APPLICATION OF THE COMPETITIVE STORAGE MODEL TO US CORN ETHANOL POLICY

A Thesis

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by

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ABSTRACT

Biofuel policies in the United States were adopted to reduce dependence on crude oil, boost farm incomes, and benefit the environment. However, recent literature has focused on the negative effects of biofuels on crop and food markets in terms of increasing price levels and volatility. Corn ethanol policy in the United States has created new price linkages between the corn, ethanol, and gasoline markets.

Grain storage has the ability to mitigate price volatility. Thus, a better understanding of grain storage in the new environment of biofuels is warranted. The competitive grain storage model is extended to include these linkages. Four policies are considered: no policy, an ethanol consumption mandate, an excise tax credit, and both a mandate and tax credit together. The results show that the application of biofuel policy increases the expected price of corn and increases the amount of corn stored.

BIOGRAPHICAL SKETCH

Elizabeth Sheryl Byrd was born and raised in the small town of St. Marys, WV. She and her parents lived on a small horse farm adjacent to her grandparents' beef cattle farm. Elizabeth grew up a "tomboy" riding horses and helping her family feed the cattle. Elizabeth was an active 4-H and FFA member. She enjoyed various animal projects during her tenure as a 4-H member and exhibited her stock at numerous fairs and festivals. As an FFA member she was a Chapter Officer and competed in competitions ranging from parliamentary procedure to livestock judging. She won several state proficiency awards and was named WV State Star Farmer during her senior year of high school. After graduating high school, she earned her American FFA Degree.

Her interest in the business aspect of agriculture led her to pursue a bachelor's degree in Agricultural Economics at Purdue University in West Lafayette, IN. During her time at Purdue, Elizabeth enjoyed her studies. She studied abroad in Honduras and Japan. She was invited to join the departmental honors program where she got her first taste of academic research. She graduated from Purdue University in 2004 with Honors and Highest Distinction.

Elizabeth chose to pursue her Master's Degree at Cornell University in Ithaca, NY. Prior to completing her degree, she left to attended West Virginia University College of Law. During her law school career, Elizabeth was named to the Marlyn E. Lugar Trial Association. As a member of the Alternative Dispute Resolution Society, she volunteered her time mediate cases for local small claims courts. Elizabeth graduated from the West Virginia University College of Law as a member of the Order of the Coif, the highest academic honor that can be bestowed on a law student.

After a brief period away from academic life, Elizabeth returned to Cornell to finish her Master's Degree. Following the completion of her Master's Degree, Elizabeth plans on continuing her education at Purdue University where she will undertake PhD studies.

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CHAPTER 1
INTRODUCTION

1.1 Introduction

The adoption of biofuel policies has created a new link between oil prices and farm level prices for agricultural commodities such as corn (Tyner and Taheripour 2007). Biofuel policies were adopted in the hopes of reducing dependence on foreign oil, improving the environment, and improving farm incomes. However, these policies have increased the level and volatility of food prices, causing substantial welfare losses and having negative consequences for the environment (de Gorter and Just 2010).

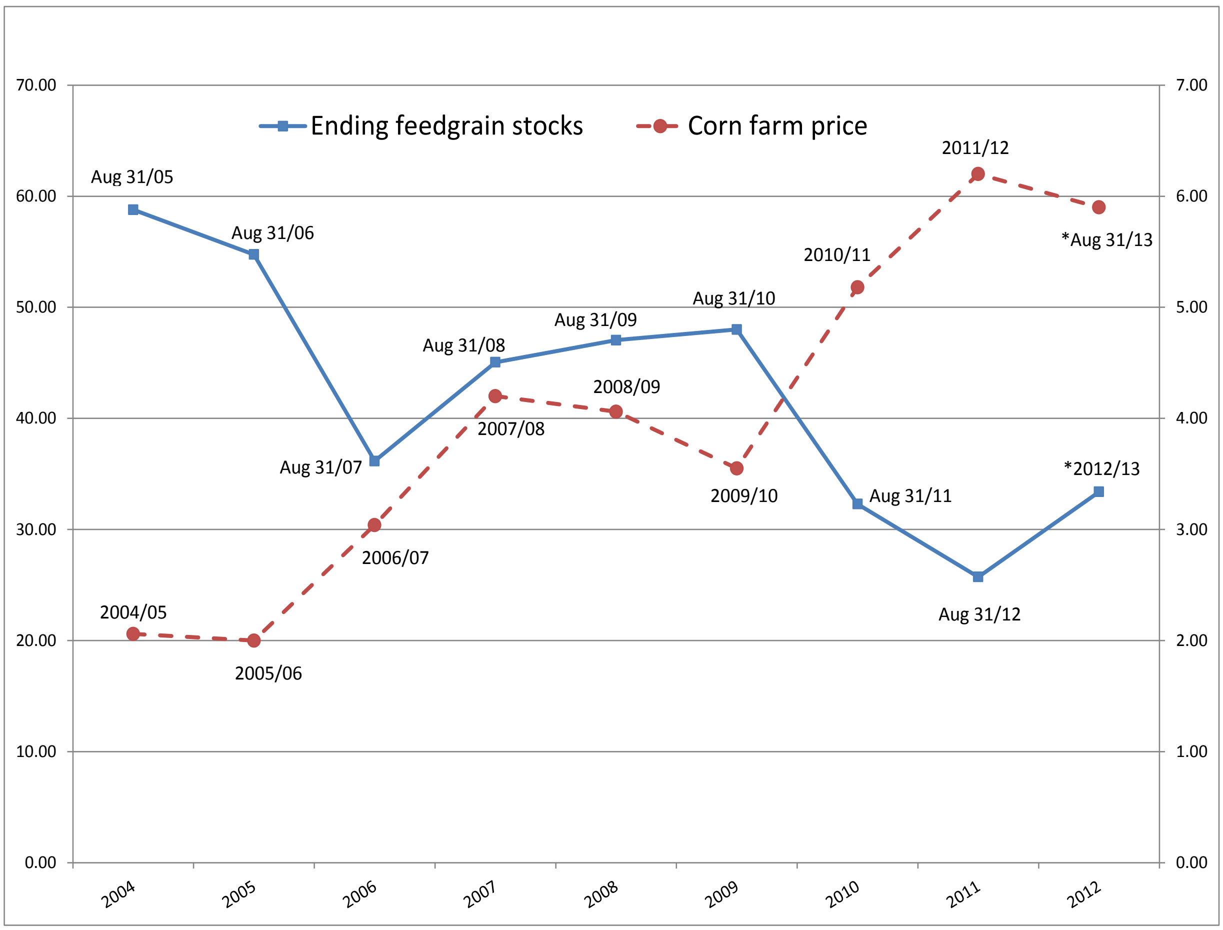
This research seeks to analyze the source of volatility in corn prices by considering the price linkages between gasoline, ethanol, and corn within the framework of the competitive model for grain storage. By doing so, two previously separate literatures, that studying the role of grain storage and that studying the price linkages between corn, ethanol, and oil, are combined. This knowledge will contribute to the body of literature exploring the impact of ethanol policy on food price level and volatility. Increasing food prices, especially volatile prices, are of concern to developing countries across the globe as well as the poor in developed countries (Barrett and Bellamare 2011).

The nature of corn production means there is one harvest per year and the amount of that harvest is determined in large part by the weather. Historically, this variation in harvest has been the most prominent source of uncertainty in the corn market. The ability to store grain is generally understood to mitigate price volatility by absorbing large harvests to support prices and releasing those stocks to lessen a price spike (Wright 2011). On a general level, this paper explores the role of storage in mitigating food price volatility ethanol policy. We will also explore how ethanol policy has affected the ability to mitigate prices using storage given that such a large proportion of the corn crop is currently being used for ethanol.

The analysis in this thesis seeks to explain what happened in the case of corn-ethanol in the United States. Figure 1 below shows how ending stocks went in the opposite direction of prices in all years except one: crop year 2007/08 where ending stocks increased with prices. This indicates in 2006/07, the increased demand for corn for biofuels was a market aberration – not a change in mean price but rather a one-time shock. As prices increased stocks were depleted. But in 2007/08, the market realized that biofuels would be a permanent shift in demand and so stocks went up with prices. For every year thereafter (at a much higher mean price), stocks and price moved in opposite directions as one would expect. For example, the current drought severely affecting corn production 2012/13 crop year is being treated by the USDA forecast as an aberration as stocks are expected to be depleted as prices rise.

Understanding how biofuel policy, with oil prices, impact farm level prices for corn in the presence of storage has important implications for farm and energy policy in the United States and for explaining current market events. The remainder of this chapter focuses on the motivation for the research and gives a brief overview of the history of corn ethanol and the policies related to it.

Figure 1: Corn Ending Stocks versus Price



Source: USDA

1.2 Brief History of Corn Ethanol in the United States

Ethanol has long been thought of as an ingredient in fuel; however, it has only recently gained traction in the United States. Ethanol has been on the energy radar in the United States since the 1920's. Then it was believed that the peak of petroleum production was near (Carter et al. 2011). At the time, new oil reserves were discovered in the US keeping the price of oil and gasoline relatively low. Ethanol's lack of profitability, due to low oil prices and the fact that it is 35 percent less efficient than regular gasoline kept ethanol from becoming a mainstream fuel ingredient (Carter et al. 2011).

Amendments to the Clean Air Act in 1990 provided another opportunity for ethanol to shine. Oxygenate additives, either ethanol or methyl tertiary butyl ether (MTBE), were required to be blended into finished gasoline in some regions (Tyner 2008). These additives increase the amount of oxygen in gasoline, help fuel burn more completely, and reduce vehicle emissions. Because MTBE was cheaper, it became the additive of choice Thus, ethanol would have to wait a few more years before it became a major fuel component. Eventually, MTBE was found to have contaminated groundwater in several states (MTBE). By 2005, twenty states had banned MTBE and it fell out of use in others (Gardner 2007). The door had finally been opened for ethanol.

Biofuel policies have been adopted with the hopes of reducing dependence on oil from a national security perspective, improving the environment and increasing agricultural incomes. To achieve these policy goals, many policies are/have been employed. These policies include consumption subsidies, consumption mandates, import barriers, and environmental sustainability standards (Gardner and Tyner 2007). Additionally, biofuel policies are designed to complement other energy policies such as cap & trade and existing fuel taxes (de Gorter and Just 2010). The benefits of biofuels are outlined by de Gorter and Just (2010) and include reducing tax costs of farm subsidy programs and improving international terms of trade.

The primary catalyst for the increase in corn being used for ethanol in the United States was the Renewable Fuel Standard (RFS) introduced in 2005. The RFS sets forth a consumption mandate or minimum amount of ethanol in gasoline. The RFS is implemented as a blend mandate based on a forecast of the coming year's total fuel consumption (de Gorter and Just 2009b). In 2005, when the RFS was introduced, 3 percent of finished gasoline was comprised of ethanol. In that same year, 14 percent of corn produced in the United States was used to produce fuel ethanol. The RFS percentage was raised to 10 percent in 2007. It is estimated this increase in the RFS resulted in a 43 percent increase in the price of corn for 2010 (Drabik 2011). As a result of the increase in the RFS the percentage of U.S. corn destined to become fuel ethanol climbed to 38 percent in 2008 (Carter et al. 2011).

In addition to the RFS, there has historically been a volumetric ethanol excise tax credit (VEETC) or ethanol tax credit in place. This credit allowed ethanol blenders to receive a federal tax credit of $.45 per gallon. When state tax credits are added, the tax credit increases to $.52 per gallon (de Gorter and Just 2010). The ethanol tax credit expired at the end of 2011. The RFS and VEETC are the policies considered in this paper.

However, biofuel policies do have downside by increasing both food price levels and increasing volatility in both food and energy markets (de Gorter and Just 2010). Further, studies reveal that biofuel policies have induced environmental externalities like precipitating land use changes that have increased greenhouse gas emissions (Searchinger et al. 2008). Additionally, biofuel policies have the potential to cause deadweight losses, which can be quite large (de Gorter and Just 2010).

