Undergraduate Economic Review

Volume 5 | Issue 1 Article 1

2009

Modeling the US Corn Market During the Ethanol Boom

Bethany Vittetoe
Knox College

Recommended Citation
Vittetoe, Bethany (2009) "Modeling the US Corn Market During the Ethanol Boom," *Undergraduate Economic Review*: Vol. 5 : Iss. 1 , Article 1.
Available at: https://digitalcommons.iwu.edu/uer/vol5/iss1/1

Modeling the US Corn Market During the Ethanol Boom

Abstract

Using the fact that ethanol first accounted for more than 10% of total corn use and ethanol production surpassed 2 billion gallons annually in 2002, I assert that an ethanol boom began in the United States in 2002. This paper uses both Two Stage Least Squares and Autoregressive time-series models to estimate the corn market in the US during the period of 1980-2007. I find that the ethanol boom caused US corn production in 2007 to be about 3 billion bushels (23%) higher than it would be in the absence of the ethanol industry. The model also suggests that ethanol is not crowding out other uses of corn; however, it may be crowding out production of soybeans and other crops competing with corn for acreage. It is likely that the ethanol industry is partially responsible for the recent increase in food prices around the world.

Undergraduate Economic Review

A publication of Illinois Wesleyan University

Volume V—2008-2009

Title: Modeling the US Corn Market During the Ethanol Boom

Author: Bethany Vittetoe

Affiliation: Knox College

Abstract: Using the fact that ethanol first accounted for more than 10% of total corn use and ethanol production surpassed 2 billion gallons annually in 2002, I assert that an ethanol boom began in the United States in 2002. This paper uses both Two Stage Least Squares and Autoregressive time-series models to estimate the corn market in the US during the period of 1980-2007. I find that the ethanol boom caused US corn production in 2007 to be about 3 billion bushels (23%) higher than it would be in the absence of the ethanol industry. The model also suggests that ethanol is not crowding out other uses of corn; however, it may be crowding out production of soybeans and other crops competing with corn for acreage. It is likely that the ethanol industry is partially responsible for the recent increase in food prices around the world.

Table of Contents

Chapter 1: Introduction …………………………………………………………………...3

Chapter 2: Literature Review ……………………………………….……………12

Chapter 3: Theory…………………………………………………………………..19

Chapter 4: Model..………………………………………………………….…………22

Chapter 5: Empirical Results & Implications..…………………………..………..29

Chapter 6: Conclusions …………………………………..……………………42

Appendix A: Log-Log Model………………………………………….……………48

Appendix B: Industry Backgrounder…………………………….……….......50

Appendix C: STATA Commands……………………………..………………..53

References ……………………………………….……………….................57

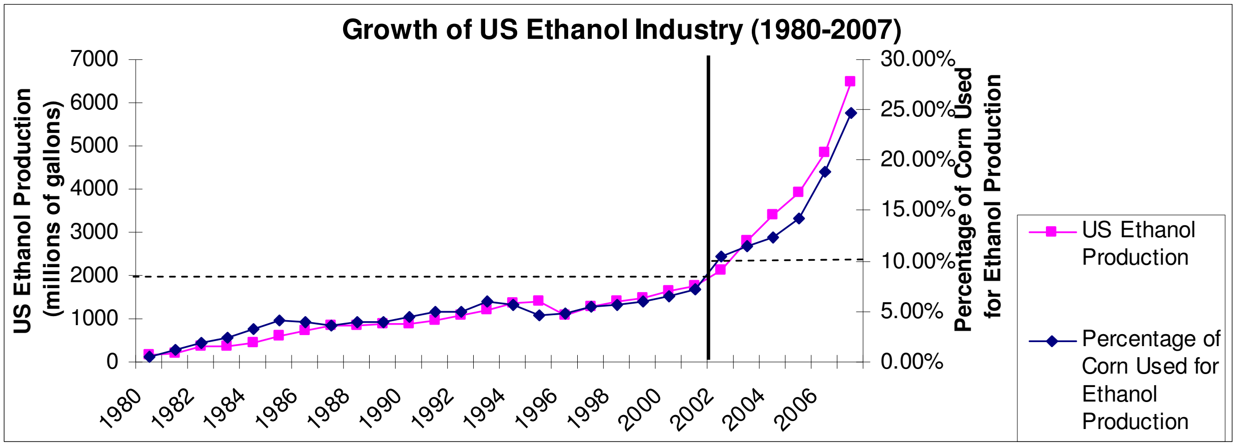
"We are at a critical time in the history of energy and agriculture."
--Keith J. Collins & James A. Duffield (p. 26)
USDA, 2005

Chapter 1: Introduction

1.1: Defining the Ethanol Boom

In 1980 ethanol production consumed about 0.4% of the total corn supply in the US; by 2007 that number had risen to 24.7%. Such a significant increase has sparked fears of food shortages and high inflation caused by increased food prices. Grocery prices most definitely have increased throughout 2007 and into 2008; nevertheless, whether this price increase is caused by the increased price of corn, by higher energy prices, or by some combination of both is still hotly debated. Headlines such as "As Prices Soar, U.S. Food Aid is Buying Less" (*New York Times*, September 29, 2007), "The End of Cheap Food" (*Economist*, December 8, 2007), "Food and Energy Compete for Land, Perhaps for Years" (*New York Times*, December 18, 2007), "An Unconvincing Shade of Green" (*New York Times*, January 20, 2008), "The Biofuel Follies" (*Newsweek*, February 11, 2008), and "The New Face of Hunger" (*Economist*, April 19, 2008) sprinkle the first pages of newspapers and make the evening news broadcasts, alerting the public to the growing impact of biofuels. This paper attempts to estimate the impact that the ethanol boom has had on the corn market.

Throughout the 1980's and early 1990's the ethanol industry in the United States began to pick up steam, growing at a steady pace, yet, for the most part, remaining under the radar of public attention. It was not until the turn of the 21st Century that the ethanol industry really began to grow. In 2002, annual ethanol production first surpassed 2 billion gallons, with a total production of 2.13 billion gallons (Industry Statistics). That same year was the first that ethanol accounted for more than 10% of total corn use (Feed Grains Database). Using these statistics, I define the ethanol boom to have begun in 2002 for the United States.



Source: Industry Statistics & Feed Grains Database.

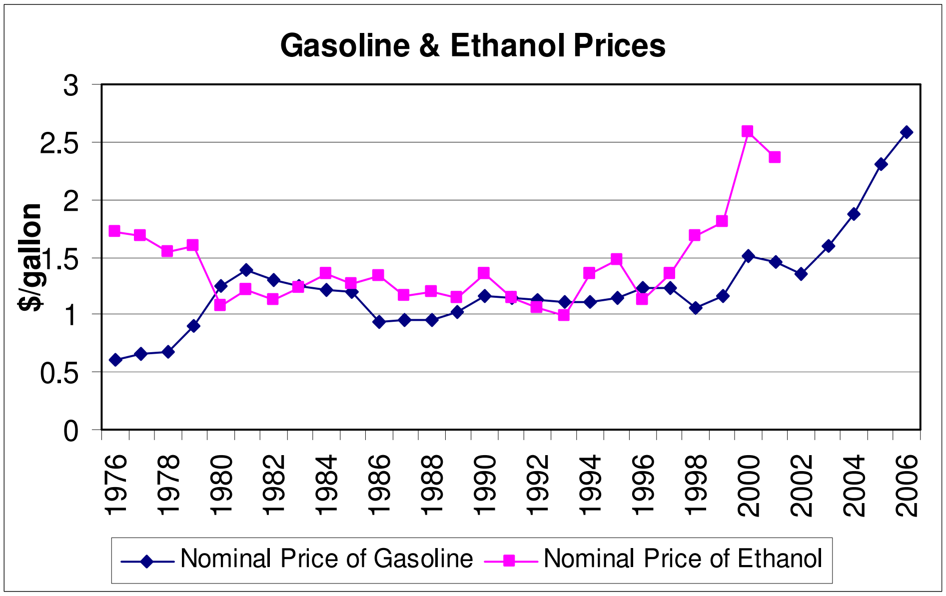
This ethanol boom may be described as overall excitement about, growth in, and public awareness of the ethanol industry. During this boom, the number of ethanol plants has increased greatly. Several ethanol firms held initial public offerings. The general media exposure given to the ethanol industry increased dramatically. Ethanol became part of the nation-wide Renewable Fuels Standard, first mandated in the Energy Policy Act of 2005. All of this was driven and inflated by growing fears of global warming (although ethanol is not a carbon-neutral fuel) and the public's reaction to higher energy prices.

1.2: Ethanol Policy

Ethanol has been around for over a century. According to the Energy Information Administration's (EIA) Ethanol Timeline, the first automobile built by Henry Ford, "the quadricycle," was designed to run on pure ethanol. A few decades later, ethanol became a popular fuel, as World War II increased fuel demand. However, after the war fuel demand decreased greatly, and ethanol took a hiatus until its popularity returned in the 1970's. In 1974, Congress passed the Solar Energy Research, Development, and Demonstration Act, which promoted research for converting biomass into fuels and energy. This is when the modern ethanol era as we know it began.

Ethanol received its second boost in demand when lead in gasoline was found to be harmful to the environment. The lead phase-out period, lasting from 1975 to1986, resulted in an increase in demand for ethanol. The first ethanol subsidy was passed in the Energy Tax Law of 1978, which excluded gasohol (a 10% blend of ethanol) from the 4¢ per gallon federal tax on gasoline. This, in effect, was a 40¢ subsidy on every gallon of ethanol blended into gasoline. The following year, in 1979, Amoco Oil Company began commercially marketing ethanol-blended fuel.

In the early 1980's Congress passed a series of laws that benefited the ethanol industry, ranging from low-interest loans and to tax benefits, to the first tariff imposed on foreign-produced ethanol (at a rate of 50¢ per gallon). During this time several states also began implementation of ethanol subsidy programs, typically in the form of blenders' credits[1]. In 1982, the Surface Transportation Assistance Act increased the ethanol tax exemption to 50¢ per gallon of ethanol (Tyner & Taheripour, 2007). In 1984, the ethanol tax exemption was raised to 60¢ per gallon under the Tax Reform Act. At this time, however, due

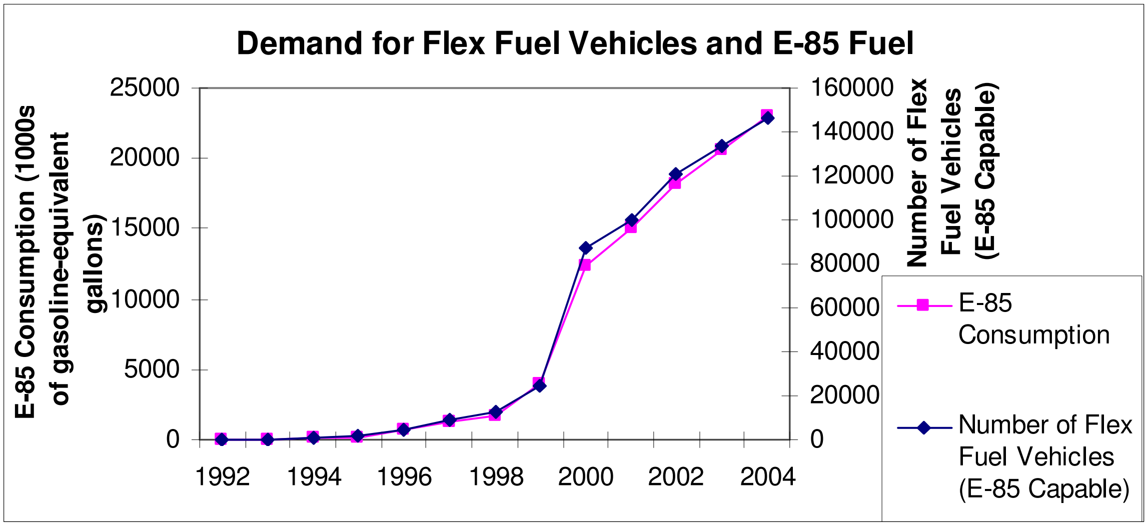


Source: Energy Information Administration & Nebraska Energy Office

---

[1] See http://www.fhwa.dot.gov/ohim/mmfr/oct07/trmfuel.htm for October 2007 state fuel tax exemptions. See also Tokgoz (2007) for other state ethanol subsidy programs.

to low oil prices, the price of ethanol was sufficiently low to cause about half of the ethanol manufacturing plants to close. In 1988, ethanol was used as a fuel oxygenate in Denver, Colorado to help control CO emissions; MTBE still dominated the market for fuel oxygenates, however. That same year the Alternative Motor Fuels Act was passed, providing credits to automakers for meeting the Corporate Average Fuel Economy (CAFE) standards. These higher standards prompted the automobile industry to produce vehicles with lower emissions; their answer: flex-fueled vehicles. These new vehicles would take some time to develop and produce (as seen in the graph below).

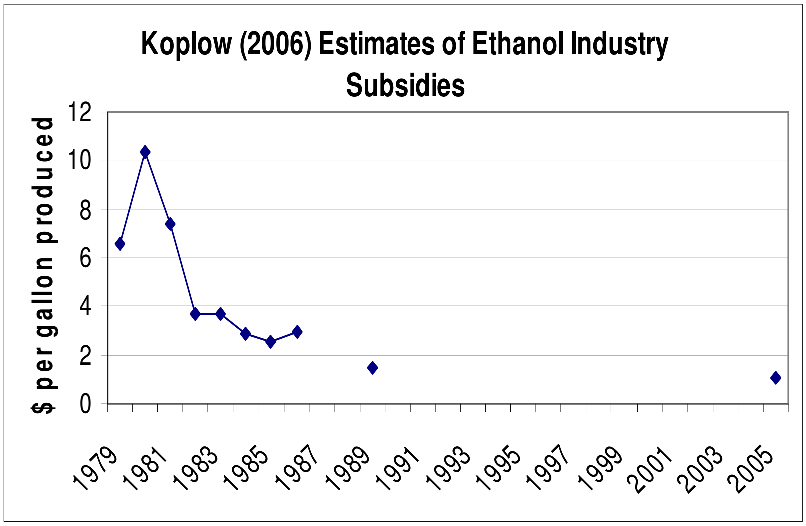


Source: Annual Energy Review of EIA

The Omnibus Budget Reconciliation Act of 1990 established the small ethanol producer tax credit, giving certain producers a 10¢ per gallon credit on the first 15 million gallons of ethanol produced each year (Koplow, 2006). That same year the ethanol tax exemption was decreased to 54¢ per gallon of ethanol and the Clean Air Act Amendments acknowledged that motor fuels contributed to air pollution (Tyner & Taheripour, 2007). The Energy Policy Act of 1992 defined "alternative transportation fuels," to include blends of 85% ethanol (E-85), and provided market incentives (such as tax credits) as well as government mandates for use of such fuels. In 1997, US auto manufactures began mass production of flex-fueled vehicles, which could run on gasoline, E-85, or any blend in between. The 1998 Transportation Efficiency Act of the 21st Century reduced ethanol subsidies to 51¢ per gallon of ethanol (Tyner & Taheripour, 2007). In 2000, the Environmental Protection Agency recommended that MTBE use should be phased out nation-wide, as it had begun to pollute drinking water; MTBE bans were implemented between 2004 and 2006 (Koplow, 2006), and as a result demand for ethanol as a fuel oxygenate increased.

The Jobs Creation Act of 2004 changed the ethanol subsidy from an excise tax exemption to a blender tax credit (Tyner & Taheripour, 2007). The Energy Policy Act of 2005 implemented the first federal purchase mandates for liquid biofuels, known as the "Renewable Fuels Standard" (RFS). The RFS mandate required the consumption of 4 billion gallons of renewable fuels by 2006 and 7.5 billion gallons by 2012 (Koplow, 2006). The RFS has been increased to require 13.2 billion gallons by 2012 and 15 billion gallons by 2015 from corn based ethanol alone (Babcock, 2008), and to a total of 36 billion gallons by 2022 coming from all renewable fuels sources (RFA).

In addition to federal subsidies, state and local ethanol subsidies vary greatly and "have targeted multiple points in the biofuels production cycle, including inputs to production, conversion, distribution and retailing, and consumption" (Koplow, 2006). Koplow (2006) calculates that at least 38



states have incentive programs in place for ethanol and/or biodiesel. Examples of the various subsidies include grants, tax breaks, lending and credit enhancement programs, regulatory mandates, and funding for research, development and demonstration plants (Koplow, 2006). The graph on the previous page shows estimated average ethanol subsidies for certain years as computed by Koplow (2006).

