a function of the price of soy, the average per unit costs of producing soy, and the lagged price of soy.

Wheat demand: $Q_s = \beta_0 + \beta_1 P_w + \beta_2 P_c + \beta_3 USpop + \beta_5 USGDPpercapita \beta_6 P_{globalwheat} + \beta_7 WorldGDPpercapita + \beta_7 Worldpop + \epsilon$ (10)

Wheat demand is a function of the price of wheat, the price of corn, US population, US GDP per capita, world population, average world GDP per capita, and global food price levels proxied by global wheat price, world population.

Corn price:

$P_{corn} = \beta_0 + \beta_1 Q_{cornsupply} + \beta_2 Q_{cornforethanol} + \beta_3 Q_{cornforsweeteners} + \beta_4 Q_{cornforexports} + \beta_5 Q_{cornforfeed} + \beta_6 P_{c,t-1} + \epsilon$ (11)

Price of corn is a function of the subcategories of demand, supply, and lagged price.

6 Results

See table 2, 3, and 4.

6.1 Ethanol

Price does not seem to have a significant effect on the quantity of corn demanded for ethanol. An increase in the flex fuel mandate by 1 million gallons increases the demand for corn ethanol by 0.00566% on average ceteris paribus. The estimated coefficient for the linear time trend indicates that the quantity of ethanol demanded increased 6.53% annually, on average ceteris paribus. Gasoline quantity was not significant, but a 1% increase in gasoline price increased the quantity demanded for ethanol by 0.42% on average ceteris paribus.

6.2 Exports

This model estimates the elasticity of demand for corn exports to be insignificant. No other variables seem to be significant, and the regression has a low R-squared value of 0.1716.

6.3 Feed

The model estimates the elasticity of demand for corn for animal feed to be -0.20, on average ceteris paribus. An increase in the number of pounds of pork produced by 1% decrease the demand for feed by 0.20% on average ceteris paribus. An increase in the quantity of soy by 1% decreases the demand for feed by .11% on average ceteris paribus.

6.4 Sweetener

The model estimates the elasticity of demand for corn for sweeteners to be -0.20, on average ceteris paribus. No other variables were significant.

6.5 Pork

This model estimates that an increase in the price of corn by 1% increases the price of pork by 0.19% on average ceteris paribus. Unexpectedly, the supply model for pork predicts that the quantity of pork produced will decrease by 1.68% for every 1% increase in pork price. This result is probably due to the complex nature of the pork market that was oversimplified by this paper's models.

6.6 Soy

This model estimates that an increase in the price of corn by 1% will increase the price of soy by 0.45% on average ceteris paribus.

6.7 Wheat

This model estimates that an increase in the price of corn by 1% will increase the price of wheat by 0.11% on average ceteris paribus.

6.8 Price

This model estimates that an increase in the quantity of corn supplied by 1% decreases the price of corn by 0.48%, on average ceteris paribus. An increase in the demand for corn for ethanol by 1% increases the price of corn by 0.25%, on average ceteris paribus. An increase in the demand for corn for exports by 1% increases the price of corn by 0.25% on average ceteris paribus. An increase in the demand for corn for sweeteners is not significant. An increase in the demand for corn for feed by 1% decreases the price of corn by 1.83% on average ceteris paribus, which is unexpected. An increase in the price of corn by 1% last year increase the price of corn this year by 0.38% ceteris paribus.

7 Conclusion

The goal of this paper was to estimate the effects that ethanol production and various ethanol policies have on the price of corn and other agricultural goods. Both models are designed to estimate elasticities, and some selected results are summarized by Table 4.

This paper predicts that both the RFS mandate and the production of ethanol in general have had a significant and large impact on food prices. The prices of the agricultural products investigated have in fact increased significantly in the last decade with the exception of pork. (It is interesting to note that pork was the most problematic of the foodstuffs to model). Several predicted price changes are included in Table 4. Since 2000, looking only at the change in ethanol production, predicts a higher change in corn price and pork price and a lower change in wheat price than what really occurred. Since 2005, it predicts a smaller changes in price than what really occurred, with the exception of pork. Unexpectedly, the effect estimated from the RFS mandate is larger than the effect estimated for the change in quantity of corn for ethanol. Obviously, a lot in the world did change within this time period, such as fuel prices and technology, so the and it is worth noting that a general downwards trend in food prices existed before the ethanol fuel boom (Graph 5). Overall, the model predicts large and significant changes in food prices due to ethanol production.