In response to recent food price volatility, many explanations have been brought forth including a “perfect storm” of factors including low interest rates, high oil prices, catastrophic weather events, low world inventories of staple crops, and rampant price speculation. (Wright 2011). However, not everyone agrees with the “perfect storm” argument. One researcher lays the blame squarely on biofuels (de Gorter 2012). Another dismisses recent explanation of interest rates, speculative bubbles and input costs on grain price volatility in favor of the competitive grain storage model to explain grain market volatility and recent price spikes (Wright 2011). This model first put forth by Gustafson (1958) asserts that rational market actors will store grain when the expected price next period exceeds the current price by at least the cost to store the grain until the next period. In other words, storage is a form of arbitrage or buying low and selling high. This arbitrage takes place over time. If prices are expected to rise, then rational actors will store grain as long as the expected price increase covers any costs associated with storing the grain.

On a global scale the primary staple grains are wheat, rice, and corn. Historically, normal shifters of supply and demand have affected these markets. In the past decade stocks of these staples have declined due to the adoption of substantial biofuel mandates (Wright 2011). In turn, low inventories have made these markets particularly sensitive to short-run shocks. Drought is a primary example of a short run supply shock. Prior to 2002, corn was becoming increasingly popular as more people worldwide began to demand corn-fed animal protein. Another example of a demand shock is the demand for biofuels in excess of that required by increasing oil price (Wright 2011). That additional demand comes from a variety of policies like blend mandates and ethanol tax subsidies. Since 2002, biofuels has become an important source of demand for corn

(Wright 2011). In this paper, analysis of biofuel policy is integrated into a model for competitive grain storage.

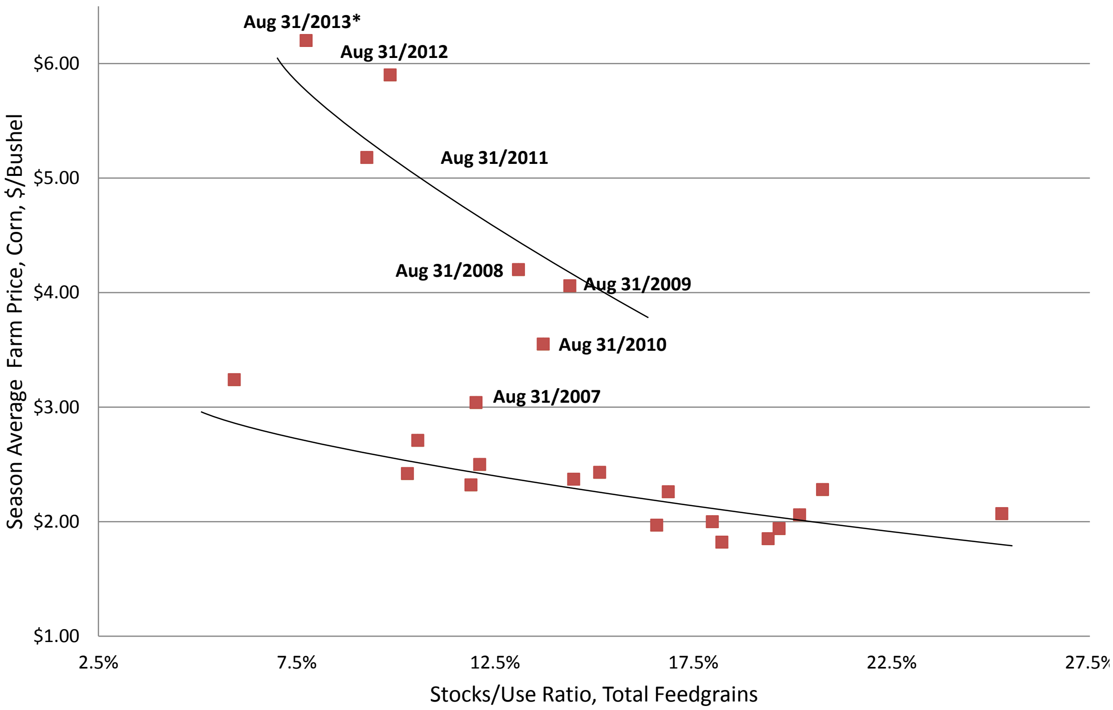
1.3 Combining Two Literatures

Biofuels, especially ethanol, have garnered much attention from news media, politicians, and academics alike. Many pages have been devoted to the welfare impacts of various ethanol policies and researchers have postulated new linkages between the previously independent corn, ethanol, and gasoline prices. Separately, a literature focusing on modeling grain storage has emerged and been tested. By combining these two literatures, this paper seeks to improve the understanding the effects of biofuels on the corn market and how newly created price linkages affect price volatility in the corn market.

Figure 2 illustrates the proposed effect of biofuels on storage. Prior to biofuels, stocks fluctuated from less than 7.5% of use to more than 22.5% of use. Meanwhile, the corn price primarily remained below $3/bushel. During this time, storage was absorbing excess supply in years with good harvest. Notice the downward trend to the line. More corn is stored at lower prices. In the post biofuel era, the higher trend line prevails at higher prices. Now, a large percentage of corn is destined to become corn ethanol. This new trend line represents a new equilibrium that will be explored through the lens of grain storage.

This paper builds on the work of de Gorter and Just (2009a,b) by adding the component of grain storage, based on the competitive grain storage model, to their substantial work on modeling biofuel policy through price linkages between corn, ethanol, and gasoline. In the current work, a model is specified that allows consumers to adjust the ethanol blend they purchase based on price and ethanol's lower contribution to mileage. This knowledge has

Figure 2. U.S. Farm Corn Price vs. Feedgrain Stocks/Use Ratio Crops of 1990 to 2012 (Sept. 1 Crop Years)



Source: USDA

important implications for policy in the United States, explaining current market events, and worldwide food prices.

Chapter 2 discusses relevant literature on the topics of the linkage between gasoline, ethanol, and corn prices and the competitive storage model. Then, Chapter 3 outlines the methodology for the current research. Chapter 4 presents and discusses the results. Chapter 5 discusses conclusions and recommendations for future research. Following a list of works cited, appendices are included of the detailed routine used to solve a model of grain storage with biofuel policies.

CHAPTER 2
LITERATURE REVIEW

2.1 Setting the Stage

Since gasoline has been an important input to agricultural products through liquid fuel and fertilizer, agricultural prices were already linked to energy prices through input costs. With the ethanol boom, beginning in 2006, agricultural and energy prices became linked through output prices (Trujillo-Barrerra, et al. 2011). Corn, an agricultural output, was now used as an input for biofuels.

This new relationship now caused the price of corn to be affected by the demand for ethanol and its market fundamentals. The demand for ethanol as an ingredient in blended fuel is, in turn, affected by the demand for gasoline and its market fundamentals. Overarching this discussion is the market for raw crude oil that is commonly understood to be much larger than the market for ethanol (de Gorter & Just 2010, Serra et al 2011). Furthermore, the oil market is highly volatile (de Gorter and Drabik 2012; Serra & Zilberman 2011). In fact, some have gone so far as to claim that ethanol production is a response to volatility in oil prices (Trujillo-Barrerra et al. 2011).

The literature regarding biofuel policy has been explored by proving agricultural and energy prices were linked, studying the price level transmission, and understanding the contributors to price volatility. There has been some debate about the impacts of this linkage on corn price and oil price volatility. For example, one group of authors asserts that the energy market gives stability to the food market albeit at the cost of higher food prices. They further assert that instability in the US agricultural market is transmitted to the energy market (Hochman, Sexton & Zilberman 2008). In a later paper studying the volatility spillovers in the Brazilian ethanol market, where sugar is the primary ingredient in ethanol, the authors find the opposite. Volatility in the oil market increases volatility in the ethanol market that spills over to the sugar market (Serra, Zilberman and Gil 2011). Clearly our understanding of the nature of price volatility in price transmission is evolving.

Understanding the nature of the relationship between the oil, ethanol, and corn markets and the direction in which the volatility flow is important. First, an accurate understanding of the effects of policy will assist policymakers in crafting targeted, effective policies while minimizing social costs and externalities. Second, an understanding the nature of the price risk involved is very important. This is especially true for the already volatile, weather-dependent corn market.

2.2 Early Research: Agricultural and Energy Markets are linked

Early studies were able to identify that agricultural commodity prices and oil prices were indeed linked. Co-integration analyses determine statistically or econometrically whether two different commodities prices move together over time. In other words, if the market for corn and gasoline were linked, we would expect their prices to generally increase or decrease at the same time.

Campiche et al. (2007) study the covariability of oil prices, corn, and other agricultural commodities in two time periods: 2003-2005 and 2006-2007. Using a vector error correction model, the authors find that none of agricultural commodities were co-integrated with oil prices from 2003-2005. However, corn and soybeans were co-integrated with oil prices in 2006-2007. This indicated that corn and soybeans were somehow linked to the price of oil with biofuels suspected to be the link. However, co-integration analyses do not provide a theoretical basis for the relationship. Further, they do not specifically identify how the price transmission occurs (Ciaian and Kancs 2011). In other words, co-integration analyses can tell us statistically whether two sets of prices are moving together. This approach does not tell us what mathematic or economic relationship governs this shared movement.

Equilibrium models have also been employed to explore the linkage between agriculture and energy markets. Through a series of papers, de Gorter and Just (2009a, 2009b) analyze multiple policy instruments (tax exemption or tax credits and blending or consumption mandates) simultaneously using a partial equilibrium model. Additional equilibrium models that examine alternative biofuel policy scenarios include Yano, Blandford, and Surry (2010); Thompson, Meyer, and Westhoff (2009); and Hochman, Sexton, and Zilberman (2008).

2.3 The Nature of Storage: An argument for Including it in a Model of Ethanol Policy

> *The idea that annual fluctuations in supplies of grains and other storable agricultural commodities can or should be evened out through the medium of the year to year storage is thousands of years old. (Gustafson 1958, pg. 1)*

Suppose for a moment that storing corn from one period to the next is impossible. Without the ability to store corn, the price is determined by the market clearing condition where quantity supplied equals quantity demanded. Because corn is an annual crop, once it is planted there is no way to supply adjustments. Thus, the market price is almost entirely determined by the quantity of the annual harvest.

However, corn is a storable commodity. In the case of an exceptionally large harvest, excess corn could be stored until a later period. When the price falls due to a large harvest, increasing the stocks of corn on hand can reduce the severity of the price slump (Wright 2011).

On the other hand, consider the case of a poor harvest. Without storage the price of corn would rise sharply to meter out the limited supply to those who can pay the increased price. Releasing stocks when the supply of corn is low can reduce the high price spike. However, storage can only mitigate price spikes as long as there are stocks of corn available (Wright 2011). Furthermore, volatility increases as stocks decline (Williams and Wright 1991; Wright 2011).

Storage can aid in smoothing both negative and positive price spikes. However, when stocks reach zero and expected prices are high, supply must equal demand. In the short run, supply is fixed. In this case, some uses may go unfilled such as the need for animal feed or demand by poor consumers (Wright 2011). Storage cannot mitigate a persistent change in the price level, but it can mitigate a price increase caused by a sudden, unforeseen jump in demand like that of biofuels.

A sudden, permanent demand shock, and economists argue that biofuels fall into this category, requires the market to adjust (Roberts and Tram 2012). This adjustment must be satisfied by a combination of releasing stored inventory and higher prices to meter out the limited supply. Market adjustment will begin as soon as the demand shock is anticipated (Roberts and Tram 2012). If the initial demand shock and resulting shifting out of demand happens unanticipated and there are sufficient inventories to absorb the shock, the initial price change will be relatively small (Roberts and Tram 2012). However, if stocks are drawn down, this may contribute to increased price volatility during the transition from old to new equilibriums. If the market can anticipate the demand shock and accumulate stocks in advance, the actual price shock is pushed backwards in time to the time of anticipation (Roberts and Tram 2012).

While, there is discussion about the linkage between stocks and price at the theoretical level, the scarcity of data on public and private stocks has limited the number of empirical applications (Serra and Gil 2012). However, there are empirical studies where stocks had a signification influence on market price behavior. For example, Kim and Chavas (2002) used econometric analysis to show that increasing private and public stocks of U.S. non-fat dry milk had significant impacts reducing price volatility.