The current ethanol blenders' subsidy is 51¢ per gallon;[2] note that this subsidy does not go directly to corn growers or to ethanol producers. This blenders' subsidy is accompanied by a 54¢ per gallon tariff on ethanol imports. Without the offsetting effects of this tariff, foreign blenders would retain the full 51¢ per gallon blenders' credit (Yacobucci, 2006).[3] Thus, in effect, there is a 3¢ per gallon tariff on ethanol imports. Most of these imports come from Brazil, the world's leading ethanol exporter. Ethanol made in Brazil comes from sugar cane and sugar beets.

A relatively new source of ethanol imports comes from the Caribbean Basin Initiative (CBI), which began in 1983 through the Caribbean Basin Economic Recovery Act (CBERA). CBERA was established to "promote a stable political and economic climate in the Caribbean region" (Yacobucci, 2006). Under the CBI, up to 7% of US consumption of ethanol may enter duty free with feedstocks not from the region. For ethanol produced from locally grown feedstock, there is no limit to imports from the CBI region. Under NAFTA, Canada and Mexico can also export ethanol to the US without import tariffs. Despite these import policies, during the period of 2002-2005, ethanol imports have accounted for less than 4.5% of US consumption (Koplow, 2006).

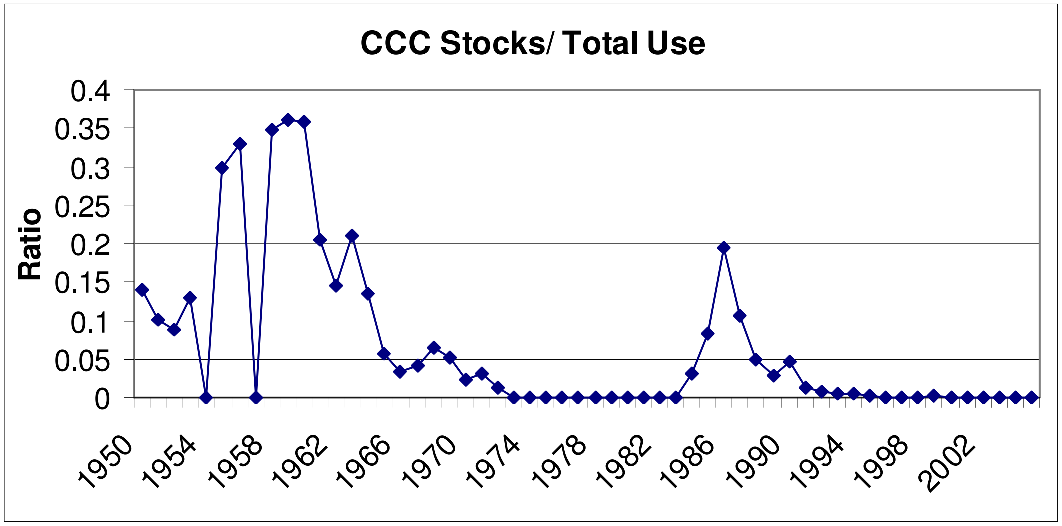
---

[2] For a social benefits and costs analysis of ethanol subsidies, see Gardner (2007). Gardner states that "a dollar spent on a direct corn subsidy increases corn growers' producer surplus more than [a] dollar spent on an ethanol subsidy under many plausible values of the relevant parameters." (Abstract)

[3] Gallagher (2006) concludes that both Brazil and the United States would benefit if their respective tariffs on ethanol were removed.

1.3: Farm Policy

The ethanol industry also benefits indirectly from corn subsidies and government agricultural policies. Such policies are rather complicated and will not be discussed fully in this paper; rather a broad overview of these policies will suffice. Farm policy in the 1950s and 1960s used price supports and production adjustments to increase farm incomes and balance production and consumption of agricultural products (APHIS, 2006). Despite the efforts of the government, farm incomes were falling relative to national incomes. In 1962 the government started to reduce its Commodity Credit Corporation (CCC)[4] stock inventories (Womack, 1976), as seen in the following graph. During the 1970s, commodity prices remained high, making price support programs redundant (APHIS, 2006), although loan rates remained high throughout the 1970s and 1980s (Westcott and Hoffman, 1999). Loan rates act as a price floor, as farmers participating in the loan program can default on their loan, turning over the corn in the loan program to the

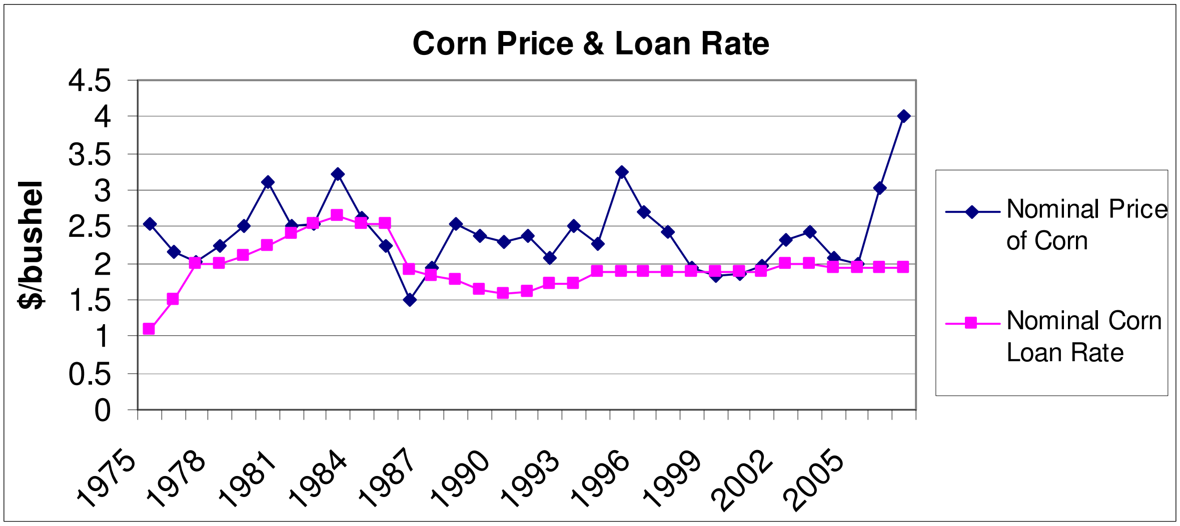


Source: Feed Grains Database.

---

[4] "The CCC Charter Act, as amended, aids producers through loans, purchases, payments, and other operations, and makes available materials and facilities required in the production and marketing of agricultural commodities. The CCC Charter Act also authorizes the sale of agricultural commodities to other government agencies and to foreign governments and the donation of food to domestic, foreign, or international relief agencies," taken from http://www.fsa.usda.gov/FSA/webapp?area=about&subject=landing&topic=sao-cc-ac.

government, and keeping the per bushel dollar amount known as the loan rate. When farmers default on their loans to the government, the government stocks of corn increase. The government urged farmers to increase their acres planted, resulting in a drop in commodity prices in the late 1970s. Prices then "returned to long-run trend of a 1.5% annual decline in real terms" (APHIS, 2006). In the 1980's cropland set aside[5] in government programs reached record levels. In 1986 loan rates were lowered as part of a trend toward somewhat greater reliance on markets. The Federal Agriculture Improvement and Reform Act of 1996 (also known as the 1996 Farm Act) shifted risk of price volatility from the government to the producer for crops such as wheat, corn, and grain sorghum (Westcott and Hoffman, 1999).



Source: Feed Grains Database & Feed Situation and Outlook Yearbook

1.4: Description of Research & Motivation

Although subsidies to the ethanol and the corn industries have impacted both markets, they are not the focus of this paper. Rather we focus on the recent trends of diversion of corn to ethanol production, higher prices for corn, and rising food prices around the globe. How much has the growth of the ethanol industry contributed to these trends? This study undertakes to estimate the quantitative impact of the ethanol boom on the market for corn.

---

[5] In the cropland set aside program, farmers agree to "set aside" some of their cropland, usually that which is prone to erosion or other environmental risks, in return for payments from the government as specified by a contract.

This paper uses time-series data from 1980 to 2007 to model the market for corn during the ethanol era. The paper begins with a literature review which covers some of the previous research on modeling the corn market. Next is a discussion of the data and variables used in the model, followed by discussion of economic theory and statistical techniques incorporated in the model. Using variables that account for both the ethanol boom and the quantity of corn being used in ethanol production, I then quantify the effect that ethanol has had on the corn market during this 28-year time period. Finally, conclusions are drawn from these results.

Chapter 2: Literature Review

Numerous studies have been conducted to model the corn market, both before and during the ethanol boom. Many of these studies focus on simulations and projections of future corn production, price, and consumption. However, the estimates of future corn prices generated by these studies have already been surpassed by current market prices.

Womack (1976) models the market for corn as well as sorghum, oats, and barley using a model with eleven structural equations over the period from 1948-1972. The model included equations for domestic feed demand, commercial stocks, and food demand. Using 2SLS, Womack finds[6]:

$$\text{US Corn Demand for Feed} = -22.0625 - \underset{(-4.13)}{30.0204}*(\text{Price of Corn})$$

$$+ \underset{(1.24)}{2.6061}*(\text{Price of Soybean Meal}) + \underset{(4.32)}{0.7431}*(\text{Livestock Prices})$$

$$+ \underset{(8.47)}{9.1025}*(\text{Livestock Quantity})$$

S.E. = 8.11 D.W. = 1.33
Corn price elasticity of demand for feed = -0.40 (point of means)[7] and -0.90 (in 1974)[8]

$$\text{US Corn Demand for Food} = 6.8476 - \underset{(-1.28)}{0.6162}*(\text{Price of Corn})$$

$$+\underset{(19.90)}{0.0265}*(\text{Real Personal Income})$$

S.E. = 0.75 D.W. = 0.49
Corn price elasticity of demand for food = -0.08 (point of means) and -0.14 (in 1972)

---

[6] R^2 statistics were not reported for the 2SLS regressions.
T-statistics are reported in parentheses.

[7] Womack adds that this estimate is consistent with the price elasticity of demand for feed corn of -0.47 reported in Foote (1958). Foote's estimate was computed for the period of 1921-1942.

[8] Womack explains this higher price elasticity as being the "result of record high prices at current low demand levels." (p. 49)

$$\text{Commercial Ending Stocks of Corn} = 30.9728 - \underset{(-3.63)}{15.4415*(\text{Price of Corn})}$$

$$+ \underset{(5.73)}{0.1731*(\text{Total US Corn Production})} - \underset{(-2.82)}{0.1083*(\text{D1*Total US Corn Prod})}$$

$$+ \underset{(2.42)}{0.6654*(\text{D1*Ending Commercial Stocks of Corn, lagged 1 year})}$$

S.E. = 4.40 D.W. = 1.66
D1 is a binary variable valued at 1 for the years 1948 to 1961, and 0 otherwise.[9]

Subotnik and Houck (1982) estimate a quarterly model of the US corn market, using a system of three structural equations including current demand, supply for current use, and demand for stocks. They report the following annual elasticities[10]: the price elasticity of the demand for corn as feed is -0.20; the price elasticity of the demand for corn as food is -0.014; the price elasticity of demand for corn as exports is -1.11. Thus, the authors found the two domestic sources of demand to be rather inelastic, while the export demand for corn was found to be elastic.

Gallagher (1994) uses a seven equation simulation model for the U.S. corn market. This model includes equations for area planted, production, consumption, commercial inventories, expected price, expected price next year, and an identity equation for the previous year's commercial stocks

$$I_{t-1} + Q_t = D_t + I_t$$

Using simulation, Gallagher's estimated demand curve is:

$$\text{Consumption} = 9576.0 - 740.0*\text{Price}$$

---

[9] "A dummy variable (D1) is used to capture the structural impact on the commercial sector associated with Government policy decisions to reduce CCC inventories beginning in 1962." (Womack, 1976, p. 72)

[10] Subotnik and Houck report one elasticity for each of 4 quarters. The elasticities reported above are an average of the 4 quarterly elasticities, which is consistent with the authors' calculations of an annual elasticity later in their report.

Using price and quantity data from 1989, Gallagher's model suggests a price elasticity of demand equal to -0.23. Gallagher found that private inventories have a large role in the corn market, and that they depend on expected returns, interest costs, and storage capacity. The estimated inventory equation, using data from 1970 to 1989, is below (with corresponding t-statistics)[11]:

$$\text{Off-Farm Storage} = \underset{(1.25)}{349.56} + \underset{(3.08)}{780.86}*(\text{Net Storage Return}) + \underset{(4.78)}{0.340}*(\text{Off-Farm Storage Capacity})$$

Wescott and Hoffman (1999) use a log-log model for the price of corn, using data from the period 1975-1996.[12] They find:[13] [14]

$$\text{Ln}(p) = 1.1619 - \underset{(8.6)}{0.2813}*\text{Ln}(\text{total ending stocks/total use}) + \underset{(3.1)}{0.0149}*(\text{CCC/total use})$$

$$+ \underset{(6.8)}{0.2269}*\text{Ln(Loan Rate)}*\text{Dum86} - \underset{(3.6)}{0.3256}*\text{Dum86}$$

$R^2 = 0.908$ F-value = 41.812 Durbin-Watson = 1.931
Standard error of the estimate = 0.0583

where CCC is the government-owned stocks of corn and Dum86 is a dummy variable equal to 1 in 1986 and 0 otherwise.[15] Specifically, their paper makes use of the ratio of ending stocks to

---

[11] Off-Farm Storage is on December 1, in millions of bushels. Net Storage Return = (Futures price delivered in year t+1) – (Futures price delivered in year t) – (Treasury bill rate, 4th quarter)*(Futures price delivered in year t), and is measured in dollars per bushel. Off-Farm Storage Capacity is measured in millions of bushels and is for 10 states, including IL, IN, UA, MI, MN, MO, NE, OH, SD, WI.

[12] See Chambers (2004) for a discussion of structural change in the feed grains sector following 1996.

[13] T-statistics are listed in parentheses.

[14] Wescott and Hoffman's model and results hold up rather well when applied to this time period (1980-2005). The results for this period are:

$$\text{Ln}(p) = 0.4898 - \underset{(-6.7)}{0.2493}*\text{Ln}(\text{total ending stocks/total use}) + \underset{(3.0)}{0.0210}*(\text{CCC/total use})$$

$$+ \underset{(4.0)}{0.2391}*\text{Ln(Loan Rate)}*\text{Dum86} - \underset{(-1.5)}{0.1531}*\text{Dum86}$$

$R^2 = 0.8125$ F-value = 22.74
Standard error of the regression = 0.0854 Mean VIF = 1.79 DW-Stat = 1.27

total corn use. Dividing by total use accounts for overall growth in the industry, and allows us to look at the relative size of ending stocks. The variable captures some underlying changes in the demand and supply model. As demand increases, this ratio is expected to decrease; as supply increases, this ratio is expected to increase. The ratio functions as a measure of cushion in the market, or as an overall "indicator of market tightness." Wescott and Hoffman use a reduced form price equation. However, since price and quantity are simultaneously determined in the market, the OLS coefficients are likely biased.

Taylor et al. (2006) use a partial equilibrium simulation model for the US corn market. The authors estimate supply and demand equations for both the US and the rest of the world (ROW) and then use simulation to forecast corn production, consumption, exports, and price ten years into the future. Taylor et al. then compare five scenarios to their baseline projection, which "allows ethanol production to increase based on current conditions." Under the baseline scenario, corn price increases to $2.32/bu by 2014; production, feed use, ethanol use, and exports are projected to increase while carry-over stocks decrease. Scenario 1 forces ethanol production to reach 7 billion gallons by 2012. It projects the price of corn will increase to $2.46/bu by 2014. Scenario 2 forces ethanol production to reach 14 billion gallons by 2012, projecting the price of corn to increase to $3.00/bu. The three remaining scenarios consider both a high and low price of gasoline as well as elimination of ethanol subsidies.

