CROP PRODUCTION VARIABILITY AND U.S. ETHANOL MANDATES

A Dissertation

by

JASON PATRICK HARRIS JONES

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Chair of Committee,	Bruce A. McCarl
Committee Members,	Ximing Wu
	Henry L. Bryant
	Gerald R. North
Head of Department,	C. Parr Rosson III

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ABSTRACT

U.S. agricultural commodity prices have been volatile in recent years, attributed to many factors, including renewable fuel standard mandates (RFS). While the RFS is legislatively able to be altered, the mandate largely required the same volume of corn for ethanol in the 2012 drought year as it would have if 2012 were a normal production year. This caused corn prices to surge, bestowing significant economic ramifications throughout the agricultural industry. An important question arose from these events, was this avoidable with a RFS relaxation policy? In this work, the economic effects of such a policy that relaxes the conventional ethanol mandates in cases of major corn production shortfalls are investigated to determine the market relationships between RFS policy and commodity markets. This is done in a three step process. First the historical incidence of shortfalls is addressed by developing a stationary probability distribution of total and regional production using econometric procedures. Second, the short-run economic impact of RFS relaxation alternatives is investigated using an optimization modeling framework where crop mix and livestock breeding herds are held fixed. Third, the long-run implications of RFS relaxation are investigated by coupling the previous model with a stochastic optimization framework of ag-producer decisions with recourse. When a shortfall driven relaxation policy is in place, crop mix/livestock breeding decisions are able to adjust.

The results show RFS relaxation has a significant impact on reducing price spikes and livestock production decreases due to reduced feeding costs when shortfalls

occur. Although an ethanol waiver benefits consumers through decreased commodity prices, the reduction in producer welfare was found to be greater, resulting in an overall negative welfare impact when only considering agricultural impacts.

In the longer-run analysis, the RFS relaxation again mitigates price spikes during production shortfall years but also stimulates a producer response of decreasing corn acreage. This caused corn prices in non-shortfall years to increase, resulting in a negligible impact on average long-run corn prices, while reducing commodity price variability. The model findings demonstrated that positive risk reduction implications could exist from a production-dependent conventional ethanol waiver, with limited long-run changes to future expected prices.

DEDICATION

I dedicate this work to my mother and my grandfather.

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NOMENCLATURE

COV	Coefficient of Variation
E10	Fuel mix with 90% gasoline and 10% ethanol
E15	Fuel mix with 85% gasoline and 15% ethanol
E85	Fuel mix with 15% gasoline and 85% ethanol
EIA	U.S. Energy Information Administration
EPA	Environmental Protection Agency
ERS	Economic Research Service of the United States Department of Agriculture
EU	European Union
FAPRI	Food and Agricultural Policy Research Institute, baseline commodity markets baseline projection model – Iowa State University and the University of Missouri
FASOM	Forest and Agricultural Sector Optimization Model
GAMS	General Algebraic Modeling System
GDP	Gross Domestic Product
GHG	Greenhouse Gas
NASS	National Agricultural Statistics Service of the United States Department of Agriculture
NOAA	National Oceanic and Atmospheric Administration
OECD	Organization for Economic Co-operation and Development

PDSI	Palmer Drought Severity Index
POLYSYS	Agricultural Policy Analysis Center, economic simulation model – University of Tennessee
Q^d	Quantity Demanded
Q^s	Quantity Supplied
RFS	Renewable Fuel Standard
RFS1	Energy Policy Act by the U.S. congress in 2005
RFS2	U.S. Environmental Protection Agency Renewable Fuel Standard of 2007
RIN	Renewable Identification Number
$S^\#$	Supply Curve and Corresponding Label Number
USD	United States Dollar
USDA	United States Department of Agriculture

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CHAPTER I

INTRODUCTION

Renewable fuel standards in the United States began in 2005 with the passing of the *Energy Policy Act* by the U.S. Congress. This legislation mandated the blending of 7.5 billion gallons of renewable fuel into gasoline by 2012 (U.S. Congress 2005) with the standard referred to as RFS1. In 2006 this amounted to a total requirement of 4 billion gallons, at that time met almost entirely with corn ethanol. RFS1 mandated the percentage of ethanol in gasoline to steadily increase until 2012. Subsequently, this was amended by the *Energy Independence and Security Act* of 2007, which extended the ethanol target to 2022 plus expanded the required volume. The revised renewable fuel standard (called RFS2) increased the blending amount, including new requirements and ending with a 36 billion gallon obligation by 2022 (U.S. Congress 2007). The RFS2 mandates include specific targets for feedstock based ethanol, advanced biofuels, and biodiesel.