Although storage has the ability to smooth out potential price highs and lows, it complicates market analysis because market clearing no longer occurs where current consumption equals current supply if stocks are changing. Storage can be characterized as inter-temporal arbitrage (Wright 2011). In other words, storing grain is a bet that prices will be higher in the future, and high enough to at least cover the storage costs. Given that ethanol policy is accused of contributing to those price highs and lows, consideration of storage is warranted. Recently, Wright (2011) asserted storage could mitigate a price increase caused by a mandated demand increase such as biofuels policy.

2.4 Competitive Grain Storage Model

The model set forth by Gustafson (1958) was the first rigorous model of the market for a storable crop. The model he introduced would later come to be known as the rational expectations model. Wright and Williams used this model as the basis for their modeling and numerical simulations of grain storage demand and the resulting impact on the market for grains using best guesses of key parameters (1982, 1984).

In the competitive storage model, understanding the relationship between prices and stocks is critical to understanding price volatility. In the basic form of the model, price behavior is entirely dependent of supply shocks (Serra and Gil 2012). Some simplifying assumptions are employed. First, the marginal cost of storage is positive but relatively small. It is thus reasonable to assume that the unit cost of storage is constant. Furthermore, they assume that storage capacity does not constrain the size of stocks (Wright 2011). One important feature of the model and interesting point to consider is that storage cannot be negative for the market as a whole. Transfers through storage are unidirectional. This means that the market, as a whole, can borrow from the past. Corn is transferred through storage from last period to this period. However, the market cannot borrow from the future. This would mean stocks would be negative (Wright 2011).

This discussion will follow Wright's work (Williams and Wright 1991, Wright 2011). This model assumes an agricultural crop that is storable and experiences planning once per year. For ease of understanding, the year the crop is sown will be referred to as $t-1$ and the year the crop is harvested is t. Likewise, h_t represents the harvest in year t. The distribution of h_t is known, but the individual draw is random due to weather disturbances. Furthermore, the variable h_t cannot be accurately predicted one year in advance (Wright 2011). In other words, you know when you plant the crop the range of possible harvest outcomes and the probability that each harvest outcome will occur. However, you do not know with certainty exactly which outcome will prevail.

The market demand for the crop is the horizontal sum of the two demands. The first is the consumption demand in period t, represented by c_t. This is the consumption for the crop in the current period. The second is the storage demand, x_t. This is also referred to carry-out. This is the amount stored or carried out of the period for sale in a later period. In any period, the sum of the current period's harvest and carry-in, amount stored last period, is the available supply, A_t.

Likewise, consumption in the current period represents the difference in available supply, A_t, and stocks that are carried out, x_t. This yields two accounting relationships

$$A_t = h_t + x_{t-1}$$

$$c_t = A_t - x_t$$

The model assumes competitive storage where the amount of stocks carried out, x_t, are positive only when the expected increase in the price of the stored grain is greater than or equal the cost of storing that grain and the prevailing interest rate. Because market actors are competitive, expected profits will fall to zero. This means that firms will enter the market to store grain as long as there are positive profits to be made. Those firms will exit when expected profits are negative. These concepts form the basis for the competitive storage model. The Wright model does not initially consider spatial questions, trade barriers, subsidies or taxes (Wright 2011). However, we will begin to address these topics within this work. A more detailed explanation of estimating the model can be found in the methodology section.

Deaton and Laroque pioneered the empirical estimation of the competitive storage model (1995). Prior to their work, the limited availability of time series data had prevented its estimation (Cafiero et al. 2011). Their results presented a dim view of the storage model and its ability to explain the serial correlation of commodity prices. Deaton and Laroque concluded this was a failure of the model itself, rather than an error in specification or estimation (1995). Recently, this finding has been overturned. Cafiero et al. (2011) recreated the analyses by Deaton and Laroque (1995) using their original data set. By improving the estimation technique, Cafiero et al. were able to show the competitive storage model was indeed capable of replicating the price variation seen in commodity markets (2011). This led the authors to conclude the competitive storage model was a useful tool (Cafiero et al 2011).

Another example of implementing the competitive storage model is Roberts and Tran (2012) where the transition between the pre-biofuel and post-biofuel economic environments is pinpointed. They characterize biofuels as a permanent shift in demand. They seek to understand when the market anticipated the biofuel demand shock, relative change in elasticities between the new and old economic environment, and inventories assisted during the adjustment period. Robert and Tram (2012) include both supply and demand responses in their model. Demand is a function of current price. Supply response is modeled as the land area cultivated based on expected future price.

They create simulated data and compute GMM-like scores to obtain the parameters with the least difference between the simulated and observed data. The model also converts corn, soybeans, rice, and wheat values for production and prices into dollars per calorie. Finally, the four commodities are aggregated to form a single series of data. The authors assert prices and inventories can both rise because a rational market can foresee continually rising prices. One possible scenario is that the market anticipated the biofuel demand shock in 2006-2007. This resulted in increased prices and inventories.

Another way of exploring the effect of expanding ethanol production on corn prices using a structural vector autoregression to model the dynamics of corn storage (Carter et al. 2011). The authors argue that it is necessary to account for inventories (i.e. storage) when constructing a model that explains the price response to the increased demand for ethanol (demand shock). In their analysis this comes into play two ways. First, that market actors in the latter part of 2006 should have been able to foresee the coming boom in ethanol and would have acted on that hunch. Second, the price response to a shock depends on the available inventories.

The model developed by Carter et al. (2011) relies on a two-period model includes supply and demand in the first period and second periods with storage between the first and second periods. The demand function includes all sources of use. For simplicity, there are no imports and the supply in the first period is fixed. Supply in the second period is given by the expected price for the good in period 2 at the end of period 1. Storage cannot be negative, but the price of storage can be (Carter et al. 2011).

Carter et al. (2012) uses a structural vector auto-regression (SVAR) to estimate curves for supply of inventory, demand for inventory, and supply of storage. The estimated parameters are based upon annual data from 1961-2005. Then, those parameters are used to conduct a counterfactual analysis by forecasting annual prices and inventory for 2006-2010 without supply and demand shocks such as the ethanol boom. The authors estimate that corn price would have been 30 percent lower during the 2006-2010 span if the ethanol boom had not occurred (Carter et al. 2011). Storage comes into play in the analysis as one of the regression variables, log crop-year ending inventories, using the US corn inventory on August 31 of each year. The authors conclude that ethanol prices had indeed increased in advance of the new RFS going into effect, corn prices would have been 30 percent lower without the ethanol boom, 2010 corn inventory was run down because of poor harvest, and 2010 prices were 50 percent above where they would have been if ethanol production had been fixed at 2005 levels.

2.5 Linking the Corn, Ethanol, and Gasoline Prices through Ethanol Policy

We will consider a competitive market to determine the linkages between corn, ethanol and gasoline prices. The development of these linkages is necessary for extending the competitive storage model to include ethanol policy. First, we will explore the link between corn and ethanol. We will then proceed to derive the relationship between corn, ethanol, and oil prices in the presence of a mandate and tax credit. This discussion will substantially follow the work of de Gorter and Just (2008; 2010).

Let us now consider the relationship between corn and ethanol. Corn is an input in the manufacture of ethanol. One bushel of corn can make 2.8 gallons of ethanol (Eidman 2007). Ethanol is not the only product made from corn in the process. When corn is used to manufacture ethanol, a co-product, dried distillers grain with solubles (DDGS), is produced. This co-product is far from useless. In fact, the DDGS is substitutable for corn in non-ethanol uses such as animal feed (Drabik, 2011). Thus, DDGS will replace corn in non-ethanol uses like animal feed. This, in turn, frees up more corn for use in the making of ethanol (Drabik, 2011).

Let β represent the gallons of gasoline produced from a bushel of corn and δ is the proportion of the value of the corn products returned to the market as byproducts of ethanol. Then the price of corn can be written as

$$P_{Eb}=\left(\frac{\beta}{1-\delta}\right)(P_G+t_C)-c_o$$

where P_{Eb} is given by the price of corn being equal to the price of ethanol in \$/bushel. Following de Gorter and Just, we adopt values from existing literature. Values for β and δ are 2.8 and .31 respectively (Eidman 2007). Inserting these values into the equation we find that $(\beta\ /1-\delta\ )$ is equal to 4 making the corn price very sensitive to a change in ethanol's price by changes in policy or oil price (de Gorter and Just 2008). The price relationship between corn and ethanol rests on the assumption that ethanol producers operate under the zero profit condition (Drabik 2011).

Most researchers have argued that consumers are unaware or do not adjust their purchases based on the reduced mileage provided by ethanol. Recall that ethanol is less efficient than gasoline and provides fewer miles per gallon that gasoline. However, the increase in flexible fuel vehicles and fuel stations offering E-85 means consumers could be adjusting their purchases based on the mileage each fuel, ethanol or gasoline, provided (de Gorter and Just 2008). According to the U.S. Department of Energy Alternative Fuels & Advanced Vehicles Data Center, E-85 is available at over 2,400 locations in 40 states across the country providing an estimated 8 million flexible fuel vehicles. The U.S. Department of Energy website also features an Alternative Fueling Station Locator ("Alternative Fueling"). The Renewable Fuels Association (RFA) also has a Flex-Fuel Station Locator application, or "app", for iPhone and Android Platforms. In addition, the RFA also provides a downloadable list of E-85 stations for users of GPS units like TomTom and Garmin ("There's an iPhone App"). It is reasonable to assume that at least some consumers are already allocating their fuel purchases based on the mileage ethanol and gasoline provide.

On the other end of the spectrum, there are gas stations selling gasoline that contains no ethanol. Because the ethanol consumption mandate is enforced at the aggregate market level, the minimum amount of ethanol consumption may be met without every gallon of fuel containing ethanol. Thus, there is flexibility for consumers to choose the gasoline/ethanol blend based on the contribution of each to mileage.

Following de Gorter and Just (2008), we can derive the "flex model" market price of ethanol where consumers adjust for ethanol's contribution to mileage. Thus, the price consumers are willing to pay for an ethanol blend, P_E , is represented by:

$$P_E = \lambda(P_G + t)$$

where

$$\lambda = .70 = \frac{miles\ per\ gallon\ of\ ethanol}{miles\ per\ gallon\ of\ gasoline}$$

(de Gorter and Just 2008). This represents the amount consumers are willing to pay for ethanol given that it yields .7 times as many miles as the same amount of gasoline. The revenue refiner's receive from the sale of ethanol is

$$P_G + t - t_c$$

Setting the two equations equal

$$P_E - \lambda(P_G + t) = P_G + t - t_c$$

solving for P_E gives a market price for ethanol of:

$$P_E = \lambda P_G - (1 - \lambda)t + t_c$$

In contrast to de Gorter and Just, Mallory et al. identify the linkage between the corn and ethanol market in the prices of corn futures more than one year to maturity. Motivated by an apparent disconnect between economic theory and the literature and in agreement with de Gorter and Just (2008), the authors maintain that the no-profit condition is appropriate. However, the authors disagree that the relationship is determined in current spot prices in favor of prices in the futures market.

The authors argue that the ethanol industry is large enough to be considered competitive. The assumption of competitiveness means that the condition of no profits in the long run holds. If there are positive profits to be made by high prices, firms will enter the market and/or expand ethanol production to force the price down. Likewise, if prices are low, production will contract. The zero-profit condition does not hold in the short run because expansion of production requires a time horizon. Because the break-even condition occurs in the long run, the relationship between corn and ethanol prices should also occur beyond the short run. The authors derive the long run zero profit condition based on total revenue equaling total cost. In testing the validity of their formulation of the link, they find that from mid-2006 until 2010 the linkage was so strong it appeared to dominate all other market forces.

CHAPTER 3
METHODOLOGY

3.1 Overview

The goal is to calibrate a partial equilibrium model of the corn, ethanol and fuel market to determine the effects of biofuel policies on the characteristics of the storage curve and stock levels. The biofuel policies under consideration are the ethanol consumption mandate and the blenders tax credit.

Like Wright's model, the competitive storage model estimated here includes the effects of uncertainty in corn production (2011). However, the model is extended to include uncertainty in gasoline prices. Wright's model is further extended to consider the price linkages between corn, ethanol and oil markets (2011).

Wright's competitive storage model solves for grain storers' expected corn price that result in a particular amount of corn stocks carried in to the period. Wright's model is based on the assumption that errors in corn yields are uncorrelated from one period to the next, and hence storage of corn is the only link between corn prices from one period to the next. Hence, the expected equilibrium price at the time of planting is a function of the amount of grain stored that will be available at the time of harvest. This relationship between expected price and storage will be used in the stylized model of the US market for corn to produce corn supply, demand, and storage demand curves.