The consequences of food price increases can be widespread. Food is usually an inferior good, the poor spend a higher percentage of their wealth on food than the rich. Subsidizing ethanol would have a regressive effect on the welfare of the poor through increases in food prices. More alarmingly, changes in world food prices are often correlated with political unrest. As one of the world's largest agricultural economies and agricultural exporters, US food prices will have an effect on global food prices with potentially alarming effects around the world.

This paper's attempt to model ethanol price effects was not without problems. As corn and other agricultural products are produced on a yearly cycle, the frequency of the data was restricted to yearly observations. Also, as the production of ethanol is a recent development, the models were limited to recent years for their observations. With very few observations, the ability to develop sophisticated models is somewhat limited. Within the models, some variables were not significant and there were unexpected results for corn sweetener demand and the pork price elasticity of supply. However, for the main focus of this paper, namely cross price elasticities and the effects of ethanol production and the RFS mandate on food prices, the results are significant and the expected sign.

The pros and cons of corn ethanol production as an alternative energy source are complex. Environmentally, ethanol production is more renewable and more green than fossil fuels, although it is far from perfect. Politically, ethanol allows politicians to satiate agricultural lobbies and promote energy independence. However, the economic consequences of ethanol production on food prices are a serious issue. Food prices will increase with ethanol production. While ultimately, politics must decide the weights placed on the different costs and benefits of ethanol policy, its effects on food prices must not be ignored.

8 Works Cited

Chakravorty, Ujjayant, et al. 2012. ”Do Biofuel Mandates Raise Food Prices?.”

Epple, Dennis, and Bennett T. McCallum. 2005. ”Simultaneous Equation Econometrics: The Missing Example.” Tepper School of Business. Paper 111. http://repository.cmu.edu/tepper/111.

Fortenbery, T. Randal and Hwanil Park. April 2008. ”The Effect of Ethanol Production on the U.S. National Corn Price.” University of Wisconsin-Madison Department of Agricultural and Applied Economics. Staff Paper No. 523.

Gustafson, Cole R. October 2002. ”Potential Corn Acreage Expansion for Ethanol Production: Western North DakotaMinot.” Department of Agribusiness and Applied Economics Agricultural Experiment Station. *Agribusiness and Applied Economics* October 2002 Miscellaneous Report No. 193.

McAloon, Andrew, Frank Taylor, Winnie Yee, Kelly Ibsen, and Robert Wooley. (2000). ”Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks - A Joint Study Sponsored by: U.S. Department of Agriculture and U.S. Department of Energy.” National Renewable Energy Laboratory.

Rask, Kevin N. 1998. ”Clean air and renewable fuels: the market for fuel ethanol in the US from 1984 to 1993.” *Energy Economics* 20 (1998) 325-245.

Roy, Sujit K. and M. Edwin Ireland. August 1975. ”An Econometric Analysis of the Sorghum Market.” *American Journal of Agricultural Economics*, Vol. 57, No. 3 (Aug., 1975), pp. 513-516. http://www.jstor.org/stable/1238416.

Salvo, Alberto and Cristian Huse. 2011. "Is Arbitrage Tying the Price of Ethanol to that of Gasoline? Evidence from the Uptake of Flexible-Fuel Technology." *The Energy Journal*, Vol. 32, No. 3.

Serra, Teresa, David Zilberman, and Jos Gil. 2011. "Price volatility in ethanol markets." *European Review of Agricultural Economics* Vol 38 (2) (2011) pp. 259280.

Serra, Teresa, David Zilberman, Jos M. Gil, and Barry K. Goodwin. 2011. "Nonlinearities in the U.S. corn-ethanol-oil-gasoline price system." *Agricultural Economics* 42 (2011) 3545.

Zellner, Arnold and H. Theil. Jan 1962. "Three-Stage Least Squares: Simultaneous Estimation of Simultaneous Equations." *Econometrica*, Vol. 30, No. 1 (Jan., 1962), pp. 54-78. http://www.jstor.org/stable/1911287.