Effects of RFS2 Mandates and Agriculture

The effects of the RFS2 required volumes (hereafter called mandates) on agriculture are multidimensional. First of all, the conventional biofuels portion of the mandate to date has largely been met using corn ethanol. As a consequence ethanol manufacturing recently became the largest end user of U.S. grown corn. Second and consequently, corn production has increased over 30% since the mandates were implemented with (Carter, Rausser, and Smith 2012) finding that corn prices were 30%

higher as opposed to the case where ethanol remained at 2005 levels. Third, livestock feeding has become more expensive (Elobeid et al. 2006). Fourth, distillers dried grains by-product, an ethanol production byproduct has become a major feedstuff (Taheripour et al. 2010; Hertel, Tyner, and Birur 2010). Fourth, Anderson, Anderson and Sawyer (2008) argue the situation may alter regional comparative advantage moving livestock production closer to distiller's grains, which are produced in corn producing regions. Fifth, a number of other developments are occurring including environmental impacts, spillover effects, alterations in infrastructure needs, and stresses on other resources (Suttles et al. 2014; Hertel, Tyner, and Birur 2010; Sorda, Banse, and Kemfert 2010; Golub et al. 2010).

Researchers have noted that until 2006, most of the increased production of corn could be attributed to yield increases, however since 2006; increasing acreage has been the dominant factor (Wallander, Claassen, and Nickerson 2011). This increased acreage of corn impacts the land availability for other crops, thus impacting the markets for such goods. Figure 1 implicitly shows the increase in corn acreage since 2008, whereas figure 2 displays corn yields have decreased from 2009-2012. Despite of these conditions, total corn production had increased.