3.2 Modeling Biofuel Policies with Competitive Storage

The competitive storage model is too complicated to be solved analytically. Following Williams and Wright (1991), the model is estimated using a polynomial approximation. Their analysis finds a low-order (quadratic) polynomial to be a good estimation technique. Polynomial approximations are useful for quickly estimating an otherwise difficult function to estimate. A brief overview of the polynomial approximation routine used to solve the competitive storage model is now given.

Suppose in each period t we want to determine how much grain to store, S_t. We can call future storage, storage next period, S_{t+1}. Suppose that storage in period $t+1$ follows a relationship, $\psi(S_{t+1})$, the expected price of corn for period $t+2$. In other words, market actors will select the amount of corn to store next period based on what they expect prices to be the following period when they will sell the corn. This function implies a relationship between expected prices and current storage. Now suppose that the potential amounts of storage in the current period S_t is represented by a set of integer values. Given any value S_t we can calculate the expected price in the following period $t+1$ given that storage decisions in that period follows $\psi(S)$, and supposing that the market equilibrium prevails in period $t+1$. Using the relationship between the average price in period $t+1$ and the amount stored in the current period, time period t, we find the solution to our system when $\psi(S)$ produces expected prices in period $t+1$ that are equal to $\psi(S)$.

The computer program is given a starting value for the function $\psi(S)$ to calculate the average price in period $t+1$, using expected storage in $t+1$, expected price, and storage in period t, S_{t+1}, ψ, and S_t respectively. Then revised or more accurate starting value of ψ is generated by using the specified relationship between the average price in period $t+1$ and the storage in period t. The program iterates to revise the function ψ until ψ approximately reproduces itself. My modification to this competitive storage model is that in solving for the equilibrium price in period $t+1$, the supply, demand and policy functions introduced by de Gorter and Just (2009) are used to simulate the effects of ethanol policy.

3.3 Solving the Model

My version of the competitive storage model is estimated by MATLAB as a constrained minimization problem. What follows is a detailed description of the computer routine used to solve the model. This discussion follows the framework of the polynomial approximation technique outlined by Williams and Wright (1991). A discussion of how the model was augmented to include ethanol policy is included with each step. This discussion mirrors that found on pages 83 through 85 of their book, but highlighting how the model of biofuels markets are superimposed on the competitive storage model.

To begin, we specify a stochastic constant elasticity supply for corn,

(1) $$Q_{t+1}^{S} = C^{S} \cdot \left(E_t(P_{t+1}^{C})\right)^{\eta^S} \epsilon_{t+1}^{S}$$

where Q_{t+1}^{S} is the quantity supplied of corn in period $t+1$, $E_t(P_{t+1}^{C})$ is the expected price of corn in period $t+1$ at the period t, $\eta^S$is the supply elasticity, and C^S is a constant. The multiplicative disturbance term ϵ_{t+1}^{S} is assumed to be distributed such that $\ln \epsilon_t^S \sim N\left(1 - \frac{\sigma^2}{2}, \sigma^2\right)$, thus $E(\epsilon_t^S) = 1$. Additionally, we specify a constant elasticity demand for non-ethanol corn,

(2) $$Q_{t+1}^{D} = C^{D} \cdot (P_{t+1}^{C})^{\eta^D}$$

where variables are defined as in the supply curve. The price of pure gasoline (with no ethanol) is assumed to be exogenous, but stochastic, and given by $P_{t+1}^{G} = \overline{P^G} \epsilon_{t+1}^{G}$. Here, $\overline{P^G}$ is the price level, and the disturbance term is distributed with $\ln \epsilon_t^G \sim N\left(1 - \frac{v^2}{2}, v^2\right)$. A constant elasticity demand for blended fuel is given by

(3) $$Q_{t+1}^{F} = C^{F} \cdot (P_{t+1}^{F})^{\eta^F}$$

where Q_{t+1}^{F} is the quantity of blended fuel, C^{F} is a multiplicative constant, P_{t+1}^{F} is the price of fuel in time period $t+1$, and η^{F} is the elasticity of fuel demand. Here, the price of fuel is determined as

(4) $$P_{t+1}^{F} = \alpha(P_{t+1}^{E} + \tau - \tau_c) + (1-\alpha)(P_{t+1}^{G} + \tau)$$

where p_{t+1}^{E} is the price of ethanol per gallon, τ is the per gallon tax on fuel, τ_c is the per gallon tax credit for blending ethanol, and α is the proportion of ethanol in the fuel blend. Equation (4) requires that the price of fuel be equal to the marginal cost of the inputs. Additionally, there is some relationship, $\psi(S_t) \equiv E_t(P_{t+1}^{C}|S_t)$, that yields the expected price as a function of storage carried in. The inverse of this function, $\psi^{-1}\left(E_t(P_{t+1}^{C})\right)$ yields the storage carry in implied by a particular expected price. The amount of available corn in any period is thus determined by the prior expected price $E_t(P_{t+1}^{C})$, which determines both planned production and storage carry-in, and the disturbance term for production, ϵ_{t+1}^{S} . The realized price is determined in one of three ways.

(i) If no ethanol is produced, then the realized price of corn is determined where

$$Q^{S}\left(E_t(P_{t+1}^{C})\right) + \psi^{-1}\left(E_t(P_{t+1}^{C})\right) = Q^{D}(P_{t+1}^{C}) + \psi^{-1}\left(E_{t+1}(P_{t+2}^{C})\right)$$

We will refer to the solution to this system as P_{t+1}^{NE}. This is equivalent to the standard model of storage described by Williams and Wright (1991).

(ii) If ethanol is produced and there is either no blend mandate or the blend mandate is not binding, then the price of corn is determined indirectly by the price of gasoline. If consumers purchase both ethanol and gasoline, they must be indifferent between both fuels—meaning their price per mile is identical. This means

$$p_{t+1}^{E} + \tau - \tau_c = \lambda(P_{t+1}^{G} + \tau)$$

where λ is the ratio of miles per gallon from ethanol to miles per gallon from gasoline. The left hand side represents what consumers pay for a gallon of ethanol, while the right hand side is what consumers pay for a gallon of gasoline. This relationship implies that

$$p_{t+1}^{E} = \lambda P_{t+1}^{G} + (\lambda - 1)\tau + \tau_c$$

The corn price is then determined by the zero profit condition for producing ethanol, equating the cost of corn inputs and conversion to ethanol and the revenue from sales. This can be written as

$$p_{t+1}^{C} + c_0 = \beta p_{t+1}^{E} + p_{t+1}^{C}\delta$$

where c_0 is the cost of converting a bushel of corn to ethanol, β is the number of gallons of ethanol yielded from one bushel of corn, and δ is the proportion of a bushel of corn that is returned to the corn market as byproduct. This results in the corn price

$$p_{t+1}^{C} = \frac{\beta}{1-\delta} p_{t+1}^{E} - \widetilde{c_0}$$

where $\widetilde{c_0}$ is the non-corn price of producing a gallon of ethanol. We will refer to this price as P_{t+1}^{NM}.

(iii) If a mandate is binding, then the corn price is determined jointly by the price of blended fuel and the amount of corn needed to meet the mandate. Define the supply of ethanol as

$$S_E(P_{t+1}^{E}) \equiv \frac{\beta}{1-\delta}\Big(Q_{t+1}^{S}(P_{t+1}^{C}) + S_t - Q_{t+1}^{D}(P_{t+1}^{C}) - \psi^{-1}\Big(E_t(P_{t+1}^{C})\Big)\Big)$$

Then, the price of corn is determined by equating the supply and demand for fuel

$$S_E(P_{t+1}^{E}) = \alpha Q_{t+1}^{F}\Big(\alpha(P_{t+1}^{E} + \tau - \tau_c) + (1-\alpha)(P_{t+1}^{G} + \tau)\Big)$$

where α is the required percentage blend of ethanol. We will refer to this price as P_{t+1}^{Man}.

The prevailing corn price that clears all markets is determined by $P_{t+1}^{C} = \max\{P_{t+1}^{NE}, P_{t+1}^{NM}, P_{t+1}^{Man}\}$. The simulation program contains several embedded loops to determine the equilibrium values for quantities and prices given a specific starting value for $\psi(S)$. The possible values of storage, S

are specified as a vector of integers. In each iteration, the expected price given each possible value of S is calculated and the sum of squared errors are calculated as $\sum_{S_i}\left(\psi(S_i) - E(P^C|S_i)\right)^2$. The process is repeated until the values of $\psi(S)$ that represent the minimum sum of squared errors are found. This minimum is found using the MatLab command fmincon. This command solves for a constrained minimum of a function of several variables using a starting value. We specify $\psi(S)$ as a third order polynomial, with starting values for the constant term given by the prevailing expected market price without storage, and other values as zero. We constrain the function to be positive and decreasing over the possible storage amounts. The algorithm proceeds as follows (see Williams and Wright, 1991):

1. For each possible storage value S_i, an initial value of the corresponding planned production level $\bar{h}^i_{t+1}$ is made. We will refer to this starting value as χ.
   A. Using the distribution of ϵ^S, create a discrete vector of possible values for ϵ^S, which values we will refer to as $\bar{\epsilon}^S_i$. Create a corresponding discrete probability density with values v^i such that $v^i = \Pr\,(\bar{\epsilon}^S_{i-1} < \epsilon < \bar{\epsilon}^S_i)$. Multiply χ by $\left(1 + \bar{\epsilon}^S_i\right)$ to create the vector of realized values of production next period.
   B. Add S^i to each realized value of production generated in step (A) to produce a vector $\bar{A}^i_{t+1}$ of the available corn in the next period.
      i. Begin a loop over each possible A^{ij}_{t+1} in $\bar{A}^i_{t+1}$.
         a. For each A^{ij}_{t+1}, numerically solve $P^C\left(A^{ij}_{t+1} - S^{ij}_{t+1}\right) + k - \frac{\psi\left(S^{ij}_{t+1}\right)}{1+r} = 0$. This is the arbitrage condition for grain stored.

            Here, P^C is calculated according to the ethanol price model described previously. Additionally, the expected corn price is calculated over the possible values of the gasoline price.

ii. For each pair, $A_{t+1}^{ij}, S_{t+1}^{ij}$ that solve the arbitrage equation, calculate the associated price $P^C(Q^C) = P^C(A_{t+1}^{ij} - S_{t+1}^{ij})$ from the equilibrium conditions given previously. Again, this will be the price expectation of the uncertain gasoline price.

C. Using the vector of these prices, calculate the expected price

$$E_t(P_{t+1}|S_t^i) = \sum_i P^C(A_{t+1}^{ij} - S_{t+1}^{ij})v^i$$

This yields the expected price in period t given the amount of carryout from t is S_t and that storage in period $t+1$ is determined by ψ.

D. Calculate $P_{t+1}^r|S_t^i$, the rational expectations price to producers.

$$P_{t+1}^r|S_t^i = \sum_j (1 + \bar{\epsilon}_j^S)P^C(A_{t+1}^{ij} - S_{t+1}^{ij})v^j$$

E. Substitute $P_{t+1}^r|S_t^i$ in the function for planned production, $\bar{h}_{t+1} = \bar{h}(P_{t+1}^r)$, and find the difference $\Delta = |\bar{h}_{t+1} - \chi|$. If Δ is too large, choose a lower guess and repeat steps A through E. Otherwise χ is considered to be consistent and the algorithm proceeds.

2. When A through E have been completed for each element of $\bar{S}_t$, fit the values of $E_t(P_{t+1}|S_t^i)$, $i = 1, \ldots, N$ using ordinary least squares assuming a third order polynomial, calling the resulting parameters $\hat{\psi}$.

3. If the fitted values of the regression a close enough (using a sum of squared error loss function) then these represent the solution. Otherwise, use $\hat{\psi}$ as the new starting values and begin at step 1 again.

Once we have obtained the coefficients of the third-order polynomial ψ, we use those values in a numerical solver, Microsoft Excel, along with the supply and demand parameters to map corn supply, corn demand and the curve for storage.