Zhang, Zibin, Luanne Lohr, Cesar Escalante, and Michael Wetzstein. 2009. "Ethanol, Corn, and Soybean Price Relations in a Volatile Vehicle-Fuels Market." Energies 2009, 2, 320-339.

9 Bibliography

Alternative Fuels and Advanced Vehicles Data Center. U.S. Department of Energy. http://www.afdc.energy

Commodity Costs and Returns Data Set. Economic Research Service. United States Department of Agriculture. http://www.ers.usda.gov/Data/CostsAndReturns/.

2011 Farm Subsidy Database. Environmental Working Group. http://farm.ewg.org/progdetail.php.

Data. World Bank. http://data.worldbank.org/

Fuels and Fuel Additives. United States Environmental Protection Agency. http://www.epa.gov/otaq/fuels

Feeds Grain Database. Economic Research Service. United States Department of Agriculture. http://www.ers.usda.gov/Data/FeedGrains/. http://www.ers.usda.gov/Data/FeedGrains.

Foreign Exchange Rates -H.10. Statistical Releases and Historical Data. Board of the Governors of the Federal Reserve System. http://www.federalreserve.gov/releases/H10/.

IMF Primary Commodity Prices. Data and Statistics. International Monetary Fund. http://www.imf.org/external/np/res/commod/index.aspx.

Natural Gas. U.S. Energy Information Administration. http://www.eia.gov/naturalgas/.

Nebraska Ethanol Board. http://www.ne-ethanol.org/index.htm.

Oil Crops Yearbook Data. Economic Research Service. United States Department of Agriculture. http://www.ers.usda.gov/Briefing/SoybeansOilcrops/data.htm.

Personal Consumption Expenditures (PCE). Federal Reserve Economic Data. St. Louis Federal Reserve. http://research.stlouisfed.org/fred2/series/PCE.

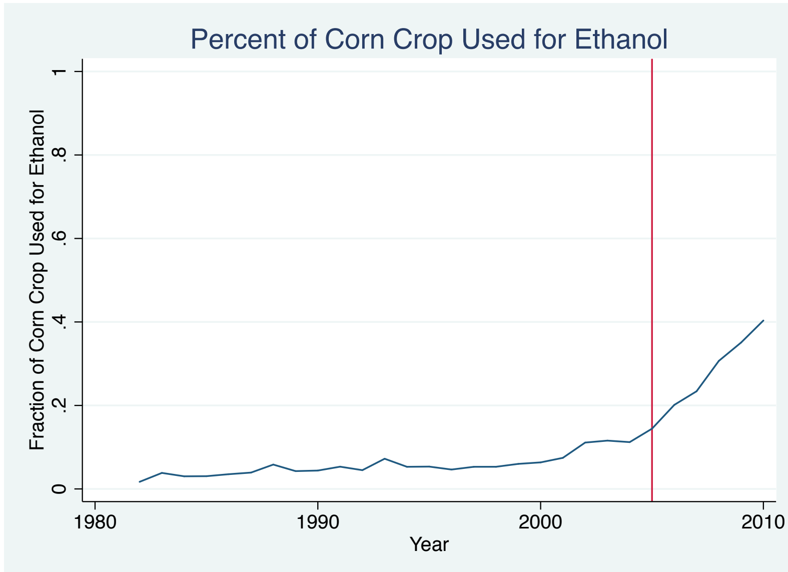
USDA ERS Meat Statistics. Economic Research Service. United States Department of Agriculture. http://www.ers.usda.gov/Data/MeatTrade/.

Wheat Yearbook Data. Economic Research Service. United States Department of Agriculture. http://www.ers.usda.gov/Data/Wheat/.