The Economic Research Service of the US Department of Agriculture also conducted a simulation of the corn and soybean markets under two scenarios of increased biofuels production. In scenario 1, annual ethanol production increases to 15 billion gallons by 2016,

---

[15] "[A] dummy variable for 1986 was added to the corn price equation to address a problem encountered regarding that year's having a particularly strong influence on the model's parameter estimates." (Wescott & Hoffman, 1999, p. 14) See also their pages 15-16 for further discussion of this variable.

resulting in a projected corn price of \$3.61/bu. In scenario 2, ethanol production increases to 20 billion gallons by 2016, resulting in a projected corn price of \$3.95/bu.[16]

Park and Fortenbery (2007) use 3 Stage Least Squares and a five equation system of demand and supply to model the US corn market on a quarterly basis, spanning from 2nd quarter 1995 to 1st quarter 2006. The five equations used correspond to corn supply, feed demand, export demand, food/alcohol/industrial (FAI) demand, and corn price.

$$\text{Price} = \underset{(5.08)}{3.46} - \underset{(-6.13)}{1.17}*(\text{Supply of corn}) + \underset{(0.34)}{0.087}*(\text{Feed consumption})$$

$$+ \underset{(3.14)}{0.27}*(\text{Exports}) + \underset{(5.30)}{0.45}*(\text{FAI consumption}) + \underset{(3.79)}{0.34}*(\text{Lagged corn price})$$

$$+ \underset{(6.58)}{0.59}*(\text{Quarter 1 dummy}) + \underset{(7.45)}{0.47}*(\text{Q2 dummy}) + \underset{(7.86)}{0.28}*(\text{Q3 dummy})$$

Root MSE=0.0301. R^2=0.88.

$$\text{Supply} = \underset{(3.96)}{3.17} - \underset{(-3.06)}{0.39}*(\text{Lagged corn price}) - \underset{(-1.32)}{0.064}*(\text{Lagged interest rate})$$

$$+ \underset{(2.49)}{0.35}*(\text{Lagged supply of corn}) + \underset{(15.95)}{0.62}*(\text{Q1 dummy}) + \underset{(6.09)}{0.27}*(\text{Q3 dummy})$$

$$+ 0.16*(\text{Q3 dummy})$$

Root MSE=0.0448. R^2=0.96

$$\text{Feed} = \underset{(-0.91)}{-1.49} - \underset{(-3.61)}{0.30}*(\text{Corn price}) + \underset{(3.38)}{0.18}*(\text{Soybean meal price}) + \underset{(1.92)}{0.20}*(\text{Number}$$

$$\text{of broilers}) + \underset{(2.04)}{0.39}*(\text{Number of cattle on feed}) + \underset{(1.34)}{0.44}*(\text{Number of hogs})$$

$$+ \underset{(36.09)}{0.39}*(\text{Q1 dummy}) + \underset{(16.72)}{0.24}*(\text{Q2 dummy}) + \underset{(9.93)}{0.12}*(\text{Q3 dummy})$$

Root MSE=0.0224 R^2=0.98.

---

[16] For more scenario studies, see De La Torre Ugarte et al. (2006), Tokgoz et al. (2007), and FAPRI (2005).

$$\text{FAI} = \underset{(1.78)}{18.80} - \underset{(-2.45)}{0.075}*(\text{Corn price}) + \underset{(7.23)}{0.40}*(\text{US ethanol production}) - \underset{(-1.63)}{6.99}*(\text{US}$$

$$\text{population}) + \underset{(1.50)}{0.0081}*(\text{Linear trend}) - \underset{(-5.27)}{0.033}*(\text{Q1 dummy}) - \underset{(-1.84)}{0.022}*(\text{Q2}$$

$$\text{dummy}) + \underset{(0.67)}{0.0048}*(\text{Q3 dummy})$$

Root MSE=0.0103. R^2=0.99.

$$\text{Exports} = \underset{(2.07)}{5.05} - \underset{(-2.01)}{0.26}*(\text{Corn price}) + \underset{(5.66)}{0.61}*(\text{Lagged exports}) - \underset{(-3.05)}{1.04}*(\text{Wheat}$$

$$\text{production for rest of world}) - \underset{(-0.72)}{0.23}*(\text{Dollar index}) + \underset{(1.29)}{0.36}*(\text{Per capita}$$

$$\text{GDP of main corn importing countries}) \underset{(-0.15)}{-0.0028}*(\text{Q1 dummy})$$

$$\underset{(-1.16)}{-0.0214}*(\text{Q2 dummy}) - \underset{(-0.15)}{0.0027}*(\text{Q3 dummy})$$

Root MSE=0.0447. R^2=0.47.

Park and Fortenbery found that each component of demand for corn has a different level of impact on the price of corn, with FAI (which includes ethanol production) having the greatest impact in terms of the magnitude of the coefficient, exports following with the second greatest impact, and feed consumption having the smallest impact on corn prices. The authors calculate the elasticity of corn price with respect to ethanol production ($\partial P_{corn}/\partial Q_{ethanol}$) to be 0.16; thus, a 1% increase in ethanol production results in a 0.16% increase in the price of corn in the short run.[17] Park and Fortenbery conclude that, "while ethanol production has a significant and positive impact on corn price, it does not fully explain price level changes in the 2006/2007 marketing year."

---

[17] From 1995-2006, corn used in ethanol increased by 435% while the price of corn fell by 6% in nominal terms and by 23% in real terms. Park and Fortenbery's paper suggests that the price should have increased by 70% over this time period, which is not consistent with the actual data.

The corn price projections by Taylor et al. and the ERS of the USDA have already been surpassed by market activity. In 2008, average corn prices surpassed $4/bushel. This paper attempts to model the corn market since the beginning of commercial ethanol production to capture the total effects of the ethanol market on the corn market.

Chapter 3: Theory

3.1: Characteristics of the Corn Market

The corn market can be characterized by many buyers and sellers, thus we assume a competitive market where no one party can set the price of corn.[18] Additionally, the corn market is largely characterized by homogeneity of product; this means that, for the most part, corn produced on one farm is seen by buyers as no different than corn produced by another farm, or that there is no product differentiation. Exceptions to this rule would include organic and non-genetically modified (GM) corn. We will base our model on the model of perfect competition, while accounting for government intervention as talked about in Chapter 1.

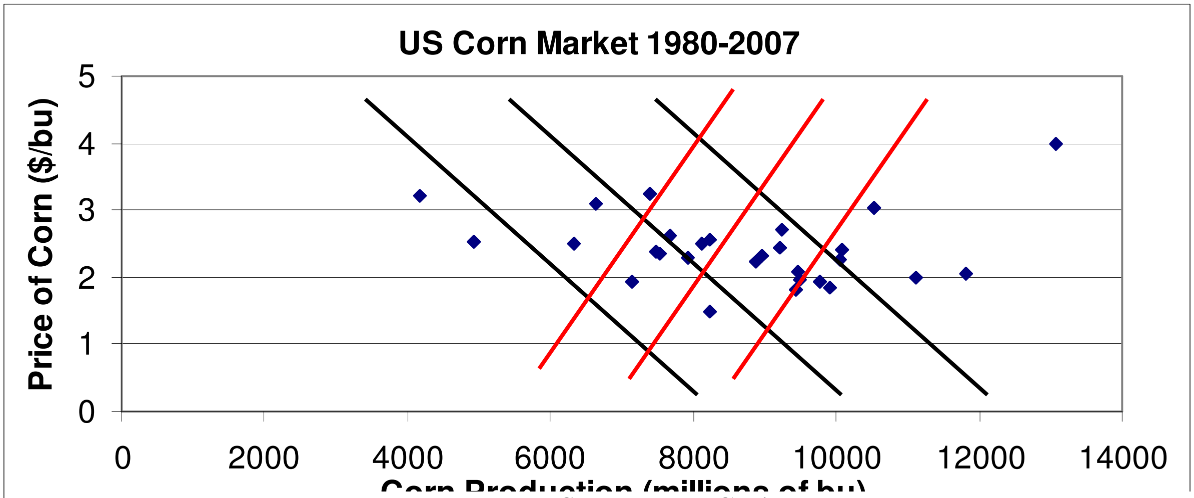
3.2: Two Stage Least Squares

In modeling the corn market we realize that both the supply and demand curves shift and simultaneously determine the endogenous price and quantity variables. When price and quantity are simultaneously determined in the market, estimating the demand and supply structural equations individually will yield biased estimates of the structural coefficients. Furthermore, a single reduced form equation similar to the model reported by Wescott and Hoffman is not up to the task of modeling the corn market. See Appendix A for an updated constant elasticity model. As Studenmund (2006) warns, “To study the demand for chicken without also looking at the supply of chicken is to take a chance on missing important linkages and thus making significant mistakes” (p. 474). Estimating a structural equation for quantity or price does not allow us to account for the bi-causal relationship between the two variables. In order to accurately estimate both the supply and demand curves, we need to specify exogenous variables that 1) shift only the supply curve, tracing along and identifying the demand curve, and 2) shift only the demand curve, tracing along and identifying the supply curve, as shown in the graphic on the next page.

---

[18] The government with loan rates might be an exception to this assumption.

For this reason we must use Two Stage Least Squares (2SLS) to obtain unbiased estimates of both price and quantity. 2SLS uses shifts in the demand (supply) curve to trace out the supply (demand) curve by running a two-stage regression. For the demand curve, a shift could be caused by a change in the price of a substitute good, a change in income, or a change in consumer tastes and preferences. Shifts in the supply curve may be caused by changes in the price of input goods, weather, new technology in an industry using corn as an input, or government policies.



Source: Feed Grains Database

The first stage estimate of one of the simultaneously determined variables captures the combined variations associated with the shift variables. Assuming all of the necessary conditions are met, the second stage estimate then captures the variation along the demand or supply curve. That is, the second stage estimates the slope of the curve. The resulting slope estimate is consistent. All the variables that shift the demand and supply curves, called instruments, are used in the first stage regression. These instruments must satisfy two conditions (Stock & Watson, 2003, p. 333):

1. They must be correlated with the instrumented variable. (Relevant)
2. They must not be correlated with the error term. (Exogenous)

Let us use a simplified model to show exactly what happens in each of the two stages of 2SLS. Here is a simplified demand and supply model of a market:

$$Q^D=\alpha_0+\alpha_1*Price+\alpha_2*Income+\alpha_3*Price\_Substitute\_Good$$

$$Q^S=\beta_0+\beta_1*Price+\beta_2*Price\_Inputs+\beta_3*Weather$$

In this model we use the exogenous (shift) variables of both the demand and supply model to run the first stage regression. Both demand and supply will have the same first stage:

$$Est\_Price =\gamma_0+\gamma_1*Income+\gamma_2*Price\_Substitute\_Good+\gamma_3*Price\_Inputs+\gamma_4*Weather$$

The above equation is called a reduced form equation for the endogenous variable price. The estimated price is the "instrumented" variable and is a function of the exogenous shift factors, or instruments. We then use this estimated price from the first stage regression in the second stage regression of quantity demanded and quantity supplied.

Chapter 4: Model

4.1: The Demand Equation

The demand equation in this model uses total use of corn as the regressand (endogenous variable). Total use represents the sum of US domestic use of corn and US corn exports. Hence, it represents all US corn purchased in a given year.

Demand for corn depends on price; economic theory predicts that these two variables have an inverse relationship. Thus, we expect a negative coefficient for the price of corn, reflecting the negative slope of demand curves. Here we use the real price of a bushel of corn, with a base year of 2000, as our endogenous price variable.

Demand for corn can be broken into a few different categories: exports, animal feed, and food/alcohol/industrial (FAI). US Corn Exports are included as a variable in the demand equation. As exports increase, we expect total use to increase with a coefficient of approximately 1. If this relationship holds, exports do not crowd out other uses of corn. We predict a positive coefficient for this variable.[19]

The demand equation also includes a variable for corn used in the production of alcohol for fuel (ethanol), which represents part of the FAI category. As corn used in ethanol production increases, we expect total use to also increase. As with exports, if this coefficient is approximately 1, ethanol production does not crowd out other uses of corn. We expect a positive coefficient for this variable.

A variable accounting for the feed category of demand was omitted from the regression to avoid perfect multicollinearity, which occurs if one of the regressor can be expressed as a

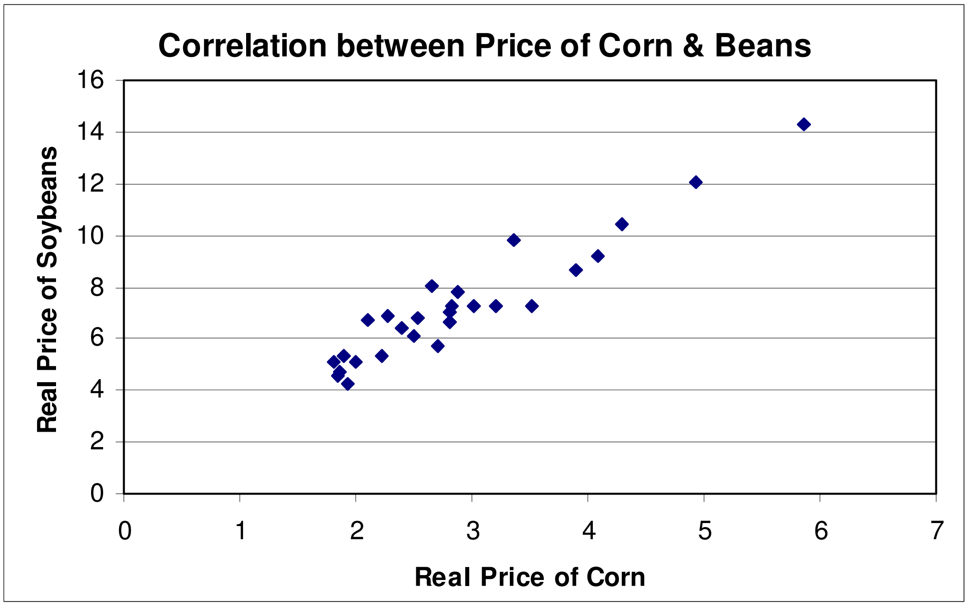
---

[19] Although this model focuses on the domestic corn market, the effects of the global market on the domestic price of corn cannot be ignored. I tried using several different variables to capture these effects, such as Chinese income and world income effects. However, US corn exports outperformed both of these variables and hence is the one included in the estimated model.

linear combination of the other regressors (Stock & Watson). A variable for US annual meat consumption was included in an earlier model of the equation as a proxy for livestock feed demand, but did not perform well,[20] and has been omitted in the current specification of the model.

Consumers' demand for a product depends on their level of income, or budget constraint. Here we include US Gross Domestic Product (GDP), adjusted for inflation with a base year of 2000, as a proxy for consumers' ability to pay. For normal goods, as income increases, demand for the good increases. For the case of corn, this income effect may be direct: as people have more money, they buy more corn; or, more likely, indirect: as people have more money, they desire more of products for which corn is a major input (such as meat). Thus we expect a positive coefficient for this variable. Furthermore, as corn is typically not viewed as a luxury good, we expect the income elasticity of demand to be between 0 and 1, that is, income inelastic.

The final variable included in the demand model is the real price of a bushel of soybeans. Soybeans are a substitute good for corn in several markets. Livestock owners may choose, to some extent, to vary



Source: NASS Quick Stats & Feed Grains Database

---

[20] In an early regression of per capita US corn production, per capita meat consumption had a z-statistic of -0.74, with a p-value of 0.461. This does not have the expected sign, nor is it statistically significant.

the mixture of corn and soybeans fed to their livestock. Soybeans and corn are substitute goods in the biofuels market as well, although to a lesser degree. Corn can be made into ethanol and soybeans into biodiesel. Thus, when decisions are being made to enter the biofuels market, the firm considers the future prices of both crops when deciding what type of plant to build. However, once a biodiesel or ethanol plant is built, it typically cannot switch feedstocks in the short run in reaction to higher input prices. The graph on the previous page shows the extremely high correlation between the real price of soybeans and the real price of corn. The high coefficient of correlation of 0.9477 is not surprising as corn and soybeans are very close substitutes in several ways.

4.2: The Supply Equation

The supply equation in this model uses US corn production as the regressand (endogenous variable).[21] This is the amount of corn produced in the US for each year, which differs from the amount of corn used domestically and for exports due to the fact that excess corn production can be carried over as stocks from one year to the next, or if demand exceeds supply, excess demand can draw down on previous stocks of corn.

Supply of corn depends on price, which economic theory predicts to have a positive relationship with the quantity supplied. Economic theory predicts that as the price of a good increases, suppliers will produce more of the good (a result of increasing marginal costs). Again we use the real price of a bushel of corn, with a base year of 2000, as our endogenous price variable. We expect a positive coefficient.