3.4 Data and Model Calibration

Data and parameters for calibrating the 2005-2006 and 2010-2011 crop year simulations came from multiple sources. Table 1 summarizes the parameters used to calibrate the simulations. Data for corn supply, non-ethanol demand, and observed corn price were taken from the USDA World Agriculture Supply and Demand Estimates (WASDE) reports for the appropriate years. The value for ethanol use was subtracted from total corn usage to obtain total non-ethanol use of corn. Corn supply and demand is given by millions of bushels and corn price is given in dollars per bushel. In the 2005-2006 crop year, there was a loan payment of $.39 per bushel (USDA). Corn supply and demand elasticities adopted were .2 and $-.2$ respectively. These values were used taken from existing literature (de Gorter & Just 2009b).

Fuel supply and demand data was obtained from the US Energy Information Administration in the form of gasoline supplied. Fuel data was given in thousands of barrels per year. This was converted to gallons using the conversion $1\ barrel = 42\ gallons$ (US EIA). Finally, it was converted to millions of gallons of finished motor gasoline per year. Because the

Table 1. Values to Calibrate Model Economy

Paramater Name	2005-06	2010-2011	Unit
Corn Supply Elasticity	0.2	0.2	
Observed Price of Corn	2	5.18	$/bushel
Price of corn	2.39	5.18	$/bushel
Ratio of mpg ethanol to mpg gasoline	0.7	0.7	ratio
Observed Price of Gas (less taxes)	2.205	2.875	$/gallon
Blend Mandate	0	0.09232	
ethanol to corn price conversion (Chsi)	4	4	
Corn Supply Constant	11114	12447	Millions of Bushels
Corn Demand Elasticity	0.2	0.2	
Corn Demand Constant	9667	8034	Millions of Bushels
Fuel Demand Elasticity	0.2	0.2	
Fuel Demand Constant	141365	135235	Millions of Gallons
Interest rate	0.0325	0.0325	
Cost to store a bushel of corn 1 period	0.34	0.34	$/bushel
CV of Corn Supply	0.09475	0.09475	
CV of gasoline price	0.0313	0.0313	
Fuel Tax	0.495	0.495	$/gallon
Ethanol Tax Credit	0.52	0.52	$/gallon
Cost of Inputs other than corn to manufacture ethanol	0.6	0.6	$/gallon

gasoline data was based on a calendar year, the weighted average of the two years making up the crop year was used. The weights represented the portion of the calendar year covered by the crop year.

Gasoline price was also obtained from the US Energy Information Administration in dollars per gallon. The gasoline prices obtained were monthly average US city gasoline prices including taxes for all types of gasoline. The average value for the months making up the respective crop years was calculated and used as the observed gasoline price to calibrate the model. The value of gasoline demand elasticity, $-.2$, was taken from existing literature (de Gorter and Just 2009b).

The blend mandate for ethanol was determined by dividing total ethanol consumed by total fuel consumed. For the interest rate, data was taken from historic Federal Reserve Bank Prime Rate for the respective crop year. The prime rate is the rate which banks base many loan rates on. The monthly values were averaged for the months contained in the crop year. The cost of storage is given by the cost to store one bushel of corn one period.

Data was also obtained to determine the variance in the corn supply (USDA NASS). Annual production in bushels for 2000-2011 was used to calculate the coefficient of variation for corn harvest and obtain a value of .09475. That value was doubled to achieve a high level of corn supply variation for the sensitivity analysis. To determine the variation in gasoline price, monthly average gas prices for all types of gasoline were obtained from the US Energy Information Administration in dollars per gallon including taxes. The annual coefficient of variation (CV) was calculated from 2000-2011. The CV’s ranged from a low value of .0313 in

2010 to a high value of .2203 in 2008. These values were transformed to construct a log-normal distribution with a mean and standard deviation representative of the observed data. Moreover, we limited storage to be between 0 and 3 million bushels.

CHAPTER 4
PRESENTATION OF RESULTS

4.1 Effect of Ethanol Policy on Storage: Comparing Pre and Post Biofuel Equilibria

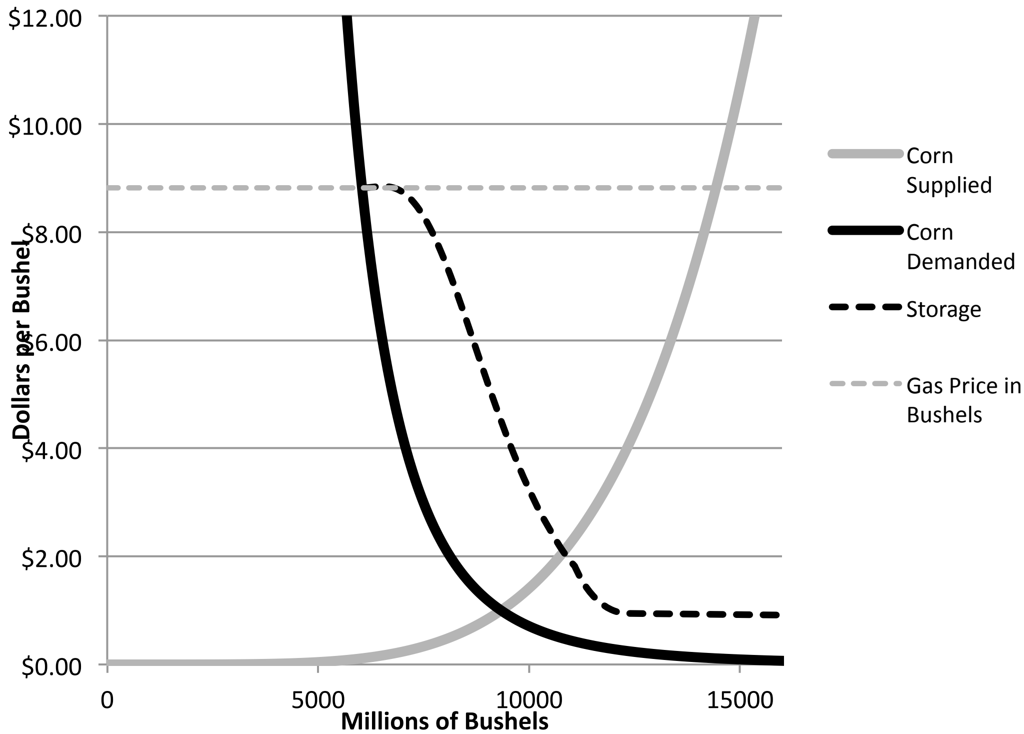
The 2005-2006 crop year was chosen as a pre-biofuel scenario because it was before the RFS took effect (and thus prior to the blend mandate). This will serve as a baseline to evaluate how ethanol policy has altered the storage curve by either shifting it outward/upward or changing its slope.

The storage curve represents additional demand, in the form of storage, at each price of corn. Storage represents market actors' expectations about future prices. If prices are expected to be higher and high enough to cover the cost of storage, represented by the interest rate and price to store gain, positive amounts of grain will be stored. If expected prices indicate it does not pay to store grain, storage will be zero. Positive storage indicates a belief that prices have some probability of being higher in the future. We expect the addition of biofuel policies to shift the storage curve rightward. This rightward shift represents an increase in storage at every price and an expectation by market actors that prices will be higher in the future. This increase could be because actors believe the corn prices will increase due to the mandate, or because actors believe that rising gasoline prices will increasing corn prices. If gasoline prices are increasing, consumers will have incentive to substitute ethanol for gasoline. Thus, market actors could rationally expect more ethanol, hence more corn, to be consumed next period raising the price of corn.

Figure 3 graphs corn supply, corn demand, and storage using the results of the simulation for 2005-06 with an excise tax credit, the policy in place during that period. The graph includes a downward sloping non-ethanol demand curve for corn and an upward sloping supply of corn. There is also a line representing the expected price of gasoline in dollars per bushel. This price of gasoline is achieved by multiplying the ethanol price conversion factor, ξ, by the gasoline price. In this case, the market would begin to store corn when the price of corn drops below the expected price of gasoline converted to bushels. More grain would be stored at lower prices because the price of corn is expected to increase more severely.

There was no appreciable difference in the results between different policy states using the 2005-06 crop year. This can be interpreted to mean very little ethanol was produced or would have been produced in 2005-06. In fact, the market could bear so little ethanol that differing biofuel policies had little effect on the amount of corn that would have been stored.

Figure 3. Storage for the 2005-06 crop year with an excise tax credit



The 2010-2011 crop year was chosen to represent a post-biofuel demand shock state where a transition to a new equilibrium has taken place. Figure 4 represents the 2010-11 crop year simulated with a mandate and tax credit in place. Notice the price of gasoline in bushels is lower than in Figure 3. In the 2005-06 crop year, ethanol was only being used for its additive value so less than one percent of fuel was ethanol. Thus the cost of ethanol was omitted form this calculation. In the 2010-2011 crop year, substantially more ethanol was consumed. Therefore, ethanol's contribution to fuel mileage was considered in the calculation for the gasoline price in bushels. This effectively lowered the gasoline price in $/bushel as seen by the corn market.

After simulating the policies in place during the 2005-06 and 2010-11 crop year, the amounts of grain stored versus price are plotted against one another. The result is contained in Figure 5. At every price, more corn is stored in 2010-2011 than in the pre-biofuel crop year of 2005-06. The increase in storage is similar at every price.

Figure 4: Storage in the 2010-11 Crop Year with a Mandate and Tax Credit

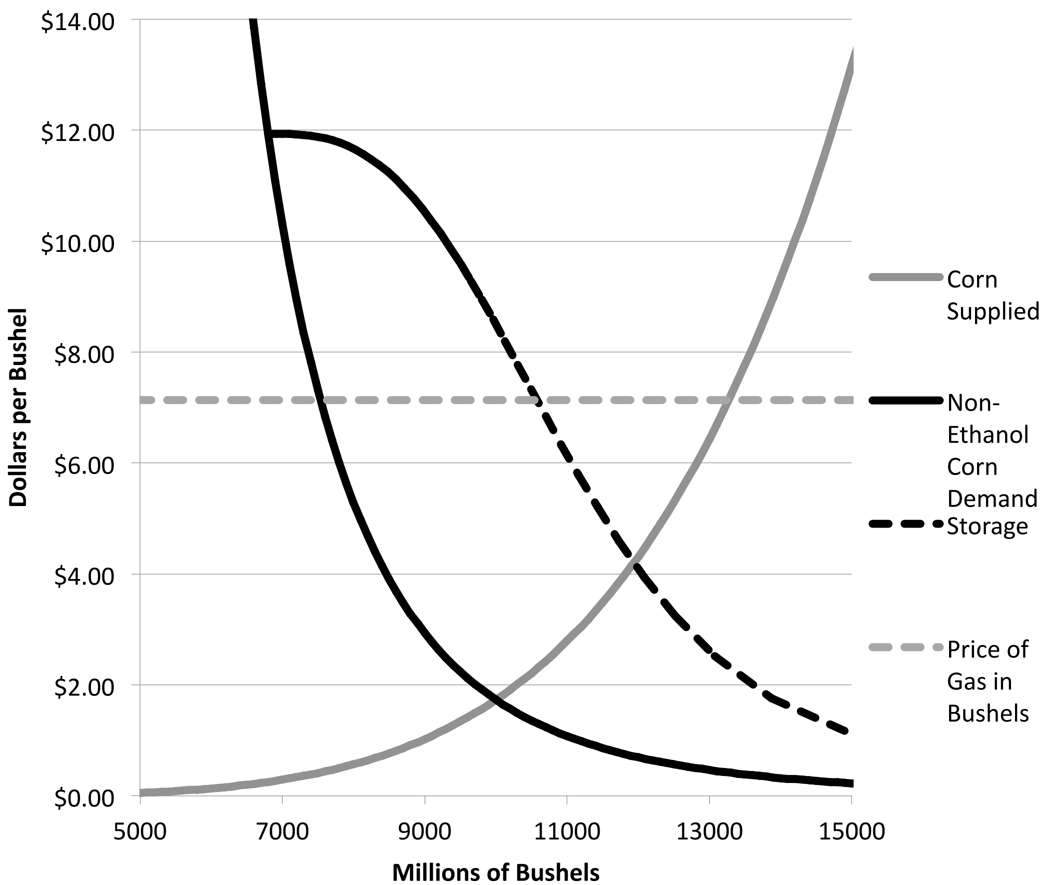
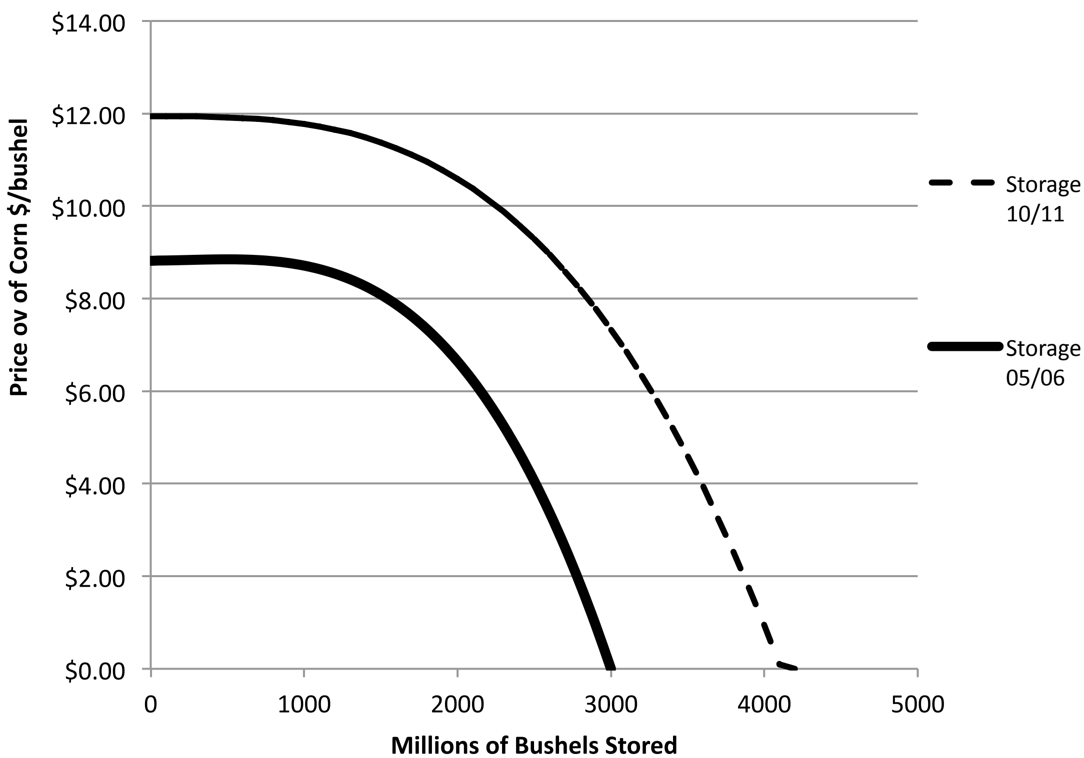