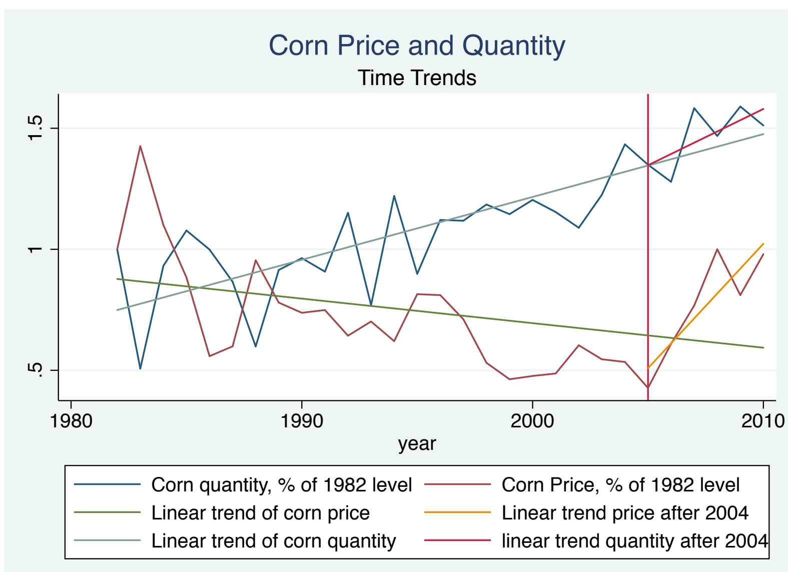
Wooldridge, Jeffery M. 2009. *Introductory Econometrics: A Modern Approach.* 4th ed.

10 Appendix

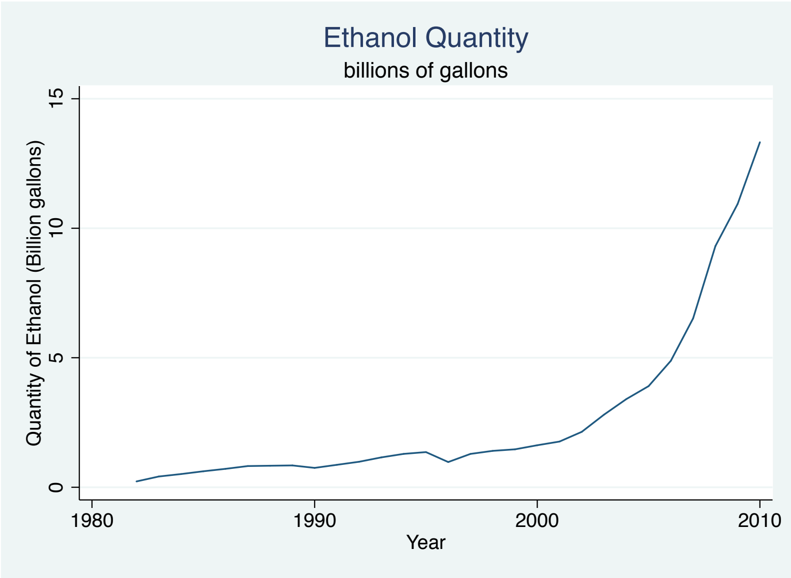
10.1 Graph 1: Ethanol as Percent of Corn Crop