---

[21] Alternatively, the number of acres planted was tried as the regressand in the supply equation. The variable made a good candidate for the regressand for a couple reasons: first, the ethanol boom is said to “buy acres” for corn away from other crops; second, farmers have better control over the acres they plant than the actual crop production, due to random factors such as weather. However, due to the finite area available for cropland, the number of acres planted is a stock variable, and we need to use flow variables for this model.

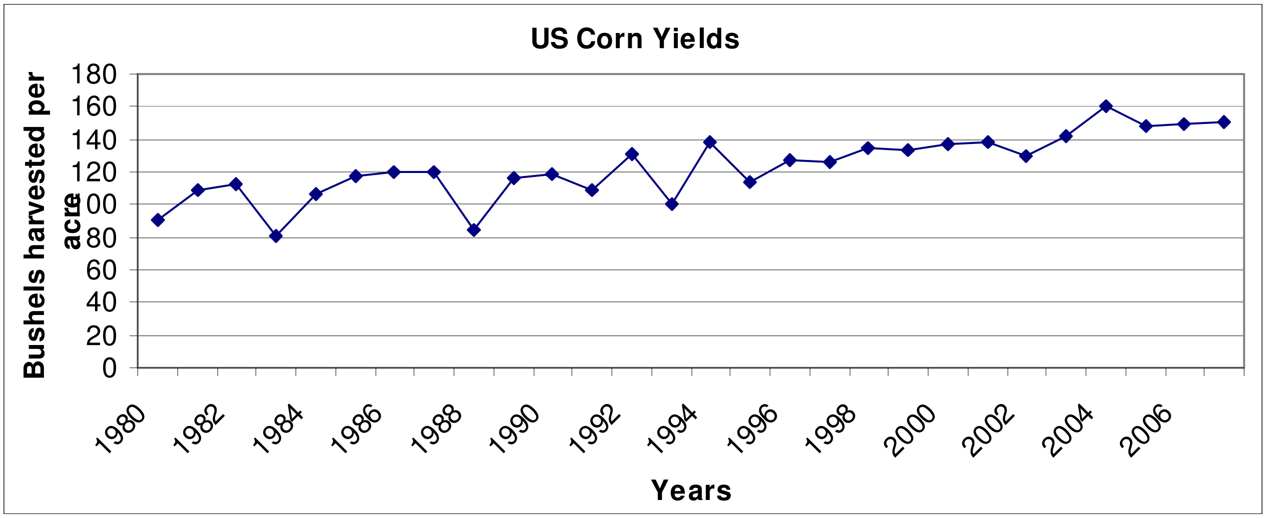
The inclusion of a stocks variable is necessary when modeling such a market. Thus, it is appropriate that the model developed by Westcott and Hoffman (1999) includes a stocks-to-use ratio variable, equal to total ending stocks divided by total use of corn for a given time period. This variable, lagged one year, is included in the supply model and is an overall indicator of market tightness. If the previous year had a relatively large carry-over (resulting in a high ratio value), farmers would plant fewer acres to corn. Thus a large ratio corresponds to a lower quantity of corn produced the following year. Or, conversely, if the previous year had a relatively small carry-over (resulting in a low ratio value), farmers would plant more acres to corn the following year. We therefore predict a negative coefficient for the ending stocks to use ratio, lagged one year.

The presence of stocks in the corn market complicates the modeling, as motivations for holding stocks are not always clear. According to Womack (1976), “Inventory accumulations are normally associated with 3 basic motivations: precaution, speculation, and transaction demand” (p. 31). Storage of corn from one year to the next is a costly decision, however. Foote, Klein, and Clough (1952) indicate that “storage costs include interest and insurance, handling charges, cost of the space used, losses from insects and rodents, and possible loss from other causes” (p. 49).

The quantity of corn supplied is equal to the average yield of corn per acre times the number of acres harvested. Only one of these two variables, average corn yields per acre, is included in the model to avoid perfect multicollinearity. Yields tend to increase at a rather constant rate due to factors such as increased technology and seed modification. The average annual growth rate for corn yields was 2.6% for the time period of 1980-2007.[22] As yields per

---

[22] Over the time period of 1927-2007, corn yields have increased at an average annual rate of 3.4%. (Feed Grains Database)



Source: Feed Grains Database

acre increase, total corn production will increase, assuming acres harvested remain constant. Thus, a positive coefficient is expected for this variable.

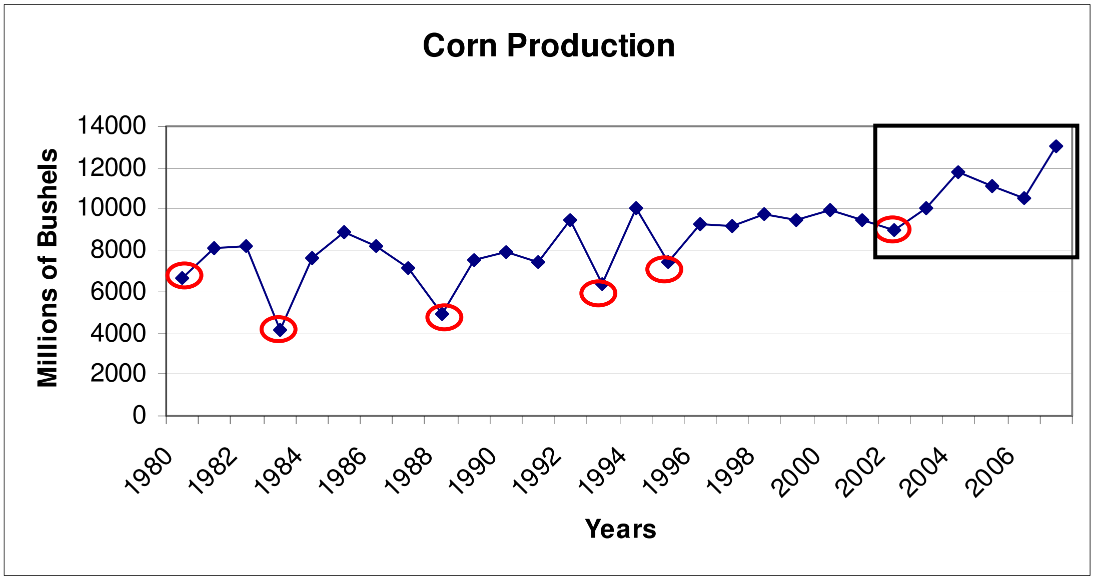
The real price of soybeans is also included in the supply model to represent the price of a substitute good. Midwest farmers typically choose whether to plant an acre of soybeans or of corn. They consider the future prices of these crops when making their planting decisions. Farmers typically stick to a corn-soybean rotation, as soybeans replenish nitrogen levels in soil. This decreases the substitutability of corn and soybeans. However, farmers have increasingly been experimenting with crop rotations such as corn-corn-soybeans, which tends to have negative consequences on the yields of the second year corn.

A binary variable for weather is also included in the supply model. [23] Weather conditions have large impacts on crop production. If part or all of the growing season is too wet, too dry,

---

[23] Real Corn Production Costs per acre were included as a regressor in an earlier specification of the second stage supply model. However, they were omitted from the final specification of the model due to poor overall performance of the model. The real price of corn becomes statistically insignificant. The magnitude of the coefficient for the weather binary variable is greatly reduced, from -349 to -8. Additionally, the coefficient for corn production costs does not have the predicted sign (negative), yet is still statistically significant. Finally, the mean VIF for the model is 121, which is significantly higher than that of the model with this variable omitted.

too hot, or too cold yields may be significantly lower than the trend line. This variable models that impact by accounting for years with especially bad weather. Years with extreme drought or flood are given a value of 1 and relatively normal weather years are given a value of 0. Bad weather lowers yields, which lowers corn production assuming no change in other variables. We therefore predict a negative coefficient for this variable. The graph below shows the US corn production from 1980-2007. The years circled are denoted as bad weather years. The years enclosed in the box are the years that make up the ethanol boom.



Source: Feed Grains Database

The real loan rate appears only in the first stage of both models. The loan rate is a type of government subsidy which acts as a price floor for the crop. This variable also appeared in the model by Wescott and Hoffman (1999). The real loan rate was originally included as an exogenous regressor in the supply model, but did not perform well.[24] It has been left in both models, but only in the first stage. Leaving the real loan rate and other policy variables out of the first stage likely results in some omitted variable bias.

---

[24] In the supply model, the real loan rate did not have the expected sign (coefficient of -80.24253) and was not found to be statistically significant (z-statistic of -0.24).

4.3: Two Stage Least Squares Model

Based on the previous discussion, we estimate the following Two Stage Least Squares demand and supply model:

2SLS Demand Model:

$$\textit{Total Use of Corn} = \beta_0 + \underset{(-)}{\beta_1}\textit{*Est Real Price of Corn} + \underset{(+)}{\beta_2}\textit{*US Corn Exports} + \underset{(+)}{\beta_3}\textit{* Corn}$$

$$\textit{Used for Ethanol Production} + \underset{(+)}{\beta_4}\textit{*Real GDP} + \underset{(+)}{\beta_5}\textit{*Real Price of Soybeans}$$

The instrumented variable is the real price of corn; the instruments used in the first stage regression of demand are the ethanol boom binary, weather, the real loan rate, real GDP, real price of beans, quantity of corn used in ethanol production, US corn exports, US corn yields, and the ending stocks ratio lagged one year.

2SLS Supply Model:

$$\textit{Q US Corn Production} = \alpha_0 + \underset{(+)}{\alpha_1}\textit{*Est Real Price of Corn} + \underset{(+)}{\alpha_2}\textit{*US Corn Yields}$$

$$+ \underset{(-)}{\alpha_3}\textit{*Weather} + \underset{(-)}{\alpha_4}\textit{* Ending Stocks/Total Use of Corn (lag)} + \underset{(-)}{\alpha_5}\textit{*Real}$$

$$\textit{Price of Soybeans}$$

The instrumented variable is the real price of corn; the instruments used in the first stage regression of supply are the ethanol boom binary, weather, the real loan rate, real GDP, real price of beans, quantity of corn used in ethanol production, US corn exports, US corn yields, and the ending stocks ratio lagged one year.

Chapter 5: Empirical Results & Implications

5.1: Descriptive Statistics

This model uses annual data ranging from 1980 to 2007. The data from NASS Quick Stats and from the Feed Grains Database are based on the marketing year, which begins on September 1.[25] The table below lists the variables along with descriptive statistics.

VARIABLE NAME	DESCRIPTION	SOURCE	MEAN	ST. DEV.
USCORNQMBU	US Corn Production (in millions of bushels)	USDA Feed Grains Database	8672.812	1931.258
TOTALUSE	Total Use of Corn[26] (in millions of bushels)	USDA Feed Grains Database	8703.047	1588.786
REALCORNP[27]	Real Price of Corn (Base year 2000; $/bushel)	USDA NASS Quick Stats	2.919213	0.9911377
REALBEANP	Real Price of Beans (Base year 2000; $/bushel)	USDA NASS Quick Stats	7.323237	2.3095
REALGDP	US Real GDP, billions of $ (Base year 2000)	Economic Report of the President, B-2	8025.129	2018.442
CORNTOETHANOLBU	Corn used in alcohol for fuel in US (millions of bu)	USDA Feed Grains Database	657.2333	689.7664
USCORNEX	US Corn Exports (millions of bushels)	USDA Feed Grains Database	1863.645	288.3482
ENDSTKUSE RLAG1	Ending Stocks to Total Use Ratio (lagged 1 year)	USDA Feed Grains Database	0.233216	0.159307
REALLOAN RATE	Real Loan Rate ($/bu)	USDA FSO Yearbook & Feed Grains Database	2.425142	0.866165
WEATHER[28]	Weather Binary Variable (1 for bad year, 0 for other)	See footnote 23.	0.214286	0.4178554
USCORNYIELD	US Corn Yields (bushels harvested per acre)	USDA Feed Grains Database	123.1286	19.8535
ETHANOLDMY 02	1 during ethanol boom. 0 otherwise.	Cassman, et al.	0.214286	0.417855

---

[25] Prior to 1986, the marketing year began October 1 for the Feed Grains Database.

[26] Total Use = Domestic Use + Exports

[27] Calculated from the annual average price of corn received on the farm, and is based on monthly prices weighted by monthly marketings.

[28] Information used to generate this variable was taken from "Ethanol, exports and livestock" and from "Costly feed situation." Although 1993 was not mentioned in other sources as a year of poor weather, it is given a value of 1 due to the severe flooding that took place in that year in Iowa, Illinois, Missouri, and many other Midwestern states. For more information about this flood, see http://mo.water.usgs.gov/Reports/1993-Flood/index.htm.

5.2: 2SLS Results

The Two Stage Least Squares regression results are reproduced on the page 29. In the demand model all coefficients have the expected sign. The coefficients of the real price of soybeans and corn variables were not statistically significant. This is likely due to the presence of multicollinearity in the model. The real price of corn and real price of soybeans have Variance Inflation Factors (VIFs) of 114.49 and 111.52, respectively.[29] Recall the high correlation (0.9477) between the real prices of corn and soybeans. All other variables in the demand model are statistically significant at the 0.001 level.

In the supply model all coefficients have the expected sign. Again, likely due to multicollinearity, the coefficient for the real price of soybeans is not statistically significant, but the coefficient for the price of corn is significant at the 0.06 level. The prices of soybeans and corn have VIFs of 154.42 and 126.47, respectively. The coefficient for the lagged ending stocks ratio variable is not statistically significant. The coefficient for corn yields is statistically significant at the 0.001 level; the weather variable has a statistically significant coefficient at the 0.10 level.

---

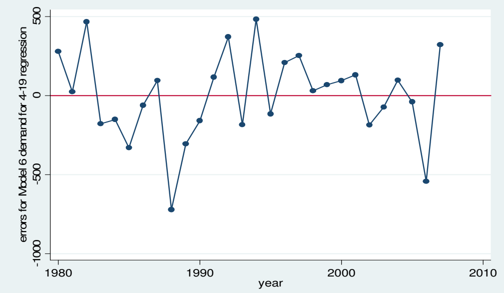
[29] The standard errors are inflated by a factor of square root of the VIF.

Regression 1 **Regressors**	**DEMAND**[30] **Coefficient** **z-stat** **(p-value)**	**SUPPLY**[31] **Coefficient** **z-stat** **(p-value)**
Regressand	Total Use (millions of bushels)	Total Production (millions of bushels)
Intercept Value	3364.015 4.77 (0.000)	-5072.464 -2.65 (0.008)
Instrument: Real Price of Corn (2000 dollars) (REALCORNP)	-256.4716 -1.43 (0.153)	590.8678 1.88 (0.060)
US Corn Exports (in millions of bushels) (USCORNEX)	0.9837379 4.02 (0.000)	
Corn used in US ethanol production (in millions of bushels) (CORNTOETHANOLBU)	0.9385649 5.04 (0.000)	
US Real GDP (in billions of 2000 dollars) (REALGDP)	0.4136479 5.49 (0.000)	
Real Price of Soybeans (2000 dollars) (REALBEANP)	43.4172 0.47 (0.637)	-31.63911 -0.24 (0.811)
US Corn Yields (USCORNYIELD)		102.0666 8.89 (0.000)
Weather (1 for bad years) (WEATHER)		-349.6434 -1.73 (0.083)
Ending Stocks of Corn/Total US Use (lagged 1 year) (ENDSTKUSERLAG1)		-1030.287 1.25 (0.212)
N	28	28
R-squared	0.9687	0.9464
Root MSE	276.01	439.1
Mean VIF	66.79	58.84
Instruments: Weather, Loan Rate, Corn Yields, Ending Stocks, Ethanol binary, Real GDP, Exports, Ethanol use		

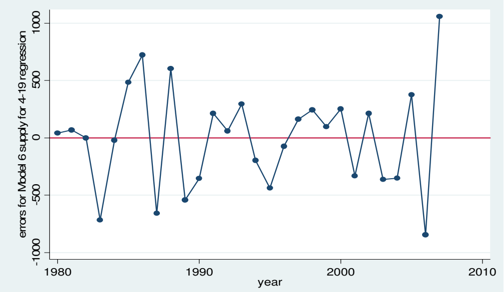
---

[30] DEMAND DIAGNOSTICS: Heteroskedastic robust standard errors were used in this regression. The mean VIF is 66.79. The error terms are approximately normally distributed, with a Shapiro-Francia test p-value of 0.52375. All variables in the model, in addition to the error terms, have finite fourth moments. The instruments are exogenous and relevant. The regressors are not correlated with the error term. The Durbin-Watson statistic is 1.99 and there are 13 runs for the runs test.