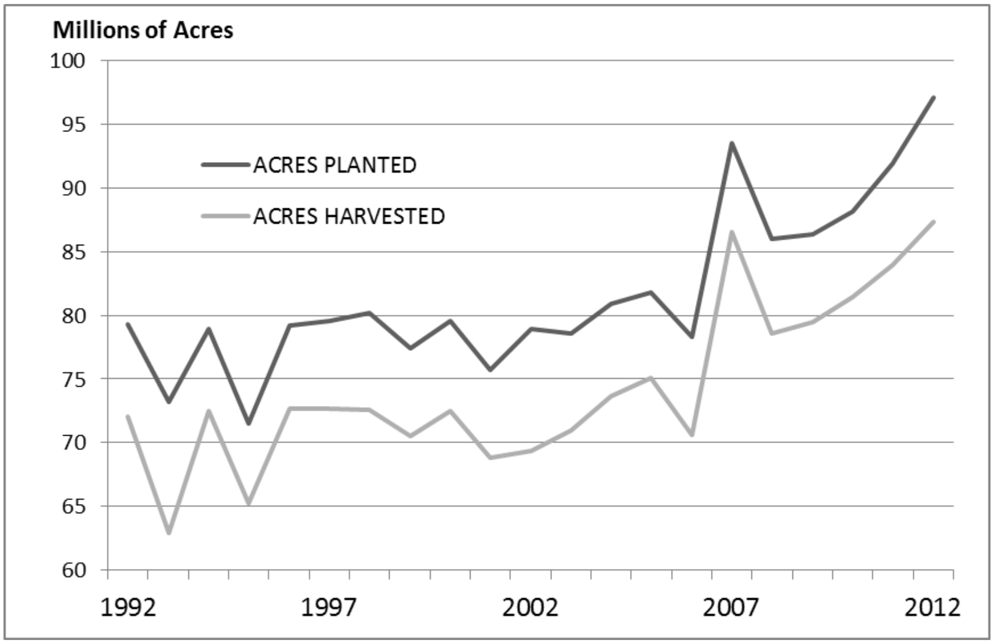


Figure 1. U.S. corn planted and harvested acreage, 1992-2012

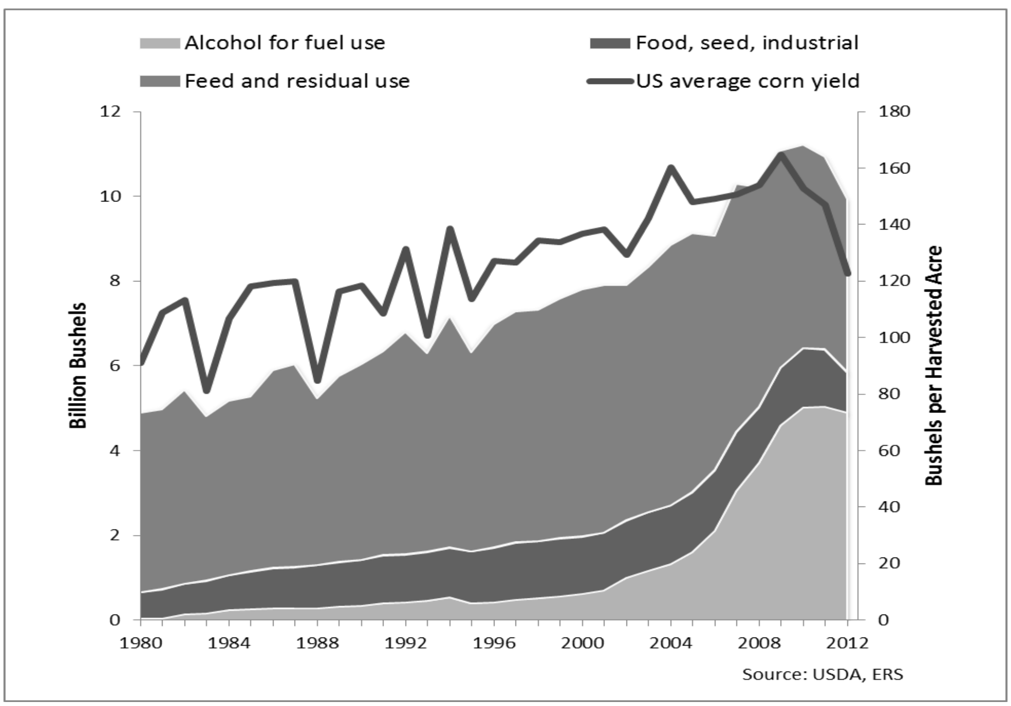


Figure 2. Corn yield and use in the US, 1980-2012

Currently, about 40% of the U.S. corn crop is used for ethanol production. Figure 3 depicts the three primary uses for corn and how they have changed since 1980. A notable feature that is better depicted in figure 3 is the variability of corn available (fluctuating primarily with the yield in that growing year) has little impact on the amount of corn that goes into ethanol or food/seed/industrial uses. Judging from figure 3, livestock feed seems to have experienced the greatest annual fluctuations. Furthermore, as the amount of corn going to ethanol production has become a relatively larger component, the variability of supply experienced by other corn users (i.e. livestock) has increased. Between 2000 and 2009, the corn that went into ethanol use increased 3.7 billion bushels, while at the same time, total U.S. corn production increased only 3.2 billion bushels (Wallander, Claassen, and Nickerson 2011). This gap between increased corn production and the grow in ethanol use has continued since this time period.