Figure 5: Corn Stored Before and After Biofuels



4.2 Simulating Biofuel Policy States: No Policy

The simulation allows us to consider four alternative policy states: no policy, a consumption mandate only, a tax credit only, and a mandate with a tax credit. Simulating these four policy states allows us to consider how each policy and combination of policies changes the storage curve.

First, the model was simulated with no mandate and no tax credit—the no policy state. Then, a case for a mandate only was simulated. The results can be seen in Figure 6. The addition of a blend mandate causes more corn to be stored at every price. This makes sense if the mandate causes more ethanol to be produced than otherwise would have. Likewise, the mandate sends a signal to market actors that even more ethanol may be produced next period. This increases expected price and increases storage at every price.

The addition of the mandate increases the equilibrium price of corn, where the storage curve intersects the supply curve. However, this equilibrium remains below that expected based on the price of gasoline in $/bushel. As the price of corn drops, more corn is stored in anticipation of higher prices under a blend mandate.

The addition of a mandate does not increase storage by the same amount at every price. Figure 7 illustrates the amount of corn stored versus price of corn for these two policy states. At high prices, very little extra corn is stored with the addition of the mandate. According to this graph, as the price approaches zero, there is less difference in the amount of corn stored between the two policy states. This could be due to the fact that estimates are less accurate as they approach the specified upper and lower bounds for storage.

Figure 6: Comparison of No Policy and Mandate Scenarios in the 2010-11 Crop Year

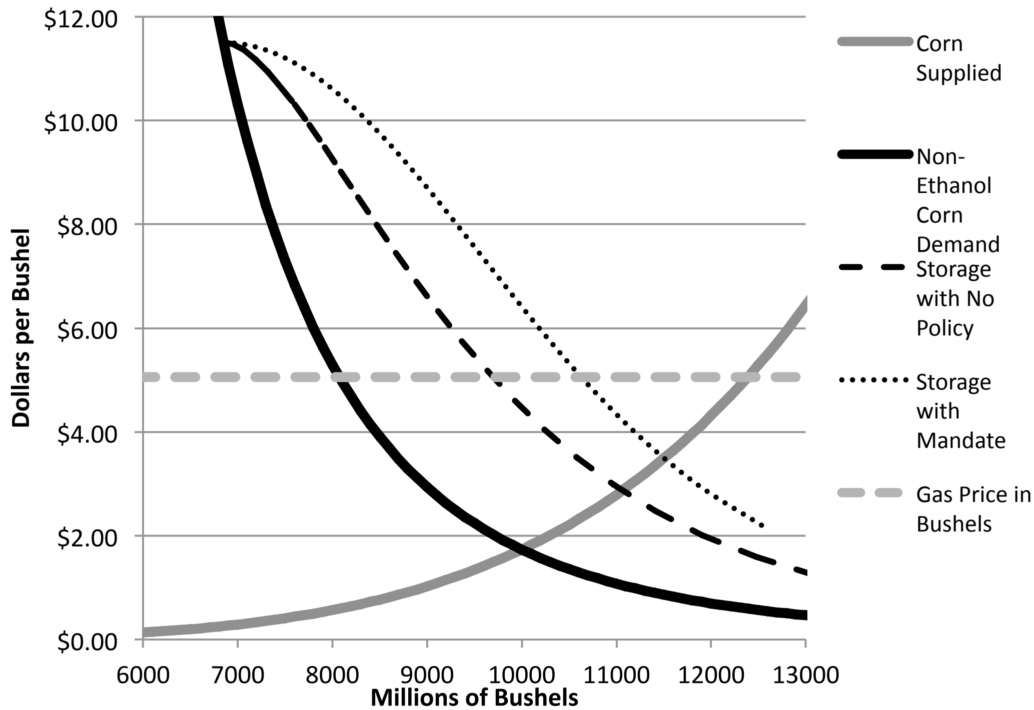
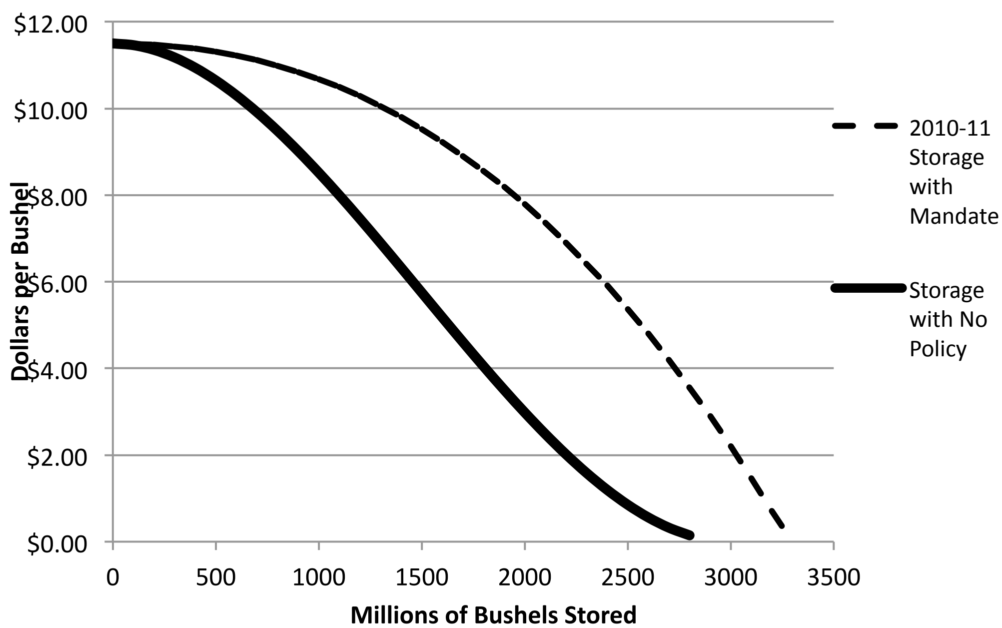


Figure 7: Comparison of Storage Under No Policy and Mandate Scenarios



Adding an excise tax credit to the ethanol consumption mandate should move the storage curve rightward. The addition of the tax credit should signal to the market that more ethanol, thus more corn, will be consumed next period. Figure 4 illustrates the case where there is both a blend mandate and tax credit in place. The price of gasoline per bushel is higher here by nearly two dollars with the tax credit. This represents the amount of the tax credit, \$.52, multiplied by ξ. Figure 8 compares the storage curve under a mandate and mandate/tax credit scenario. This rightward shift represents increased storage at every price by approximately the same amount. Because the tax credit is on a per gallon of ethanol basis, the shift is equivalent across the range of prices.

Next, let us compare the bushels of corn stored with a mandate and mandate/tax credit. From our previous analyses, we would expect the addition of the tax credit to the mandate would increase storage at every price. Figure 10 illustrates that this is indeed true. At every price, more corn is stored with a blend mandate and tax credit than with a tax credit alone.

At high prices, less additional corn is stored than along the rest of the curve. This is likely due to the fact that the price is nearly to the maximum expected by market actors. Thus, the market does not expect the price to increase much more, or at least not enough to cover the costs of storage at these higher prices.

Figure 8. Comparison of Mandate and Mandate/Tax Credit Scenarios in the 2010-11 Crop Year