[31] SUPPLY DIAGNOSTICS: Heteroskedastic robust standard errors were used in this regression. The mean VIF is 58.84. The error terms are approximately normally distributed, with a Shapiro-Francia test p-value of 0.87158. All variables in the model, in addition to the error terms, have finite fourth moments. The instruments used were found to be both relevant and exogenous. The regressors are not correlated with the error term. The Durbin-Watson statistic is 2.53 and there are 15 runs for the runs test.



Demand Model Errors



Supply Model Errors

As this is a time-series model, it merits some discussion of the tests for autocorrelation. Both the runs test and Durbin-Watson test were used to test for autocorrelation of the errors. The demand model has 13 runs for the 28 observations. With a p-value of 0.46 on the runs test, we do not reject the null hypothesis that the data are not serially correlated. The demand model, with k=6 and n=28, has a Durbin-Watson statistic of 1.990815. The test statistic is within the regions where we do not reject H_0: no autocorrelation. For a significance level of 1% the do-not-reject region is [1.729, 2.271]; for a significance level of 5% the do-not-reject region is [1.958, 2.042]. Hence, again, we do not reject the null hypothesis that there is no positive autocorrelation in the model. The supply model has 15 runs for the 28 observations. With a p-value of 0.98 on the runs test, we do not reject the null hypothesis of no serially correlated errors. The supply model, with k=5 and n=28, has a Durbin-Watson statistic of 2.535995. The test statistic is within the regions of uncertainty [2.382, 3.168] and [2.150, 2.972], with significance levels of 1% and 5% respectively. Here the test results are inconclusive.

		Durbin Watson d Statistic		
$0 \leftarrow\rightarrow d_L$	$d_L \leftarrow\rightarrow d_U$	$d_U \leftarrow 2 \rightarrow 4\text{-}d_U$	$4\text{-}d_U \leftarrow\rightarrow 4\text{-}d_L$	$4\text{-}d_L \leftarrow\rightarrow 4$
Reject H_0. Evidence of positive auto-correlation.	Region of uncertainty.	Do not reject H_0 or H_0*.	Region of uncertainty.	Reject H_0*. Evidence of negative auto-correlation.
H_0: No positive autocorrelation H_0*: No negative autocorrelation				

The demand model fits the data rather well, with an R^2 of 0.9687 and a Root Mean Squared Error (MSE) of 276 million bushels. (In 2007, total use of corn was 12,955 million bushels.) The Real Price of Corn was not found to be a statistically significant predictor of total use of corn, likely due to multicollinearity between the real price of corn and soybeans. It does, however, have practical significance; this model predicts that for every $1 increase in the real price of corn, total use of corn will decrease by approximately 256 million bushels.

US Corn Exports of corn are a statistically significant determinant of total use of corn. For every 1 bushel increase in corn exports, total use increases by approximately 0.98 bushels. Corn Used in Ethanol is also a statistically significant determinant of total use of corn. For every 1 bushel increase, total use increases by approximately 0.94 bushels. Neither of these coefficients is statistically significantly different from 1[32]; this means that neither exports nor ethanol production is crowding out other uses of corn. For every additional bushel demanded by these sectors, an additional bushel of corn is produced rather than taken from another sector of demand. However, it seems that increased demand for corn is crowding out land used for soybean production.

US Real GDP is a statistically significant determinant of total use, as predicted by the income effect. This model predicts that for every $1 billion increase in real GDP, total use of corn will increase by approximately 414,000 bushels. The US Real GDP rose from $11,319.4 billion in 2006 to $11,658.9 billion in 2007, which shifted demand for corn by approximately 141 million bushels as suggested by this model.

The Real Price of Soybeans, although it does not have statistical significance (likely due to multicollinearity), does have practical significance. This model predicts that for every $1

---

[32] Exports has a t-statistic of -0.0664 with a one-sided p-value of 0.474. We do not reject H_0: $\beta = 1$.
Ethanol corn use has a t-statistic of -0.3296 with a one-sided p-value of 0.372. We do not reject H_0: $\beta = 1$.

increase in the real price of soybeans, total use of corn will increase by approximately 43 million bushels. Since corn and beans are substitutes, when the price of corn rises, buyers substitute away from corn and buy more beans. The coefficient for the price of soybeans measures this effect, which is known the substitution effect.

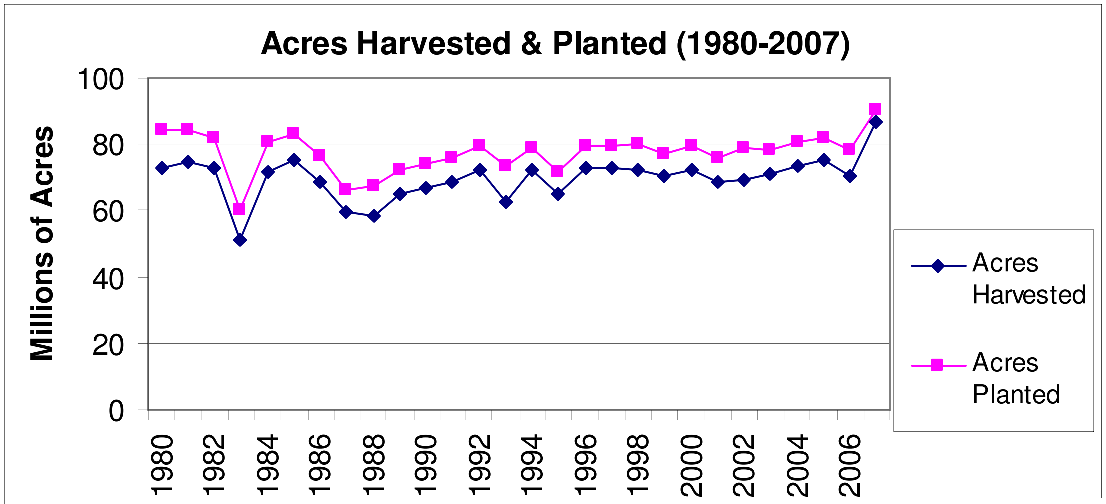
The supply model also fits the data well, with an R^2 of 0.9464. However, the supply model has a higher Root MSE than the demand model, with a value of 439 million bushels. Here the Real Price of Corn has a statistically significant coefficient at the 0.06 level. The model predicts that for every $1 increase in the real price of corn, farmers will produce approximately 591 million more bushels of corn.

The Real Price of Soybeans has the predicted sign, but is not statistically significant, again likely due to the presence of multicollinearity in the model. This model predicts that for every $1 increase in the real price of soybeans, farmers will decrease supply of corn by approximately 32 million bushels. Most, if not all, of the decrease in acreage planted to corn will be shifted towards soybean production.

The coefficient for US Corn Yields is highly statistically significant. For every one bushel per acre increase in corn yields, total corn production increases by approximately 102 million bushels. This result is larger than expected, as the highest recorded number of acres harvested during this time period was 87 million acres[33], which occurred in 2007 (Feed Grains Database). Note from the graph on the following page that the acres harvested represent 95.7% of the acres planted in 2007; the gap between acres planted and harvested was narrower than in previous years. This is likely a result of the price increase for corn, which makes the marginal revenue greater than the marginal cost of harvesting the last few acres.

---

[33] However, 87 is within the 95% confidence interval of [79.55293, 124.5802].



Source: Feed Grains Database

The Weather binary variable, which accounts for years with unusually poor weather, also has a statistically significant coefficient at the 0.10 level. During the six years of extreme drought or flood during the relevant period, corn production was approximately 350 million bushels lower on average. This decrease in yields represents approximately 3% of total production in 2007.

Finally, the Ending Stocks to Total Use Ratio variable, lagged one year, is not statistically significant in this specification. However, this model predicts that for every 0.1 increase in the stocks to use ratio, the following year farmers will decrease corn production by approximately 100 million bushels. As stocks increase, farmers will plant less of that crop the following year.

Additionally, the real loan rate variable was not included in either of the second stage regressions, but rather only in the first stage regression. When the real loan rate was included in the second stage of the supply model, the R^2 was 0.9439, only slightly lower than 0.9464 when the variable was excluded from the second stage. However, the coefficient for the real loan rate did not have the predicted sign, nor was it statistically significant. Its inclusion in the second stage increased the model's mean VIF from 58.84 to 71.19. Therefore it was left out of the second stage model.

5.3: Short Run Elasticities

We may calculate the price elasticities of supply and demand, as well as the income elasticity of demand from the 2SLS estimates on page 29. Elasticities measure the responsiveness of quantity to another variable.

$$E = \%\Delta Q / \%\Delta\# = (\Delta Q / \Delta\#)*(\#/Q)$$

Below are demand elasticities with respect to price of corn, income, exports, ethanol use, and price of soybeans; and supply elasticities with respect to price of corn and price of soybeans.

	E_D^P	E_S^P	E_D^Y	E_D^{Ex}	E_D^{Eth}	E_D^{PB}	E_S^{PB}
Point of Means (P=3.30, D=8365, S=8384, Y=8025, Ex=1864, Eth=657, PB=7.32)	-0.101	0.233	0.397	0.219	0.074	0.038	-0.028
Year 2007 (P=3.48, D=12955, S=13074, Y=11659, Ex=1975, Eth=3200, PB=9.05)	-0.069	0.157	0.372	0.150	0.232	0.030	-0.022
$\beta_D^P=-256$, $\beta_D^Y=0.41$, $\beta_D^{Ex}=0.98$, $\beta_D^{Eth}=0.94$, $\beta_D^{PB}=43$, $\beta_S^P=591$, $\beta_S^{PB}=-32$							
Where $E_D^\#$ *is the demand elasticity with respect to #, and* $E_S^\#$ *is the supply elasticity with respect to #.* *P=real price of corn, Y=income, Ex=US corn exports, Eth=ethanol corn use, PB=real price of soybeans*							

We see that the corn market is characterized by price inelasticity of supply and demand, as is normal for agricultural goods. Labys & Pollack (1984) report,

> "[C]ommodity markets can be distinguished from other markets such as those for manufactured goods in that they display low price elasticities of supply and demand. That is, amounts supplied and demanded are relatively unresponsive to changes in prices, at least in the short run." (p. 15)

The estimated price elasticity of demand is slightly less elastic than that calculated from Gallagher's results for 1989. These estimates concur with others reported in the Literature Review, which includes estimates of price elasticity of demand ranging from -0.014 to -1.11.

Using price and quantity data from 2007, this model suggests that for a 1% increase in the real price of corn, quantity demanded will drop by 0.07% and quantity supplied will increase by 0.16%. A 1% increase in income results in a 0.37% increase in quantity demanded. A 1% increase in corn exports causes a 0.15% increase in quantity demanded. A 1% increase in ethanol corn use results in a 0.23% increase in quantity demanded. A 1% increase in the price of soybeans results in a 0.03% increase in quantity demanded and a 0.02% decrease in quantity supplied

5.4: Autoregressive Model & Results

Time-series models commonly suffer from autocorrelation. Autocorrelation is "[t]he correlation between a time series variable and its lagged value" (Stock & Watson, 2003, p. 672). David Hallam (1990) explains, "Where the additional problems of autoregression and autocorrelation commonly encountered in agricultural commodity market models are present in a simultaneous equations model, 2SLS will no longer be consistent" (p. 120). The autocorrelation tends to be positive because variables such as income, yields, exports, and ethanol production usually grow together over time. We therefore use an autoregressive model, which includes one or more lags of the dependent variable. For example, here is a simple dynamic model, including a one-year lag of the dependent variable:

$$Y_t = \alpha_0 + \alpha_1 * X_t + \alpha_2 * Y_{t-1}$$

Why would we want to include a lagged dependent variable? The impact of independent variables may be spread out over several time periods. Instead of including one or more lagged values of every independent variable, we can include one or more lags of the dependent variable. Note that the impact of the lagged variables decreases as the length of the lag increases.[34]

---

[34] Studenmund (2006).

Our autoregressive model has the following 2SLS demand and supply equations.

2SLS Autoregressive Demand[35]:

$$\textit{Total Use of Corn} = \beta_0 + \underset{(-)}{\beta_1}\textit{*Est Real Price of Corn} + \underset{(+)}{\beta_2}\textit{*US Corn Exports} + \underset{(+)}{\beta_3}\textit{* Corn}$$

$$\textit{Used for Ethanol Production} + \underset{(+)}{\beta_4}\textit{*Real GDP} + \underset{(+)}{\beta_5}\textit{*Total Use (lagged 1 year)}$$

The instrumented variable again is the real price of corn; the instruments used in the first stage regression of demand are the real price of soybeans, ethanol boom binary, weather, real loan rate, US corn yields, ending stocks to use ratio (lagged 1 year), corn exports, corn used for ethanol production, real GDP, real price of corn (lagged 1 year), total use (lagged 1 & 2 years), and US corn production (lagged 1 & 2 years).

2SLS Autoregressive Supply[36]:

$$\textit{Q US Corn Production} = \alpha_0 + \underset{(+)}{\alpha_1}\textit{*Est Real Price of Corn} + \underset{(+)}{\alpha_2}\textit{*US Corn Yields}$$

$$+ \underset{(-)}{\alpha_3}\textit{*Weather} + \underset{(-)}{\alpha_4}\textit{* Ending Stocks/Total Use of Corn (lag)} + \underset{(+)}{\alpha_5}\textit{*US Corn}$$

$$\textit{Production (lagged 1 year)}$$

The instrumented variable is the real price of corn; the instruments used in the first stage regression of supply are the real price of soybeans, ethanol boom binary, weather, real loan rate, US corn yields, ending stocks to use ratio (lagged 1 year), corn exports, corn used for ethanol production, real GDP, real price of corn (lagged 1 year), total use (lagged 1 & 2 years), and US corn production (lagged 1 & 2 years).

---

[35] The real price of soybeans was included in the 2nd stage demand regression, but was not statistically significant (z=0.13), so was left only in the 1st stage.

[36] The real price of soybeans was also tried in the 2nd stage supply regression, but again was not statistically significant (z=0.42), so was left only in the 1st stage.

The results from the autoregressive 2SLS demand and supply estimation are reported on page 38. The demand equation fits the data quite well with $R^2 = 0.9692$. All coefficients have the expected sign except for the lagged regressand, which additionally is not statistically significant. The real price of corn was also not found to be statistically significant. Three tests for autocorrelation were run; two of the three suggest that there is no autocorrelation present in the model.

The supply equation also fits the data well with $R^2 = 0.9501$. All coefficients have the expected signs. With the exception of the lagged stocks to use ratio and the lagged regressand, all variables are statistically significant at the 0.02 level. Again, of the three tests for autocorrelation that were run, two suggest that there is no autocorrelation present in the model.

Regression 2 **Regressors**	**DEMAND** **Coefficient** **z-stat** **(p-value)**	**SUPPLY** **Coefficient** **z-stat** **(p-value)**
Regressand	Total Use (millions of bushels)	Total Production (millions of bushels)
Intercept Value	3467.939 5.91 (0.000)	-4408.452 -2.48 (0.013)
Instrument: Real Price of Corn (2000 dollars) (REALCORNP)	-53.42819 -0.39 (0.697)	481.2225 2.97 (0.003)
US Corn Exports (in millions of bushels) (USCORNEX)	0.9305788[37] 3.72 (0.000)	
Corn used in US ethanol production (in millions of bushels) (CORNTOETHANOLBU)	0.8967354[38] 5.07 (0.000)	
US Real GDP (in billions of 2000 dollars) (REALGDP)	0.5770213 3.23 (0.001)	
Total Use of Corn, lagged 1 year (millions of bushels) (L1.TOTALUSE)	-0.1836511 -0.99 (0.324)	
US Corn Yields (USCORNYIELD)		93.45387 9.16 (0.000)
Weather (1 for bad years) (WEATHER)		-546.9791 -2.44 (0.015)
Ending Stocks of Corn/Total US Use (lagged 1 year) (ENDSTKUSERLAG1)		-1391.366 -1.72 (0.086)
US Corn Production, lagged 1 year (millions of bushels) (L1.USCORNQMBU)		0.0720139 1.38 (0.166)
N	28	28
R-squared	0.9692	0.9501
Root MSE	273.95	423.48
Mean VIF	359.13	27.46
Durbin Watson Statistic (*not reliable for autoregressive models)	1.89*	2.53*
Durbin h Statistic	1.78 (p=0.037)	-1.47 (p=0.071)
Breusch-Godfrey Lagrange Multiplier Test	1.58 (p=0.208)	6.7418 (p=0.009)
Run Test	Runs=13 (p=0.5)	Runs=15 (p=0.63)
Instruments:	US corn exports, corn used in ethanol, real price of soybeans, ethanol boom binary, weather, real loan rate, US corn yields, end stocks to use ratio (lag 1), real price of corn (lag 1), total use (lag 1 & 2), US corn production (lag 1 & 2), real GDP	

---

[37] Exports has a t-statistic of -0.27745 with a p-value of 0.392. We do not reject H_0: $\beta = 1$.