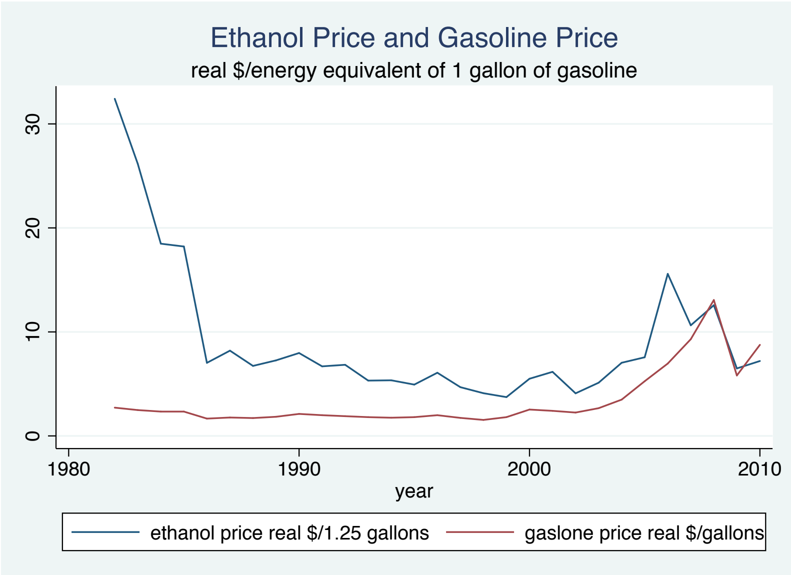
10.2 Graph 2: Corn Quantity and Price



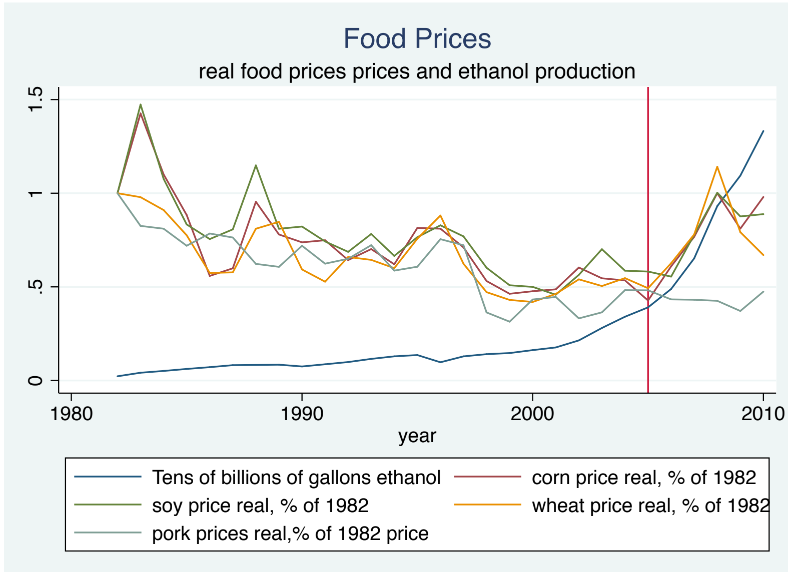
10.3 Graph 3: Ethanol Production



10.4 Graph 4: Ethanol Price and Gasoline Price



10.5 Graph 5: Food Prices and Ethanol Production



10.6 Table 1: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Corn production	36	9.042442	.2618612	8.33669	9.479746
Corn price	36	1.20249	.4049191	.5538843	2.066173
Change in corn stocks	35	7.723041	.7429203	4.421247	8.515456
Corn used for ethanol	31	6.300804	1.133663	3.555348	8.521427
Corn exports	36	7.530943	.1585803	7.112598	7.798688
Corn used for sweeteners	31	6.019477	.3322469	5.105946	6.313414
Corn for feed	36	8.481727	.1547561	8.18361	8.721778
Corn costs of production	36	1.328463	.3506854	.7833714	2.014134
Pork quantity	36	9.737455	.1827903	9.333884	10.05822
Pork price	29	-.5512947	.3155207	-1.120815	.0374475
Pork costs of production	27	4.249107	.2330213	3.845776	4.795076
Soy quantity	36	7.719388	.2420279	7.161318	8.119402
Soy price	36	2.145504	.3981351	1.498011	2.997784
Soy costs of production	36	1.845687	.3420899	1.362175	2.517361
Wheat quantity	36	7.704786	.1264124	7.381427	7.932132
Wheat price	36	1.56423	.3625425	.9927821	2.395307
Wheat total costs of production	36	1.437092	.5059874	.8827536	3.2954
US population	36	19.37136	.1118696	19.19066	19.54902
US gdp per capita	36	10.05399	.5371879	8.925249	10.76212
World gdp	36	30.71204	.6737499	29.38907	31.77612
RFS mandate quantity	36	1119.444	3073.557	0	12100
Linear time trend	36	18.5	10.53565	1	36
Sugar price	36	4.020926	.2100445	3.773679	4.749242
Real interest rate	36	5.016975	3.83172	-1.449408	22.91211
World wheat prices	31	208.9741	64.26021	125.0614	380.6453