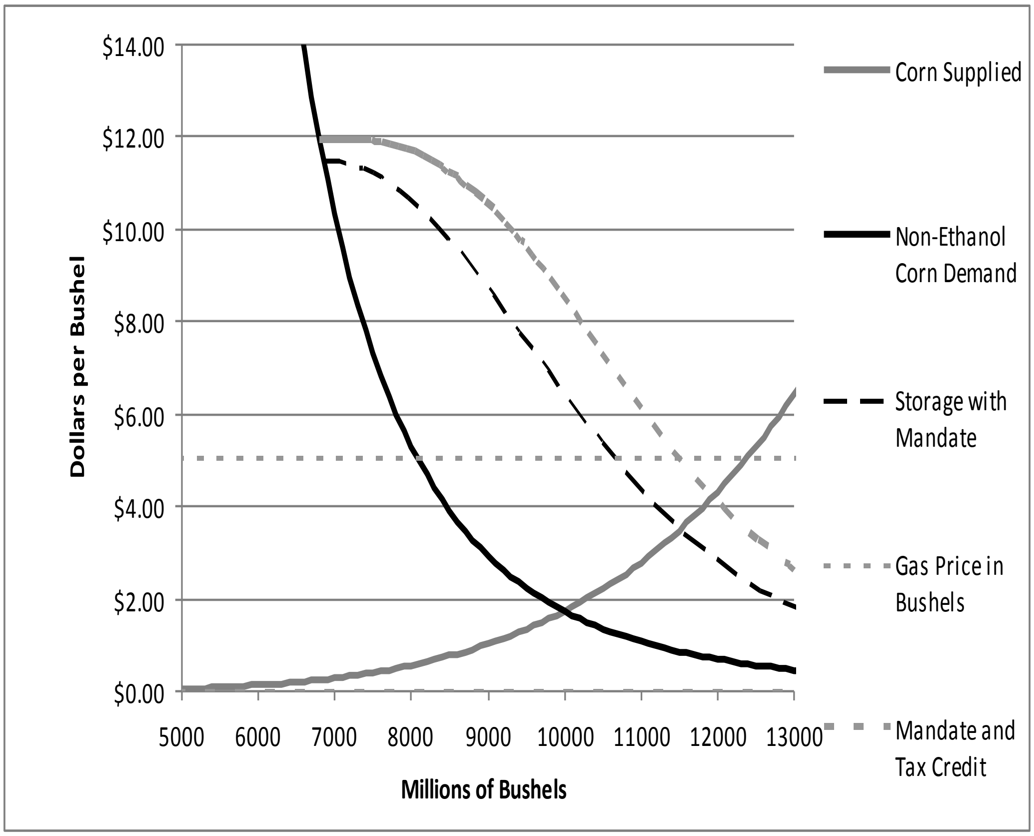
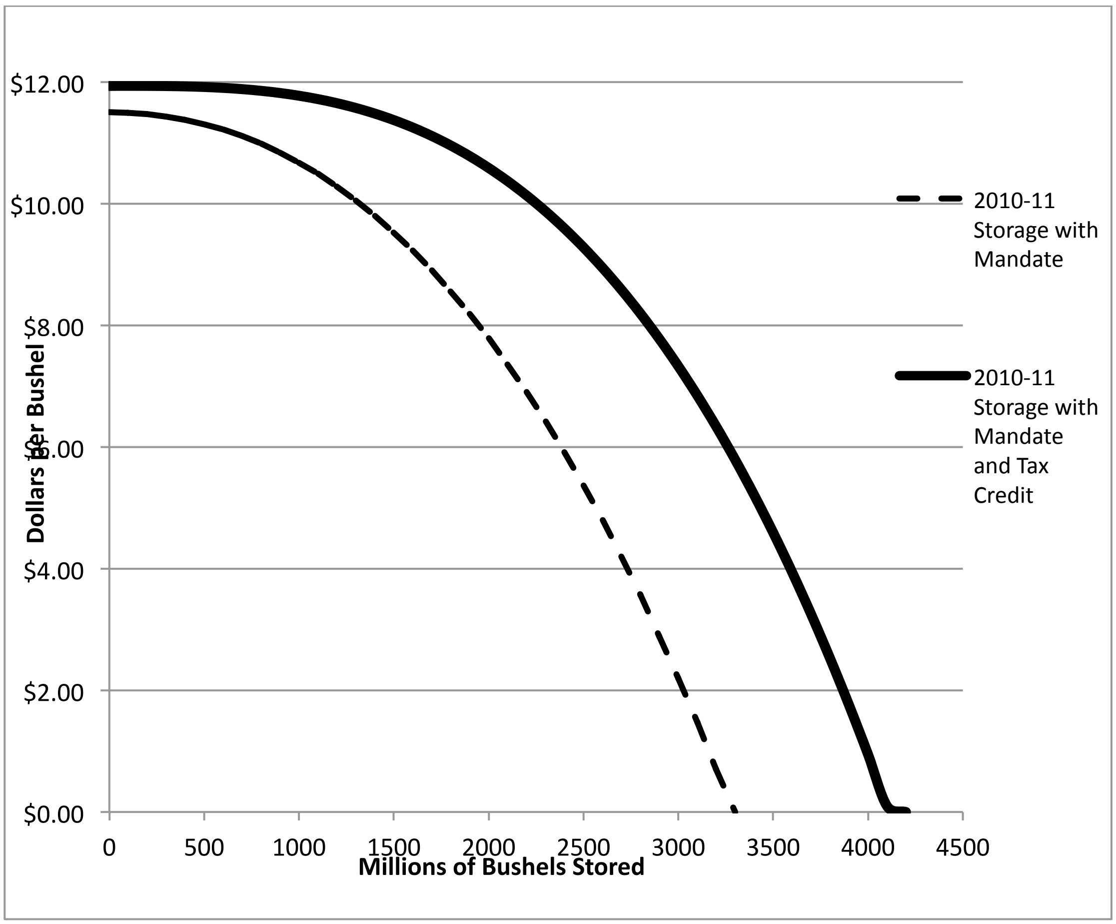
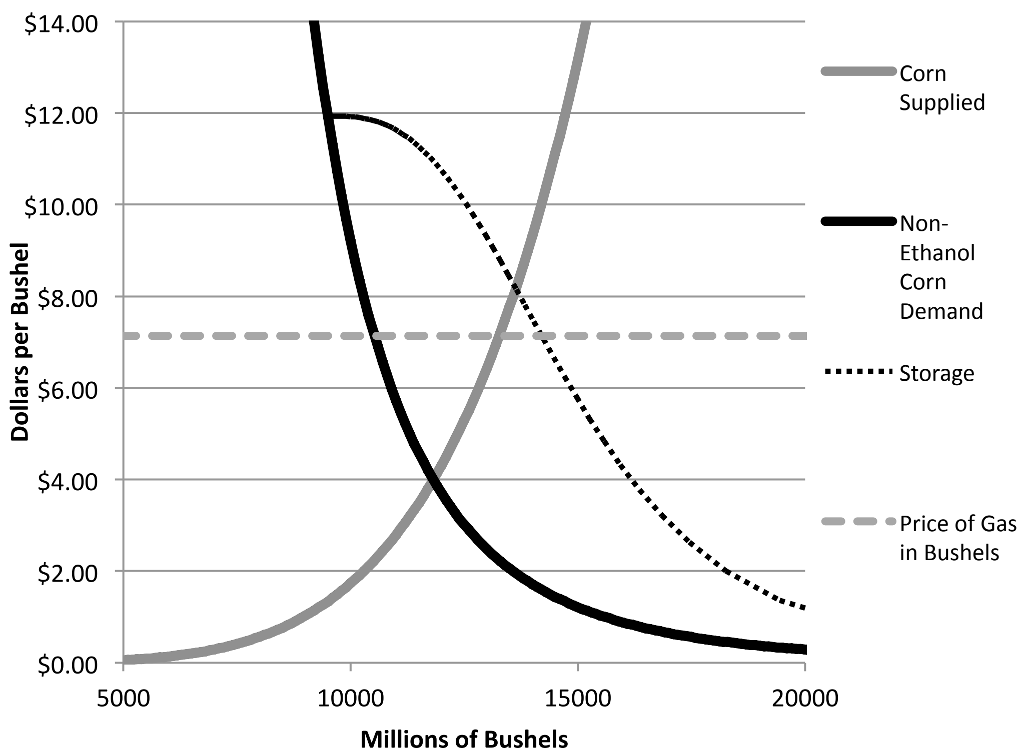


Figure 9: Comparison of Storage under Mandate and Mandate/Tax Credit Scenario



Finally, the model was simulated with only an ethanol tax credit. Although the excise tax credit is no longer in place, it is still a useful simulation to run. Notice that with the tax credit and the given economic parameters. The intercept of the storage and corn supply curve is above the expected gasoline price in bushels.

Figure 10: Grain Storage with a Tax Credit Only



4.3 Summary

Four possible policy scenarios were analyzed using a version of the competitive storage model extended to account for price relationships created by corn ethanol policy. These results are consistent with the heuristic analysis undertaken by Wright (2011). His static analysis predicts that biofuels represent an upward shift of the storage curve so that more grain is stored at a given price. Similarly, the current analysis shows that corn ethanol policies have shifted the storage curve out such that more corn is stored at each price. This outward shift indicates market actors expect prices to be higher next period due to the particular biofuel policies in place.

CHAPTER 5
CONCLUSIONS

There is an abundance of information regarding the effect of biofuel policies on price levels, price volatility and price linkages between corn, ethanol and gasoline markets. The existing literature on the effects of biofuel policy on prices and welfare has largely overlooked the effects of storage in their analyses. Because storage has the potential to mitigate price shocks through changing levels of inventory, it warrants consideration. The competitive storage model represented the first comprehensive understanding of the ability of storage to smooth out prices (Wright 2011). The model has been empirically tested and forms the basis for the current analysis. The competitive storage model of Wright (2011) has been extended in this thesis to include the effects of ethanol policy on corn storage and corn price level. In the process, we have specified relatively new linkages between the corn, ethanol, and gasoline prices. Further, the competitive storage model, which accounts for variation in corn harvest, has been extended to account for variation in the gasoline price to model those new linkages. This analysis takes into account the effects of a U.S. ethanol consumption mandate and ethanol tax credit on the corn market.

First, the simulation was calibrated for the 2005-2006 crop year to provide a baseline for the pre-biofuel era. Then, the simulation was repeated using parameters for the 2010-2011 crop year. Four policy scenarios were considered: no policy, a consumption mandate only, a tax credit only, and finally a mandate and tax credit. In terms of the production of ethanol, there are three possible outcomes. First, there could be no ethanol produced where there is no mandate and the price of gasoline is lower than the intercept of the ethanol supply curve, with or without a tax credit. Second, there could be a consumption mandate that binds to force the production of ethanol in a certain amount. Finally, there could be ethanol production in excess of a binding mandate such that price of ethanol is determined by gasoline prices.

The results show that biofuel policy causes more grain to be stored. Increased grain storage indicates an expectation that prices will be higher in the next period. This makes sense because ethanol policies have the potential to cause more ethanol to be produced than otherwise would have been the case. An increase in the production of ethanol means an increased demand for corn. This analysis has confirmed previous analysis that biofuel policy shifts the storage curve outward (Wright 2011). We have shown that a mandate increases the amount of grain stored over a no policy scenario. Furthermore, the addition of a tax credit to a mandate causes a rightward shift in the storage curve.

Future research could utilize this framework to more precisely analyze the welfare impacts of U.S. ethanol policy. Because storage has the potential to mitigate price volatility, failing to consider storage in welfare analysis could misstate the effects. Likewise, a sensitivity analysis could be conducted to determined how responsive storage is to changes in the expected volatility of corn supply and gasoline price. The use of the competitive storage model, and its consideration of variation in supply, is particularly timely given the current drought conditions across the country. Drought conditions will represent a negative supply shock that could increase prices. Likewise, the current analysis could be extended to any number of other countries or storable commodities. Furthermore, the competitive storage model could be estimated using more sophisticated econometric techniques.

CHAPTER 6
REFERENCES

"Alternative Fueling Station Locater," Last modified on July 26, 2012. http://www.afdc.energy.gov/afdc/locator/stations/.

Barrett, C. and M. Bellamare. Last modified July 12, 2011. http://www.foreignaffairs.com/articles/67981/christopher-b-barrett-and-marc-f-bellemare/why-food-price-volatility-doesnt-matter.

Cafiero, C., Bobenrieth, H., Bobenrieth, H., and B. Wright. 2011. "The empirical relevance of the competitive storage model." *Journal of Econometrics* 162:44-54

Ciaian, Pavel & Kancs, d'Artis, 2011. "Food, energy and environment: Is bioenergy the missing link?," Food Policy, Elsevier, vol. 36(5), pages 571-580, October.

Campiche, J., Bryant, H., Richardson, J., Outlaw, J. 2007. Examining the Evolving Correspondence Between Petroleum Prices and Agricultural Commodity Prices. *Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Portland, OR, July 29-August 1, 2007*

Carter, C., G. Rausser, and A. Smith. 2011. "The Effect of the U.S. Ethanol Mandate on Corn Prices." Working paper, Dept. of Agr. Econ., University of California , Davis.

Deaton, A., and G. Laroque. 1995. "Estimating a nonlinear rational expectations commodity price model with unobservable state variables," *Journal of Applied Econometrics* 10, S9-S40.

de Gorter, H., 2012. "U.S. Policy Contributions to Agricultural Commodity Price Fluctuations 2006-2012." July 12, 2012 Political Economy of Food Price Policy Project: Workshop 3

de Gorter, H., Drabik, D. 2012. "Biofuel Policies and Grain Crop Price Volatility Biofuels" *Biofuels* Vol. 3, No. 2, p. 111-113.

de Gorter, H., and D. Just. 2008. "'Water' in the U.S. Ethanol Tax Credit and Mandate: Implications for Rectangular Deadweight Costs and the Corn-Oil Price Relationship." *Review of Agricultural Economics* 30(3): 397-410

de Gorter, H., and D. Just. 2010. "The Social Costs and Benefits of Biofuels: The Intersection of Environmental, Energy and Agricultural Policy." *Applied Economic Perspectives and Policy* 32(1):4-32

de Gorter, H., and D. Just. 2009a. "The Welfare Economics of a Biofuel Tax Credit and the Interaction Effects with Price Contingent Farm Subsidies." *American Journal of Agricultural Economics* 91(2):477-488

de Gorter, H., and D. Just. 2009b. "The Economics of a Blend Mandate for Biofuels." *American Journal of Agricultural Economics* 91(3):738-750

de Gorter, H., and D. Just. 2010. "The Social Costs and Benefits of Biofuels: The Intersection of Environmental, Energy and Agricultural Policy." *Applied Economic Perspectives and Policy* 32(1):4-32

Drabik, D. 2011. "The Theory of Biofuel Policy and Food Grain Prices." Working paper, Dept. of App. Econ., Cornell University.