[38] Ethanol corn use has a t-statistic of -0.58436 with a p-value of 0.282. We do not reject H_0: $\beta = 1$.

5.5: Long Run Elasticities

Autoregressive models allow us to calculate long-run multipliers of the regressors by determining the total change after all the lagged effects have taken place; that is, finding the total effects of a change when it is prolonged into the future. For example, the long run multiplier for X in the autoregressive model in Section 5.4 is

$$\alpha_1/(1-\alpha_2)$$

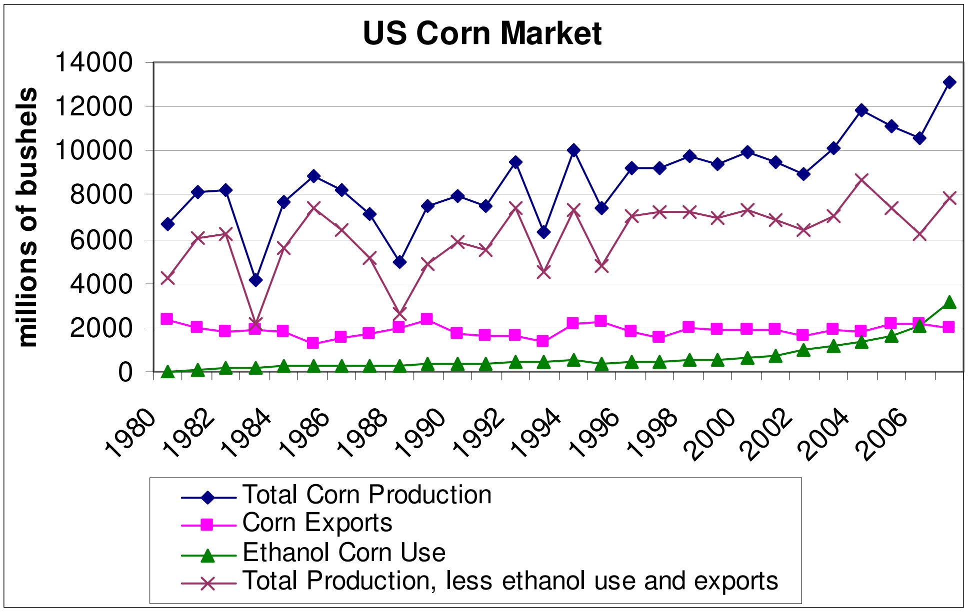
This is important in that a change in a variable today has ripple effects that span more than just the current time period. The long-run multiplier seeks to capture this ripple effect.

We use the long run multiplier to calculate the long run elasticity. The long run response to price in the demand equation is -45.138. This coefficient, however, is not statistically significant; furthermore, it has a negative sign, which is the opposite of what we expect. The resulting long run price elasticity of demand equal to -0.0121, which is less elastic than the short run price elasticity suggested by this model ($\boldsymbol{E_D^P}$=-0.0144). Again, this result is not consistent with economic theory. The long run response to price in the supply equation is 518.566, which results in a long run price elasticity of supply equal to 0.139. Both of these elasticities are extremely inelastic for the long run.

Chapter 6: Conclusion

6.1: Impact of the Ethanol Boom on the Corn Industry

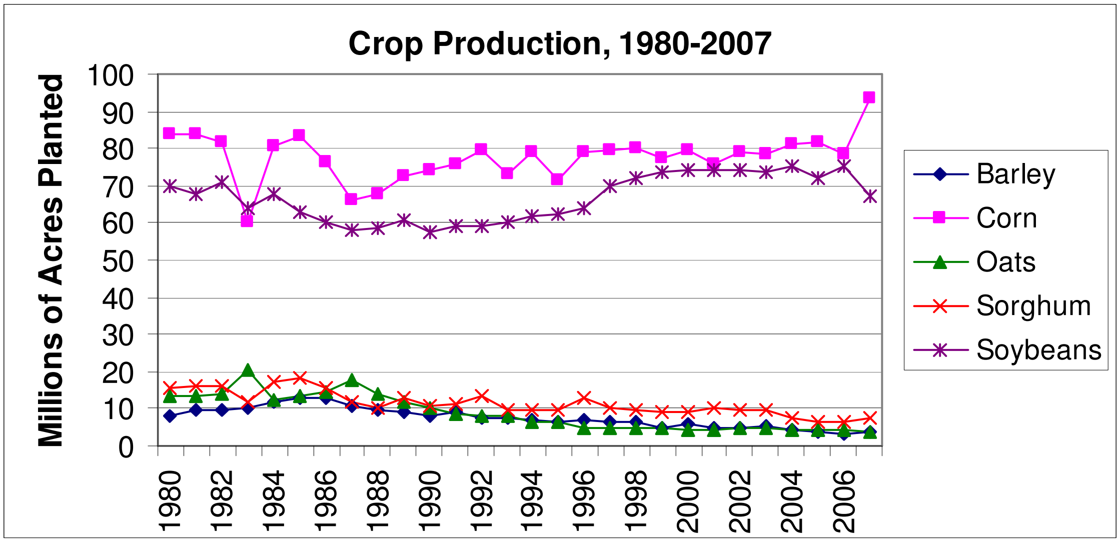
This paper has shown that the corn market has indeed been affected by the ethanol boom. The demand equation from Regression 1 predicts that for every 1 bushel increase in the amount of corn used in ethanol production, total use of corn will increase by approximately 0.94 bushels. This implies that there is a very slight, if any, crowding out effect for other uses of corn caused by the ethanol industry. However, as shown in the graph below by the crossing of the ethanol corn use and exports lines, ethanol may have had a crowding out effect with respect to exports in the last few years. Additionally, corn is likely having a crowding out effect for other crops, such as soybeans, as acres are shifted to corn production. This is illustrated by the graph on the next page by the significant decrease in acres planted to soybeans corresponding to the increase in acres planted to corn.



Source: Feed Grains Database

In 2007, approximately 3.2 billion bushels of corn were used in ethanol production, out of nearly 13 billion bushels of corn produced. Hence, approximately 3 billion more bushels of corn were produced that year than would have been produced in the absence of the ethanol industry. This is significant in that this accounts for approximately 23% of corn production in

2007. These 3 billion additional bushels of corn have likely come from crowding out other crops, such as soybeans, wheat, and barley. However, some of the additional corn production likely came from marginal acres that were not being planted previously. Government officials will need to carefully redesign farm policy in this new era of higher crop prices, higher input prices, and greater risk in the farm sector.



Source: Feed Grains Database & NASS Quick Stats

6.2: Ethanol and the Fuel Industry

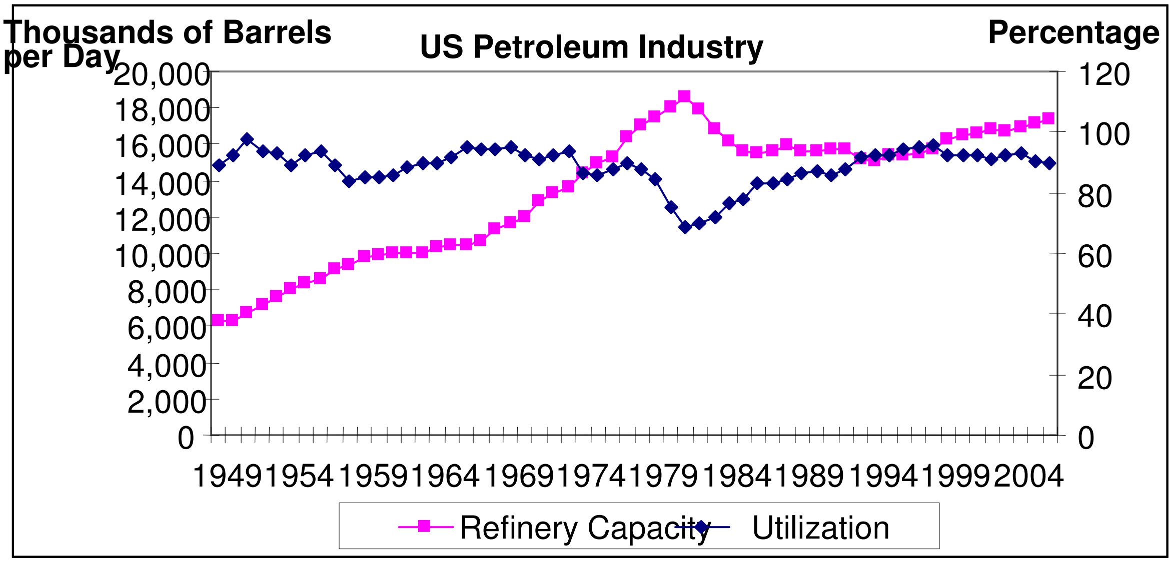
In 2007, approximately 3.2 billion bushels of corn were converted into ethanol, producing approximately 8.5 billion gallons of ethanol.[39] In 2006, approximately 5.6 billion gallons of ethanol were produced. That same year, the US transportation sector alone consumed approximately 3.3 billion barrels of petroleum for motor gasoline (Estimated Petroleum Consumption). This converts to about 64.5 billion gallons of finished motor gasoline.[40] Thus, by these numbers, ethanol accounted for approximately 11.6% of all US motor fuel use in the transportation sector in 2006. As ethanol costs are just over $2/gallon (Cassman, Eidman, &

---

[39] Using a conversion rate of 2.65 gallons of ethanol per bushel of corn, reported by Tyner & Taheripour (2007).

[40] Using a conversion rate of 19.6 gallons of gasoline per barrel of petroleum, found at the Energy Information Administration's website: http://tonto.eia.doe.gov/ask/gasoline_faqs.asp#gallons_per_barrel.

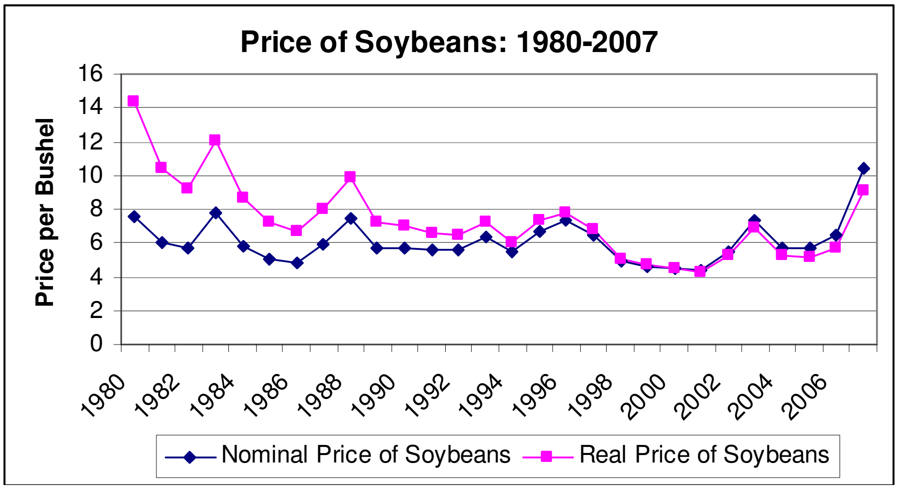
Simpson, 2006), ethanol impacts the motor fuels market by lowering the cost of blends of fuel containing ethanol. Ethanol also has the effect of increasing US petroleum refinery capacity, which has remained relatively stable since the mid 1980s, as shown in the graph below. If the federal government wishes to lower prices at the gas pump for consumers, it should continue to support the ethanol industry.



Source: Annual Energy Review.

6.3: Ethanol and the Food Industry

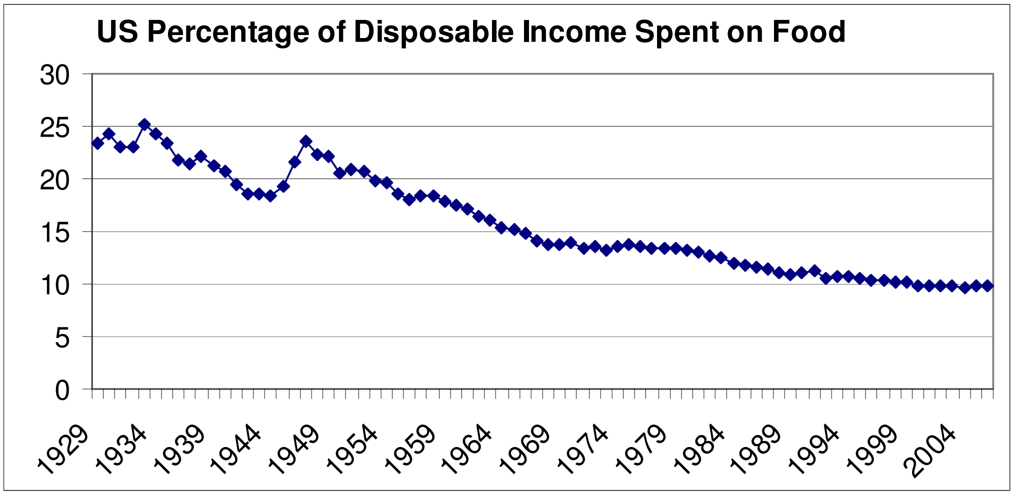
We have seen that the ethanol industry is not crowding out other uses of corn, such as exports. However, it may be crowding out production of other crops, such as soybeans. This will effect food prices



Source: Quick Stats.

world-wide. Not only has the price of corn increased, so has the price of other crops such as soybeans and rice. Rice, for instance, has increased from $460/tonne in the beginning of March to over $760 by mid-April 2008. (Reuters)

As the graph below shows, the percentage of disposable income spent on food in the US has decreased significantly this past century. An increase in the price of groceries will more greatly affect countries that spend a higher percentage of disposable income on food, as do many of the developing countries.



Source: Food CPI, Prices and Expenditures

Whether the ethanol boom has indeed caused food prices to increase is still hotly debated. One argument is that the fraction of total cost of food that comes from the raw food product is rather small for most foodstuffs, whereas other costs (such as packaging, processing, and transportation) make up a higher fraction of the total cost. Thus, some argue, the increased energy prices we are currently experiencing have a larger impact on the price of food than the increased price of corn. This is demonstrated by the following passage from a 2001 issue of *Ethanol Today*:

> A bushel of corn is 56 pounds or 896 ounces. If the corn in a box of cereal contains 15 ounces of corn, then that's about a percent-and-a-half of the total volume of a bushel. When you have two-dollar corn, you've got three pennies'

> worth of corn in those cornflakes. When the price goes to four dollars, then you have six pennies worth of corn in the box. 'It's negligible compared to all the costs that go into producing that box of cereal,' [says Geoff Cooper, director of commercialization and business development for National Corn Growers Association]. (Eisenthal, p. 11)

A recent study published by Texas A&M (Anderson et al, 2008) furthers the NCGA argument. The report states that 19¢ out of every retail food dollar goes to the farm, 38.5¢ goes to labor, and the other 42.5¢ goes to packaging, transportation, energy, profits, advertising, depreciation, rent, interest, repairs, business taxes, and other costs (in descending order). These numbers were based on 2002 data. However, the study goes on to say "[the] research supports the hypothesis that corn prices have had little to do with rising food costs. Higher corn prices do have a small effect on some food items." (Anderson et al, 2008, p. 3). Nevertheless, products for which corn and other crops are a higher percentage of the input costs (such as meat) are more greatly affected by increases in crop prices.