10.7 Table 2: Regression Output

VARIABLES	(1) corn_for_ethanol	(2) corn_for_feed	(3) corn_for_exports	(4) corn_for_sweetener	(5) corn_supply	(6) pork_quantity	(7) pork_price	(8) soy_price	(9) soy_quantity	(10) wheat_price	(11) wheat_quantity	(12) corn_price
Corn price	-0.184	-0.204***	-0.290	-0.196***	-0.179		0.193*	0.455***		0.114*		
	(0.122)	(0.0489)	(0.249)	(0.0685)	(0.213)		(0.110)	(0.147)		(0.0653)		
Time trend	0.0688***											
	(0.0163)											
RFS mandate	5.66e-05***											
	(2.03e-05)											
Gasoline quantity	0.0653											
	(1.111)											
Gasoline price	0.425***											
	(0.0802)											
Soy price		-0.110**							-0.0454			
		(0.0502)							(0.101)			
Pork quantity		0.511***					-1.685***					
		(0.0700)					(0.314)					
World GDP per capita			0.385			0.240***		0.774***		-0.121		
			(0.355)			(0.0731)		(0.274)		(0.139)		
World population			-0.673			-1.266		-9.318**		3.521**		
			(1.176)			(0.906)		(3.671)		(1.791)		
Global wheat prices			0.457			0.0447*		0.0665		1.046***		
			(0.286)			(0.0251)		(0.171)		(0.0783)		
US GDP per capita				0.385		-0.463***		-0.692		-0.473		
				(0.452)		(0.160)		(0.690)		(0.344)		
US population				0.671		3.866***		12.24***		-1.994		
				(1.567)		(0.832)		(3.316)		(1.634)		
US sugar price				-0.0768								
				(0.293)								
Corn costs of production					-0.685***							
					(0.223)							
L.corn_price					0.199							0.378***
					(0.148)							(0.115)
Pork price						-0.113***						
						(0.0227)						
Pork costs of production							-0.431***					
							(0.160)					
L.pork_price							0.265***					
							(0.0983)					
Soy quantity								-0.694***				
								(0.171)				
Soy costs of production									-0.703***			
									(0.116)			
L.soy_price									0.0301			
									(0.0748)			
Wheat quantity										-0.111**		
										(0.0504)		
Wheat price											-0.0294	
											(0.0935)	
Wheat costs of production											-0.453***	
											(0.112)	
L.wheat_price											0.507***	
											(0.0678)	
Corn production												-0.480**
												(0.188)
Corn used for ethanol												0.249***
												(0.0479)
Corn used for sweeteners												0.128
												(0.207)
Corn exports												0.258**
												(0.129)
Corn for feed												-1.833***
												(0.433)
Constant	3.874	3.963***	17.27	-10.37	9.851***	-34.39***	17.68***	-21.18	8.984***	-37.86*	7.589***	16.32***
	(12.69)	(0.717)	(24.04)	(26.34)	(0.167)	(9.061)	(3.504)	(42.61)	(0.142)	(20.25)	(0.104)	(2.360)
Observations	26	26	26	26	26	26	26	26	26	26	26	26
R-squared	0.973	0.882	0.172	0.899	0.471	0.978	0.782	0.932	0.780	0.974	0.570	0.800

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

10.8 Table 3: Regression Statistics

Equation	Obs	Parms	RMSE	"R-sq"	chi2	P
Corn for ethanol	26	5	1296804	0.9730	1266.26	0.0000
Corn for feed	26	3	.0464873	0.8819	228.24	0.0000
Corn for exports	26	4	.1484246	0.1716	12.43	0.0144
Corn for sweeteners	26	4	.0666449	0.8994	286.19	0.0000
Corn supply	26	3	.1838797	0.4715	30.72	0.0000
Pork demand	26	6	.0205727	0.9782	1372.16	0.0000
Pork supply	26	4	.1374591	0.7821	112.17	0.0000
Soy demand	26	7	.0691352	0.9316	390.46	0.0000
Soy supply	26	3	.0960577	0.7801	100.59	0.0000
Wheat supply	26	7	.042222	0.9737	1179.92	0.0000
Wheat demand	26	3	.0806825	0.5696	69.08	0.0000
Corn price	26	6	.1269175	0.7996	158.05	0.0000

10.9 Table 4: Selected Results

	% Increase Corn Price	% Increase Soy Price	% Increase Pork Price	% Increase Wheat Price
1% Increase Corn Price	1	0.4547	0.1935	0.1141
1% Increase Ethanol Production	0.2486	0.1130	0.0481	0.0284
Increase RFS Mandates of 1 million gallons	0.0057	0.0026	0.0011	0.0006
Ethanol Production Since 2000	173.32	78.828	33.54	19.78
Actual Change Since 2000	106	77.6	9.8	59.7
Ethanol Production Since 2005	52.95	24.08	10.25	6.04
Increase RFS Mandates since 2005	68.49	31.14	13.25	7.81
Actual Change Since 2005	149.99	52.71	-1.46	36.39