"E-85," Last Modified July 30, 2012. http://www.afdc.energy.gov/afdc/fuels/ethanol_e85.html.

Eidman, V. 2007. "Ethanol Economics of Dry Mill Plants." Chapter 3 in *Corn-Based Ethanol in Illinois and the U.S.: A Report*, R.J. Hauser, ed. Department of Agricultural and Consumer Economics, University of Illinois, November. 2007.

Gardner, B., 2007. "Fuel Ethanol Subsidies and Farm Price Support." *Journal of Agricultural & Food Industrial Organization* 5 Article 4:1-20

Gardner, B., and W. Tyner, 2007. Explorations in Biofuels Economics, Policy, and History: Introduction to the Special Issue. *Journal of Agricultural & Industrial Organization* 5(2): Article 1 Berkeley Electronic Press, Berkeley, CA.

Gustafson, R.L.1958. *Carryover Levels for Grain: A Method for determining amounts that are optimal under specified conditions*. Washington DC: U.S. Department of Agriculture, Technical Bulletin No. 1178

Hochman, G., S. Sexton, and D. Zilberman, 2008. "Biofuel Policy and Biotechnology." *Journal of Agricultural & Food Industrial Organization* 6 Article 8:1-22

Kim, K. and J. Chavas. 2002. "A Dynamic analysis of the effects of a price support program on price dynamics and price volatility." *Journal of Agricultural and Resource Economics* 27: 495-514.

Mallory, M., D. Hayes, and S. Irwin. 2010. "How Market Efficiency and the Theory of Storage Link Corn and Ethanol Markets." Working paper, Midwest Agribusiness Trade Research and Information Center (MATRIC) Publications.

"Methyl tertiary-butyl ether," Last Modified on July 27, 2012. http://www.epa.gov/mtbe/faq.htm.

Roberts, M. and N. Tram. 2012. "Commodity Price Adjustment in a Competitive Storage Model with an Application to the US Biofuel Policies. *Selected Paper prepared for presentation at the AAEA Annual Meeting, Seattle, Washington, 12-14 August, 2012.*

Searchinger, T., Heimlich, R., Houghton, R., Dong, F., Elobeid, A., Fabioso, , J., Tokgoz, s., Hayes, D., Yu, T. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land Use Change." *Science* 319 (5867): 1238-1240.

"Selected Interest Rate," accessed on July 20, 2012. http://www.federalreserve.gov/releases/h15/data.htm.

Serra, T., D. Zilberman and J. Gil. 2011. "Price Volatility in Ethanol Markets." *European Review of Agricultural Economics* 38 (2): 259–280.

Serra, T., and J. Gil. 2012. Price volatility in food markets: can stock building mitigate price fluctuations? *Selected Paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.*

"There's an iPhone App to find E-85 Fuel," Last Modified on February 17, 2011. http://www.ethanolrfa.org/news/entry/theres-an-iphone-app-to-find-e85-fuel/.

Thompson, W., Meyer, S. and P. Westhoff. 2009. "How Does Petroleum Price and Corn Yield Volatility Affect Ethanol Markets With and Without an Ethanol Use Mandate?" *Energy Policy* 37(2009):745-49

Trujillo-Barrera, A., M. Mallory, and P. Garcia. 2011. "Volatility Spillovers in the U.S. Crude Oil, Corn and Ethanol Markets." Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. St. Louis, MO. 18-19 April.

Tyner, W. 2008. "The US Ethanol and Biofuels Boom: Its Origins, Current Status, and Future Prospects." *Bioscience.* Available online at http://www.agecon.purdue.edu/news/financial/Bioscience_2008_Tyner.pdf.

Tyner W., Taheripour F. 2007. Renewable energy policy alternatives for the future. American Journal of Agricultural Economics 89: pp. 1303–1310.

United States Department of Agriculture National Agricultural Statistics Service (USDA NASS). Washington DC: U.S. Department of Agriculture.

United States Department of Agriculture (USDA). World Agricultural Supply and Demand Estimates (WASDE) Reports. Washington DC: U.S. Department of Agriculture. *various years*

United States Energy Information Administration (US EIA). Motor Gasoline Retail Prices, US City Average. Release Date June 27, 2012. Available online at http://www.eia.gov/petroleum/data.cfm#prices.

United States Energy Information Administration (US EIA). Product Supplied. Available online at http://www.eia.gov/petroleum/data.cfm#consumption.

"VEETC," Last modified on July 30, 2012. http://www.afdc.energy.gov/laws/law/US/399.

Williams, J., and B. Wright. 1991. *Storage and Commodity Markets.* Cambridge, UK: Cambridge University Press, 502 p.

Wright, B. 2011. "The Economics of Grain Price Volatility" *Applied Economics Perspectives and Policy* 33(1):32-58.

Wright, B. and J. Williams. 1982. "The Economic Role of Commodity Storage." *Economic Journal* 92(59): 596-614

Wright, B. and J. Williams. 1984. "The Welfare Effects of the Introduction of Storage." *Quarterly Journal of Economics* 99(1): 169-182.

Yano, Y., Blandford, D., and Y. Surry. 2010. "The Impact of Feedstock Supply and Petroleum Price Variability on Domestic Biofuel and Feedstock Markets-The Case of the United States." Working paper Swedish University of Agricultural Sciences.

CHAPTER 7
APPENDIX

runone.m

```
clear all
psi0=5.06;
psi1=-0.0000000;
psi2=0000000116907;
psi3=-0.0000000001746;

psi=[psi0; psi1; psi2; psi3];
diary 'on';
s=(0:500:3000)';
ss=[-ones(size(s)) -s -s.^2 -s.^3];
ss2=[zeros(size(s)) ones(size(s)) 2*s 3*s.^2];
b=zeros(2*size(s,1),1);
A=[ss;ss2];
hbari=[13586 13586 13586 13586 13586 13586 13586 13586 13586 13586 13586] ;
save ('hbari', 'hbari');
h=fmincon('BlendMandateWithStorageapp',psi,A,b);
```

blendmandatewithstorageapp.m

```
function out=BlendMandateWithStorage(psi);
Ecornsupply=.2; % corn supply elasticity
pcorn=5.18;
lambda=.7 %miles using a gallon of ethanol/miles using a gallon of fuel
pgas=3.37-.495; %exogenous mean gasoline price w/o 49.5 cent tax
alpha=0;%0.09232; % mandated blend of ethanol
chsi=4; %gallon ethanol to corn price conversion
Ccornsupply=12447/pcorn^Ecornsupply;  %multiplicative constant for corn
supply
Ecorndemand=-.20;%corn demand elasticity
Ccorndemand=8034/pcorn^Ecorndemand; % multiplicative constant for non-ethanol
corn demand
Efueldemand=-.2;  %fuel demand elasticity
r=0.0325; %interest rate
k=0.34; %cost per bushel of storage for one period (34-58)
sigmac=.09475*1.0 % variance of corn supply
muc=((-log((sigmac^2)+1))/2)
sigmasqc=log((sigmac^2)+1)
sigmag=.0313 % variance of gasoline prices
mug=((-log((sigmag^2)+1))/2)
sigmasqg=log((sigmag^2)+1)
lb=0;%lowest possible storage
ub=3000;%largest possible storage
tax=.495 %tax credit
taxcredit=.52 %ethanol tax credit including federal and state
costeth=.6 %cost to produce ethanol other than corn

Cfueldemand=135235/(((1-.09232)*(pgas+.495)+(.09232*(pcorn/chsi+.495-
.52+.60))))^Efueldemand; %multiplicative constant for fuel demand
```

```
%%%%Initial guess for 3rd order polynomial expectation of price of corn next
period given storage this period
psi0=psi(1);
psi1=psi(2);
psi2=psi(3);
psi3=psi(4);

%Uncertainty about production
    v=.1:.1:3;
    lv=log(v)./sigmac;
    lgp=log(v)./sigmag;
    probv=normpdf(lv,muc,sigmasqc)./sum(normpdf(lv,muc,sigmasqc));
    probgp=normpdf(lgp,mug,sigmasqg)./sum(normpdf(lgp,mug,sigmasqg));
%First loop

i=1;
Ept=psi0;
load hbari

for sit=lb:500:ub
hbar(i)=hbari(i);
    %%calculating expected price
    %%%guess at planned production
        diff2=9999999;
    while diff2>100
        probprod=hbar(i).*(v);
        A(i,:)=probprod+sit*(ones(size(v)));
        for j=1:length(probprod);
            %%solve for current equilibrium price
            si(i,j)=fminbnd('findsi',lb,ub,[],pgas, Ccorndemand, Ecorndemand,
Cfueldemand, Efueldemand, A(i,j), alpha, chsi, r, psi0, psi1, psi2, psi3,k,
v, probgp, lambda, tax, taxcredit, costeth);
            Ecornp(i,j)=eqprice(pgas, Ccorndemand, Ecorndemand, Cfueldemand,
Efueldemand, A(i,j), si(i,j), alpha, chsi,v, probgp, lambda, tax, taxcredit,
costeth);
        end
        Ecornpgs(i)=Ecornp(i,:)*probv';  %step 7
        Iprice(i)=Ecornp(i,:).*(ones(size(v)))*probv';
        hbarc(i)=cornproduced(Iprice(i),Ccornsupply,Ecornsupply)
        diff2=(hbarc(i)-hbar(i))^2
        if diff2>100
            hbar(i)=hbar(i)+0.5*(hbarc(i)-hbar(i))

        end
    end
    i=i+1;
end
hbari=hbar;
save ('hbari', 'hbari');
si=(lb:500:ub)';
xs=[ones(size(si)) si si.^2 si.^3];
beta=regress(Ecornpgs', xs);
psi=[psi0; psi1; psi2; psi3]
out=sum((psi-beta).^2)
load bestpsi
v=size(psitry,1);
psitry(v+1,:)=psi;
```

```
outtry(v+1)=out;
save ('bestpsi', 'psitry','outtry');
```

eqprice.m

```
%% possible gas prices
gasprice=pgas*v;
noethprice=(max(A-St,0)/Ccorndemand)^(1/Ecorndemand)*ones(size(gasprice));
nonmanprice=(chsi*((lambda*gasprice)+((lambda-1)*tax+costeth)+taxcredit));
pcorn=pgas*chsi:.01:40.00;
m=length(v);
NEdem=Ccorndemand*pcorn.^Ecorndemand;
SE=max(((A-St).*(ones(size(NEdem)))-NEdem)*chsi,zeros(size(NEdem)));
Peth=(pcorn./chsi)+costeth;
Pf=alpha*ones(m,1)*(Peth+tax-taxcredit)+(1-
alpha)*(pgas+tax)*(ones(m,1).*v')*ones(size(Peth));%mandate not binding
demfuel=Cfueldemand.*Pf.^Efueldemand;
SF=(ones(m,1)*SE)./alpha;
sqe=(SF-demfuel).^2;
[dumb ind]=min(sqe');
pc1=pcorn(ind)';
[finalprice Q]=max([noethprice; nonmanprice; pc1']);
highest=5000*ones(size(finalprice));
finalprice=min([finalprice;highest]);
out=finalprice*probgp';
```

findsi.m

```
function out=findsi(si,pgas, Ccorndemans, Ecorndemand, Cfueldemand,
Efueldemand, A, alpha, chsi, r, psi0, psi1, psi2, psi3,k,v,probgp, lambda,
tax, taxcredit, costeth)
for i=1:length(si)
cornp=eqprice(pgas, Ccorndemans, Ecorndemand, Cfueldemand, Efueldemand, A,
si(i), alpha, chsi,v, probgp, lambda, tax, taxcredit, costeth);
wrong(i)=cornp+k-(psi0+psi1*si(i)+psi2*si^2+psi3*si^3)/(1+r);
end
out=(wrong.^2);
if si<0
out=900000*(-si)+9000;
end
```

cornproduced.m

```
 function out=cornproduced(cornprice, constant, elasticity)
out=constant.*cornprice.^elasticity;
```