6.4: Recommendations for Future Research

As the ethanol industry is still rapidly growing, research must continue to be done on the industry and its effects on the agricultural and energy sectors. This is more easily said than done, as we have seen that these markets are complicated and depend on many factors, both domestic and international. To more carefully analyze the corn market, future research may develop models that include the soybean industry, which is highly correlated with the corn industry, as well as international markets.

More specifically, future research may look at the effect of futures prices on farmers' planting decisions. Farmers typically make planting decisions in the spring, but will base these decisions on the futures price for the harvest months of September and October. Thus, spring futures prices may be more (or at least equally) relevant than the average price received throughout the year.

Additionally, further research could be done looking at the effect of stock inventories on the market; specifically, do private and government-owned stocks have different impacts on the markets? With current high prices, neither private nor government-owned stocks make up a significant percentage of the market. However, inventories made up a large part of the corn market throughout the 1950s and 1960s as well as in the mid 1980s. Should the corn market start to cool down in the future, inventories again could play a large role in the market.

Appendix A: Log-Log Model Empirical Results

Westcott and Hoffman (1999) use a log-log model for a reduced form price equation. A log-log model was estimated for this study, with rather unsuccessful results. Several variations of the model were tried, following the method used in Epple and McCallum (2005). With an R^2 of 0.6299, the demand equation poorly fits the data when compared to other specifications. Additionally, the real price of corn and ethanol use variables do not have the predicted sign. The

Regressors	**DEMAND** **Coefficient** **z-stat** **(p-value)**	**SUPPLY** **Coefficient** **z-stat** **(p-value)**
Regressand	Log (Total Use of Corn, Bushels Per Capita)	Log (US Corn Quantity, Millions of Bushels)
Intercept Value	-1.765561 -0.76 0.456	9.385917 34.03 (0.000)
Log Real Price of Corn (2000 dollars) (LNREALCORNP)	0.0211897 0.23 (0.819)	-0.3555868 -1.69 (0.106)
Log US Real GDP Per Capita (in 2000 dollars) (REALGDP)	0.5074586 2.25 (0.035)	
Log Real Price of Soybeans (2000 dollars) (LNREALBEANP)	0.0105045 0.10 (0.921)	-0.3449314 -1.63 (0.119)
Log US Ethanol Use Per Capita (gallons) (LNUSETHANOLQPC)	-0.0135781 -0.30 (0.767)	
Ethanol Dummy Variable (1 for 2002 and after, 0 otherwise) (ETHANOLDMY02)		0.1188234 1.92 (0.068)
Log Ending Stocks of Corn, Lagged 1 Year (LNENDSTKLAG1)		-0.1920232 -4.44 (0.000)
Real Loan Rate (2000 $/bushel) (REALLOANRATE)		0.13735 3.00 (0.007)
N	27	27
R-squared	0.6299	0.8075
Root MSE	0.05393	0.11391
F-Statistic	9.36	17.62
Durbin-Watson Statistic	2.200524	1.904705
Mean VIF	9.39	4.46

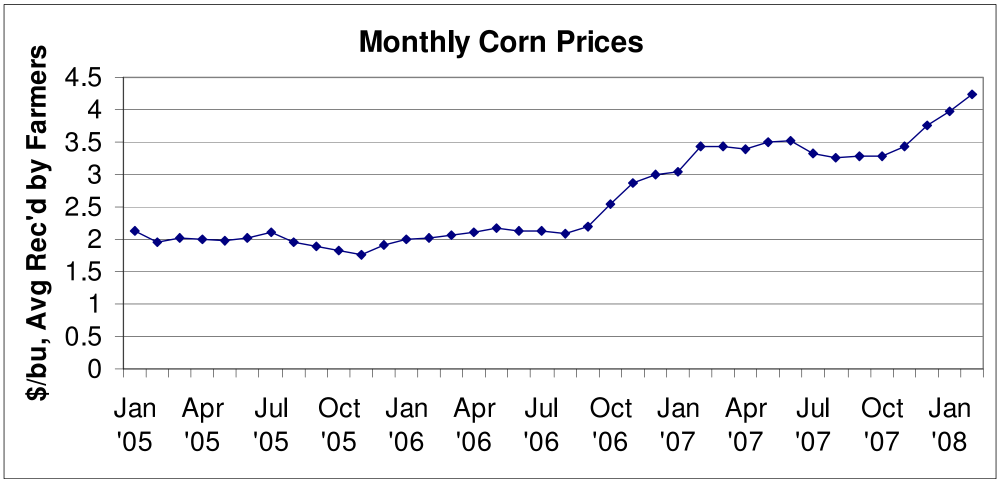
supply model has a higher R^2 with a value of 0.8075, but is still significantly lower than that in my 2SLS model. Again, the real price of corn does not have the predicted sign. Further efforts were not made to adapt this model to 2SLS, as the results looked unpromising, likely due to the large variations present in this data set.

Appendix B: Industry Backgrounder

Following are an assortment of facts about the ethanol industry to give the reader additional background information.

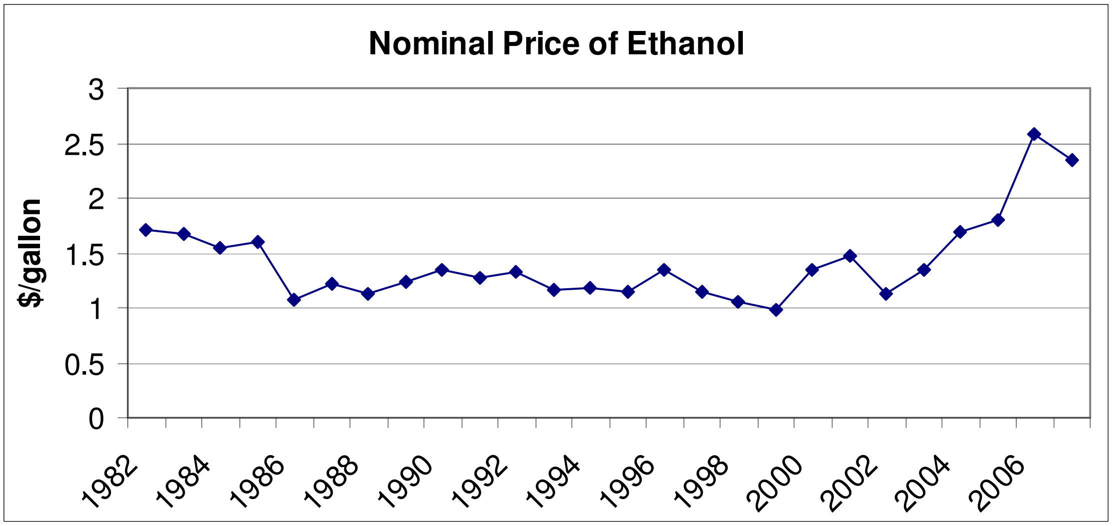
- The Corn Belt consists of Michigan, Wisconsin, Minnesota, Ohio, Indiana, Illinois, Iowa, and Missouri. (Womack, 1976)
- One bushel of corn weighs 56 pounds.
- Distillers grains are a byproduct of ethanol which can be fed to livestock (particularly cattle). According to Cassman, Eidman, and Simpson (2006), distillers grains can substitute for up to 35-40% of the total diet for feedlot cattle. This helps alleviate the demand for corn as feed.
- According to Hammerschlag (2006), the energy return on investment (rE) is the "total product energy divided by nonrenewable energy input to its manufacture. Defined this way, $rE > 1$ indicates that the ethanol product has nominally captured at least some renewable energy, and $rE > 0.76$ indicates that it consumes less nonrenewable energy in its manufacture than gasoline." Hammerschlag reports the results of several studies on this topic. "The reviewed corn ethanol studies imply $0.84 \leq rE \leq 1.65$; three of the cellulosic ethanol studies imply $4.40 \leq rE \leq 6.61$. The fourth cellulosic ethanol study reports $rE = 0.69$ and may reasonably be considered an outlier." Hence, while ethanol is not a carbon-neutral fuel, it does appear to decrease carbon emissions when compared to gasoline.
- Most new ethanol plants constructed have a production capacity of at least 100 million gallons annually. (Cassman, Eidman, & Simpson, 2006)

- Cassman, Eidman, and Simpson (2006) estimate the net cost of ethanol production to be $1.27 per gallon for $2/bushel corn and $1.98 for $4/bushel corn. (This assumes no construction or operating subsidies for the manufacturing plant, and DDGs sell for a price of $80/ton.)



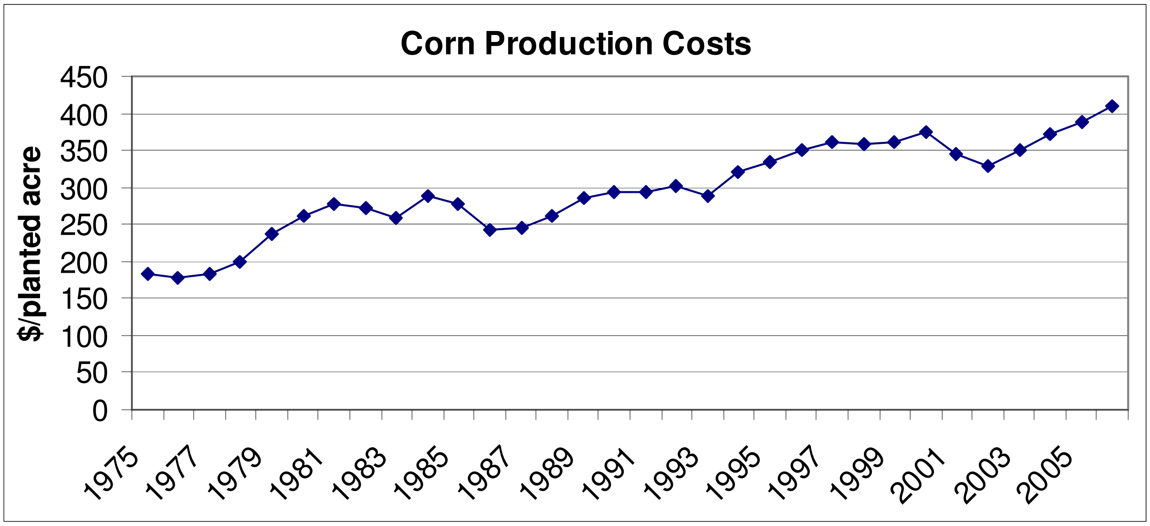
Source: Feed Grains Database

- "Ethanol prices were mostly on a downswing throughout 2007, but the last quarter of the year saw ethanol prices rebound from $1.55 per gallon to prices over $2.00 per gallon." (Hart, 2008)



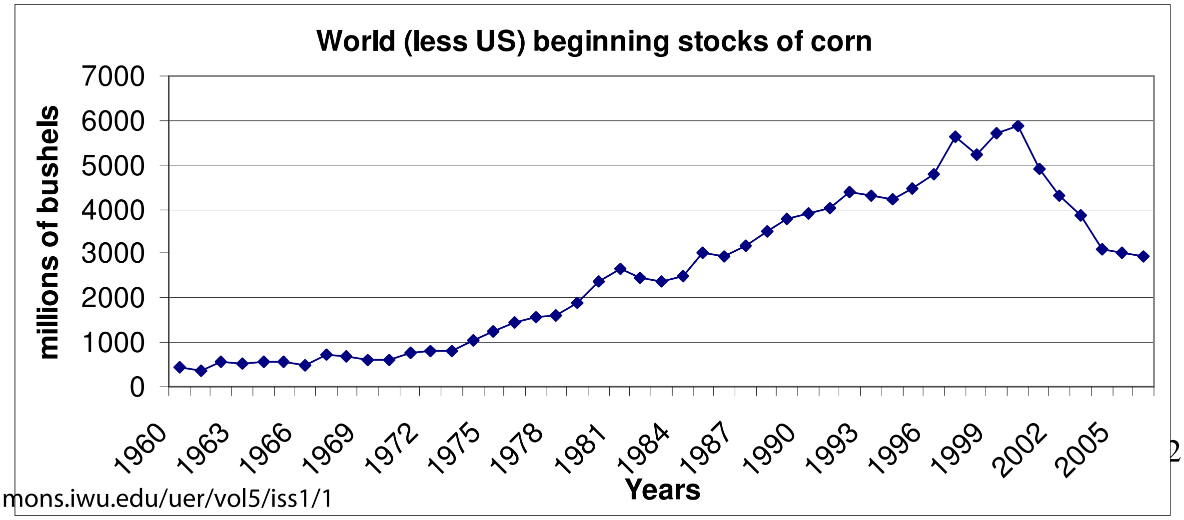
Source: Nebraska Energy Office

- Corn production costs continue to increase as corn prices increase.



Source: Commodity Costs and Returns

- World stocks of corn are down.



Source: Feed Grains Database

Appendix C: STATA Commands

```
2SLS Demand:

ivregress 2sls totaluse (realcornp = ethanoldmy02 weather realloanrate uscornyield
endstkuserlag1) uscornex corntoethanolbu realgdp realbeanp, first robust

First-stage regressions
-----------------------

                                                  Number of obs   =         28
                                                  F(   9,     18) =     171.51
                                                  Prob > F        =     0.0000
                                                  R-squared       =     0.9782
                                                  Adj R-squared   =     0.9673
                                                  Root MSE        =     0.1792

------------------------------------------------------------------------------
             |               Robust
   realcornp |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    uscornex |   .0004361   .0001354     3.22   0.005     .0001518    .0007205
corntoetha~u |   .0005347   .0001129     4.74   0.000     .0002976    .0007719
     realgdp |  -.0001489   .0000654    -2.28   0.035    -.0002864   -.0000115
   realbeanp |   .1981062   .0341054     5.81   0.000     .1264534     .269759
ethanoldmy02 |  -.2547567    .142987    -1.78   0.092    -.5551613    .0456479
     weather |   .3486854   .1716525     2.03   0.057    -.0119431    .7093139
realloanrate |   .3695973   .0761706     4.85   0.000     .2095687    .5296259
 uscornyield |  -.0072324   .0070204    -1.03   0.317    -.0219818     .007517
endstkuser~1 |  -1.391934   .3254996    -4.28   0.000    -2.075784   -.7080849
       _cons |   1.798058   .8891544     2.02   0.058    -.0699865    3.666102
------------------------------------------------------------------------------


Instrumental variables (2SLS) regression               Number of obs =      28
                                                       Wald chi2(5)  =  811.42
                                                       Prob > chi2   =  0.0000
                                                       R-squared     =  0.9687
                                                       Root MSE      =  276.01

------------------------------------------------------------------------------
             |               Robust
    totaluse |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   realcornp |  -256.4716   179.4656    -1.43   0.153    -608.2178    95.27459
    uscornex |   .9837379   .2449328     4.02   0.000     .5036785    1.463797
corntoetha~u |   .9385649   .1863871     5.04   0.000     .5732529    1.303877
     realgdp |   .4136479   .0752995     5.49   0.000     .2660636    .5612322
   realbeanp |    43.4172   91.93903     0.47   0.637      -136.78    223.6144
       _cons |   3364.015   704.8905     4.77   0.000     1982.455    4745.575
------------------------------------------------------------------------------
Instrumented:  realcornp
Instruments:   uscornex corntoethanolbu realgdp realbeanp ethanoldmy02
               weather realloanrate uscornyield endstkuserlag1
```

```
2SLS Supply:

ivregress 2sls  uscornqmbu ( realcornp=   ethanoldmy02 realgdp  uscornex corntoethanolbu
realloanrate )  realbeanp uscornyield weather   endstkuserlag1, first robust

First-stage regressions
-----------------------

                                                  Number of obs   =         28
                                                  F(   9,     18) =     171.51
                                                  Prob > F        =     0.0000
                                                  R-squared       =     0.9782
                                                  Adj R-squared   =     0.9673
                                                  Root MSE        =     0.1792

------------------------------------------------------------------------------
             |               Robust
   realcornp |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   realbeanp |   .1981062   .0341054     5.81   0.000     .1264534     .269759
 uscornyield |  -.0072324   .0070204    -1.03   0.317    -.0219818     .007517
     weather |   .3486854   .1716525     2.03   0.057    -.0119431    .7093139
endstkuser~1 |  -1.391934   .3254996    -4.28   0.000    -2.075784   -.7080849
ethanoldmy02 |  -.2547567    .142987    -1.78   0.092    -.5551613    .0456479
     realgdp |  -.0001489   .0000654    -2.28   0.035    -.0002864   -.0000115
    uscornex |   .0004361   .0001354     3.22   0.005     .0001518    .0007205
corntoetha~u |   .0005347   .0001129     4.74   0.000     .0002976    .0007719
realloanrate |   .3695973   .0761706     4.85   0.000     .2095687    .5296259
       _cons |   1.798058   .8891544     2.02   0.058    -.0699865    3.666102
------------------------------------------------------------------------------


Instrumental variables (2SLS) regression               Number of obs =      28
                                                       Wald chi2(5)  =  353.77
                                                       Prob > chi2   =  0.0000
                                                       R-squared     =  0.9464
                                                       Root MSE      =   439.1

------------------------------------------------------------------------------
             |               Robust
  uscornqmbu |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   realcornp |   590.8678   314.5431     1.88   0.060    -25.62525    1207.361
   realbeanp |  -31.63911    132.164    -0.24   0.811    -290.6758    227.3976
 uscornyield |   102.0666   11.48676     8.89   0.000     79.55293    124.5802
     weather |  -349.6434   201.8859    -1.73   0.083    -745.3325    46.04576
endstkuser~1 |  -1030.287   826.1626    -1.25   0.212    -2649.536     588.962
       _cons |  -5072.464   1915.321    -2.65   0.008    -8826.425   -1318.504
------------------------------------------------------------------------------
Instrumented:  realcornp
Instruments:   realbeanp uscornyield weather endstkuserlag1 ethanoldmy02
               realgdp uscornex corntoethanolbu realloanrate
```

```
Autoregressive 2SLS Demand:

ivregress 2sls totaluse uscornex corntoethanolbu (realcornp = realbeanp ethanoldmy02 weather
realloanrate uscornyield endstkuserlag1 L1.realcornp L2.totaluse) realgdp L1.totaluse, first
robust

First-stage regressions
-----------------------

                                                  Number of obs   =         28
                                                  F(  12,     15) =     259.93
                                                  Prob > F        =     0.0000
                                                  R-squared       =     0.9874
                                                  Adj R-squared   =     0.9773
                                                  Root MSE        =     0.1494

------------------------------------------------------------------------------
             |               Robust
   realcornp |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    uscornex |   .0004293    .000143     3.00   0.009     .0001244    .0007342
corntoetha~u |   .0004983   .0000814     6.12   0.000     .0003247    .0006719
     realgdp |  -.0003844   .0001148    -3.35   0.004     -.000629   -.0001398
    totaluse |
         L1. |   .0002292   .0000952     2.41   0.029     .0000262    .0004322
   realbeanp |   .2134045    .033451     6.38   0.000     .1421053    .2847036
ethanoldmy02 |  -.1499663   .1411171    -1.06   0.305    -.4507502    .1508177
     weather |   .1158758   .1374256     0.84   0.412    -.1770399    .4087914
realloanrate |   .4330318   .0793149     5.46   0.000     .2639761    .6020876
 uscornyield |  -.0084604   .0052978    -1.60   0.131    -.0197524    .0028316
endstkuser~1 |   -1.79694   .3308076    -5.43   0.000     -2.50204    -1.09184
   realcornp |
         L1. |  -.2110758   .1088182    -1.94   0.071    -.4430163    .0208647
    totaluse |
         L2. |   .0000208   .0000703     0.30   0.772    -.0001291    .0001707
       _cons |   2.235204   .7845386     2.85   0.012     .5629991    3.907408
------------------------------------------------------------------------------


Instrumental variables (2SLS) regression               Number of obs =      28
                                                       Wald chi2(5)  =  804.56
                                                       Prob > chi2   =  0.0000
                                                       R-squared     =  0.9692
                                                       Root MSE      =  273.95

------------------------------------------------------------------------------
             |               Robust
    totaluse |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   realcornp |  -53.42819   136.9799    -0.39   0.697    -321.9038    215.0475
    uscornex |   .9305788    .250212     3.72   0.000     .4401723    1.420985
corntoetha~u |   .8967354   .1767135     5.07   0.000     .5503834    1.243087
     realgdp |   .5770213   .1784504     3.23   0.001      .227265    .9267775
    totaluse |
         L1. |  -.1836511   .1862267    -0.99   0.324    -.5486488    .1813466
       _cons |   3467.939    586.786     5.91   0.000      2317.86    4618.019
------------------------------------------------------------------------------
Instrumented:  realcornp
Instruments:   uscornex corntoethanolbu realgdp L.totaluse realbeanp
               ethanoldmy02 weather realloanrate uscornyield endstkuserlag1
               L.realcornp L2.totaluse
```

```
Autoregressive 2SLS Supply:

ivregress 2sls  uscornqmbu  weather   (realcornp = uscornex corntoethanolbu realbeanp realgdp
ethanoldmy02     realloanrate L1.realcornp L2.uscornqmbu L1.totaluse L2.totaluse  )   uscornyield
endstkuserlag1 L1.uscornqmbu, first robust

First-stage regressions
-----------------------

                                                  Number of obs   =         28
                                                  F(  14,     13) =     244.23
                                                  Prob > F        =     0.0000
                                                  R-squared       =     0.9878
                                                  Adj R-squared   =     0.9747
                                                  Root MSE        =     0.1577

------------------------------------------------------------------------------
             |               Robust
   realcornp |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     weather |   .1490878   .1703305     0.88   0.397    -.2188889    .5170645
 uscornyield |  -.0063988   .0064882    -0.99   0.342    -.0204158    .0076181
endstkuser~1 |  -1.526682   .6337444    -2.41   0.032    -2.895803   -.1575602
  uscornqmbu |
         L1. |  -.0000293   .0000629    -0.47   0.649    -.0001652    .0001066
    uscornex |   .0004007   .0001728     2.32   0.037     .0000274    .0007741
corntoetha~u |   .0004682    .000101     4.64   0.000       .00025    .0006863
   realbeanp |   .2182172   .0363143     6.01   0.000     .1397651    .2966694
     realgdp |  -.0004005    .000121    -3.31   0.006    -.0006618   -.0001391
ethanoldmy02 |  -.1938603   .1743464    -1.11   0.286    -.5705128    .1827922
realloanrate |   .4514373   .0845801     5.34   0.000     .2687132    .6341615
   realcornp |
         L1. |  -.2217992   .1142432    -1.94   0.074    -.4686067    .0250082
  uscornqmbu |
         L2. |  -.0000271   .0000411    -0.66   0.521    -.0001159    .0000617
    totaluse |
         L1. |   .0002747    .000132     2.08   0.058    -.0000104    .0005598
         L2. |   .0000843   .0000964     0.87   0.398     -.000124    .0002927
       _cons |   1.632108   1.270944     1.28   0.221    -1.113599    4.377815
------------------------------------------------------------------------------


Instrumental variables (2SLS) regression               Number of obs =      28
                                                       Wald chi2(5)  =  361.40
                                                       Prob > chi2   =  0.0000
                                                       R-squared     =  0.9501
                                                       Root MSE      =  423.48

------------------------------------------------------------------------------
             |               Robust
  uscornqmbu |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   realcornp |   481.2225    162.288     2.97   0.003     163.1438    799.3012
     weather |  -546.9791   224.2547    -2.44   0.015    -986.5102   -107.4479
 uscornyield |   93.45387   10.19696     9.16   0.000     73.46819    113.4396
endstkuser~1 |  -1391.366   809.2315    -1.72   0.086     -2977.43    194.6988
  uscornqmbu |
         L1. |   .0720139   .0520255     1.38   0.166    -.0299542    .1739821
       _cons |  -4408.452    1780.75    -2.48   0.013    -7898.658   -918.2454
------------------------------------------------------------------------------
Instrumented:  realcornp
Instruments:   weather uscornyield endstkuserlag1 L.uscornqmbu uscornex
               corntoethanolbu realbeanp realgdp ethanoldmy02 realloanrate
               L.realcornp L2.uscornqmbu L.totaluse L2.totaluse
```

References

Anderson, D.P. et al. The Effects of Ethanol on Texas Food and Feed. Agricultural and Food Policy Center, Texas A&M University. April 2008. http://www.afpc.tamu.edu/pubs/2/515/RR-08-01.pdf (accessed May 26, 2008).

Animal and Plant Health Inspection Service (APHIS). USDA. 2006. *Farm Policy*. http://www.aphis.usda.gov/vs/ceah/cei/bi/emergingmarketcondition_files/6farmpol.pdf (accessed November 7, 2007).

Annual Energy Review. Tables 5.9, 10.1, and 10.4. EIA of DOE. http://www.eia.doe.gov/emeu/aer/renew.html (accessed May 5, 2008).

Babcock, B.A. 2008. When Will the Bubble Burst? *Iowa Ag Review, 14*. Center for Agricultural and Rural Development.

Cassman, K., Eidman, V., & Simpson, E. November 2006. Convergence of Agriculture and Energy: Implications for Research and Policy. *CAST Commentary*, QTA2006-3.

Chambers, W. July 2004. Forecasting Feed Grain Prices in a Changing Environment. *Electronic Outlook Report from the ERS*. FDS-04F-01. Economic Research Service, USDA.

Collins, K.J. and J.A. Duffield. 2005. Energy and Agriculture at the Crossroads of a New Future. In Outlaw, J.L., K.J. Collins, and J.A. Duffield (Eds.), *Agriculture as a Producer and Consumer of Energy* (pp. 1-29). USDA. Washington, DC: CAB International.

Commodity Costs and Returns: U.S. and Regional Cost and Return Data. USDA ERS. http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm (accessed August 12, 2007).

Costly feed situation for hog industry different than in past. 2006. *Iowa Farmer Today (SE)*, 9 Dec, 48.

De La Torre Ugarte, D. et al. December 2006. Economic and Agricultural Impacts of Etanol and Biodiesel Expansion. Department of Agricultural Economics, University of Tennessee.

Economic Report of the President. GPO Access. http://www.gpoaccess.gov/eop/tables07.html (accessed November 7, 2007).

Economic Research Service and Office of the Chief Economist, USDA. May 2007. An Analysis of the Effects of an Expansion in Biofuel Demand on U.S. Agriculture.

Eisenthal, J. February-March, 2001. Investigate the Debate: Food and Fuel in the Ethanol Expansion. *Ethanol Today*.

Epple, D. and McCallum, B.T. 2005. Simultaneous Equation Econometrics: The Missing Example. Carnegie Mellon University and NBER.

Estimated Petroleum Consumption, Table 5.13c. Energy Information Administration of the Department of Energy. http://www.eia.doe.gov/emeu/aer/petro.html (accessed May 5, 2008).

Ethanol and Unleaded Gasoline Average Rack Prices. Nebraska Energy Office. http://www.neo.ne.gov/statshtml/66.html (accessed May 5, 2008).

Ethanol, exports and livestock: Will there be enough corn to supply future needs? *Feedstuffs*, 26 July 2004, 21-22.

Ethanol Timeline. Energy Information Administration of the Department of Energy. http://www.eia.doe.gov/kids/history/timelines/ethanol.html (accessed November 7, 2007).

FAPRI (Food and Agricultural Policy Research Institute), University of Missouri. August 2005. Implications of Increased Ethanol Production for US Agriculture. *FAPRI-UMC Report* #10-05.

Feed Grains Database. Economic Research Service of the US Department of Agriculture. http://www.ers.usda.gov/data/feedgrains/ (accessed November 7, 2007).

Feed Situation and Outlook Yearbook. April 2000. Market and Trade Economics Division, Economic Research Service, USDA. FDS-2000. http://usda.mannlib.cornell.edu/usda/ers/FDS-yearbook//2000s/2000/FDS-yearbook-04-24-2000.pdf (accessed September 5, 2007).

Food CPI, Prices and Expenditures. ERS of USDA. http://www.ers.usda.gov/Briefing/CPIFoodAndExpenditures /Data/table7.htm (accessed May 5, 2008).

Foote, R.J. August, 1958. Analytical Tools for Studying Demand and Price Structure. *Agricultural Handbook No. 146*, USDA.

Foote, R.J., Klein, J.W., & Clough, M. October 1952. The Demand and Price Structure for Corn and Total Feed Concentrates. *USDA Technical Bulletin, No. 1061.*

Gallagher, P. 1994. Stabilizing the U.S. Corn Market. *Review of Agricultural Economics*, 16, 301-319.

Gallagher, P., Schamel, G., Shapouri, H., & Brubaker, H. 2006. The International Competitiveness of the U.S. Corn-Ethanol Industry. *Agribusiness: An International Journal*, Vol. 22, 1, pp. 109-134.

Gardner, B. 2007. Fuel Ethanol Subsidies and Farm Price Support. *Journal of Agricultural & Food Industrial Organization*, 54.

Hallam, D. 1990. *Econometric Modelling of Agricultural Commodity Markets*. London: Routledge.

Hammerschlag, R. 2006. Ethanol's Energy Return on Investment: A Survey of the Literature 1990 – Present. *Environmental Science & Technology*, 40, 1744-1750.

Hart, C.E. 2008. The Outlook for Corn and Ethanol. *Iowa Ag Review*, 14. Center for Agricultural and Rural Development.

Industry Statistics: Historic U.S. fuel Ethanol Production. Renewable Fuels Association. http://www.ethanolrfa.org/industry/statistics/#A (accessed November 7, 2007).

Koplow, D. October, 2006. Biofuels – At What Cost? Government support for ethanol and biodiesel in the United States. Prepared by Earth Track, Inc., Cambridge, MA. Prepared for The Global Subsidies Initiative (GSI) of the International Institute for Sustainable Development (IISD), Geneva, Switzerland.

Labys, W. C., and Pollak, P. K. 1984. *Commodity Models for Forecasting and Policy Analysis*. New York: Nichols Publishing Company.

Park, H., and T. R. Fortenbery. 2007. The Effect of Ethanol Production on the U.S. National Corn Price. *Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management.* Chicago, IL. [http://www.farmdoc.uiuc.edu/nccc134].

Quick Stats. National Agricultural Statistics Service of the USDA. http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/index.asp (accessed July 10, 2007).

Renewable Fuels Association (RFA), Renewable Fuels Standard. http://www.ethanolrfa.org/resource/standard/ (accessed May 26, 2008).

Retail Motor Gasoline and On-Highway Diesel Fuel Prices, 1949-2006. Table 5.24. EIA of DOE. http://www.eia.doe.gov/emeu/aer/txt/ptb0524.html (accessed May 5, 2008).

Reuters AlerNet. WFP food aid costs up 'dramatically' in past weeks. http://www.alertnet.org/thenews/newsdesk/N15470173.htm (accessed May 26, 2008).

Stock, J. H. and Watson, M. W. 2003. *Introduction to Econometrics*. Boston: Addison-Wesley.

Studenmund, A. H. 2006. *Using Econometrics: A Practical Guide* (5th ed.). Boston: Addison-Wesley.

Subotnik, A. and Houck, J. P. 1982. A Quarterly Econometric Model for Corn: A Simultaneous Approach to Cash and Futures Markets. In G. C. Rausser (Ed.), *New Directions in Econometric Modeling and Forecasting in U.S. Agriculture* (pp. 225-255). New York, New York: Elsevier Science Publishing Co.

Taylor, R. D. et al. March 2006. Ethanol's Impact on the U.S. Corn Industry. *Agribusiness & Applied Economics Report* No. 580. Center for Agricultural Policy and Trade Studies. North Dakota State University.

Tokgoz, S. et al. July 2007. Emerging Biofuels: Outlook of Effects on U.S. Grain, Oilseed, and Livestock Markets. *Staff Report* 07-SR 101. Center for Agricultural and Rural Development (CARD), Iowa State University.

Tyner, W.E. and Taheripour, F. Future Biofuels Policy Alternatives. Paper presented at a conference on Biofuels, Food, and Feed Tradeoffs. St. Louis, MO. April 12-13, 2007.

Wescott, P. C., and L. A. Hoffman. July 1999. Price Determination for Corn and Wheat: The Role of Market Factors and Government Programs. *Technical Bulletin* No. 1878. Market and Trade Economics Division, Economic Research Service, USDA.

Womack, A. August 1976. The U.S. Demand for Corn, Sorghum, Oats and Barley: An Econometric Analysis. *Economic Report* 76-5. Department of Agricultural and Applied Economics, University of Minnesota.

Yacobucci, B.D. March, 2006. Ethanol Imports and the Caribbean Basin Initiative. *Congressional Research Service (CRS) Report for Congress*, Order Code RS21930.