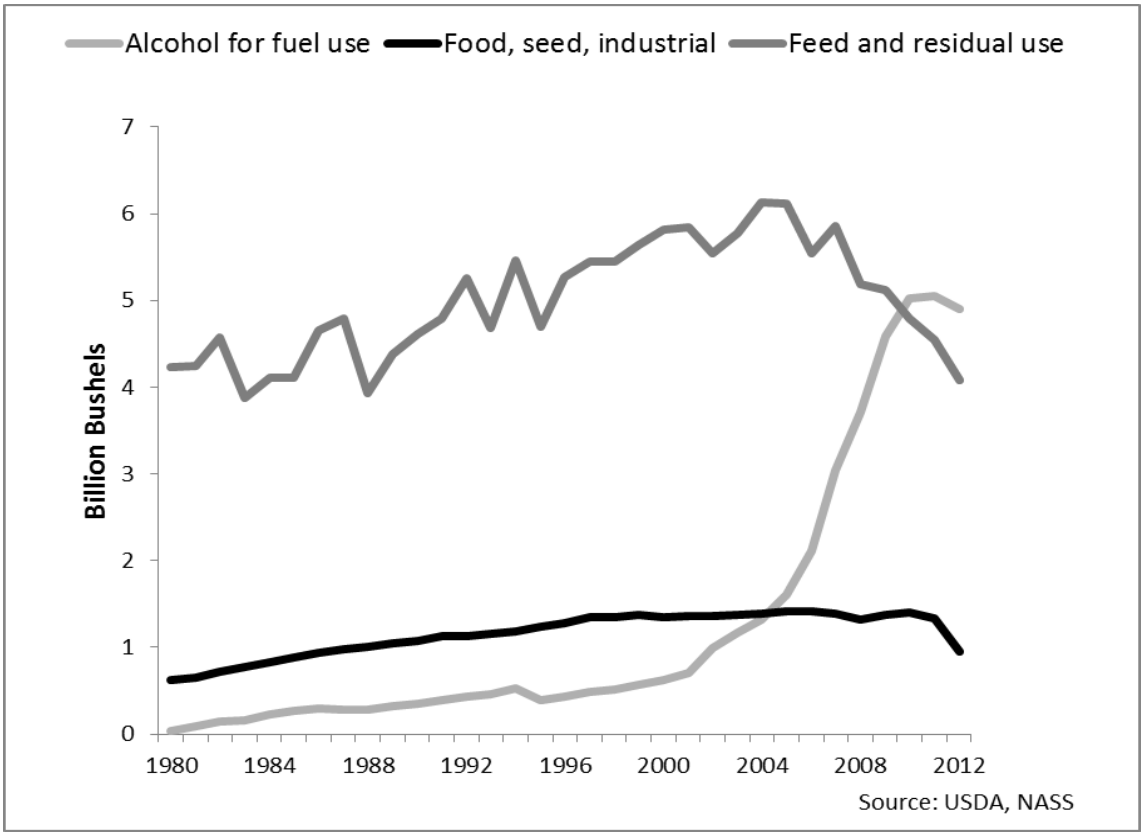
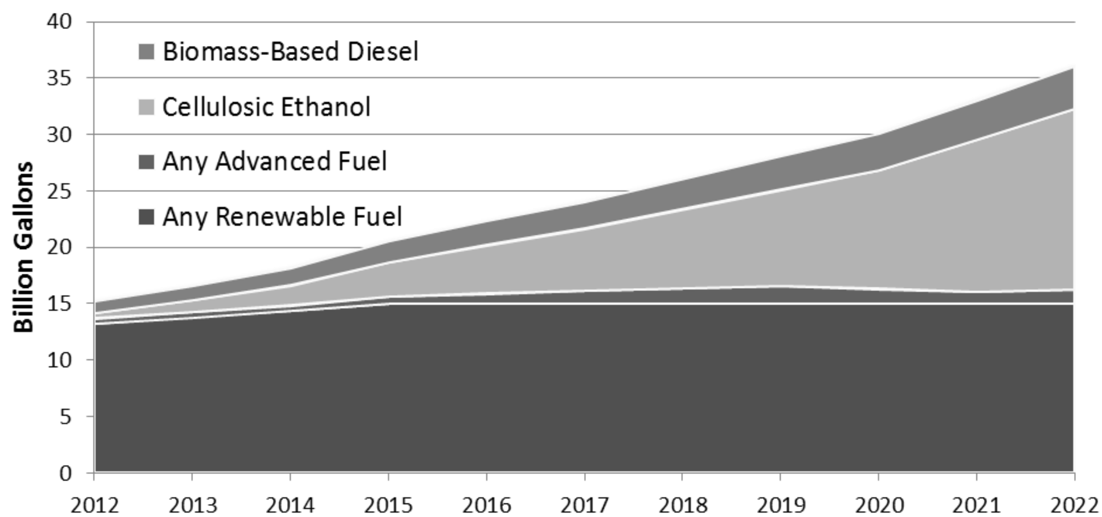


Figure 3. Corn use in the US, 1980-2012

RFS2 was written such that the total renewable fuel quota is to reach the maximum quantity of 15 billion gallons of conventional (mainly corn) ethanol by 2015. The current RFS2 mandate is depicted in figure 4, showing the mandates from 2012-2022. It should be noted that the 15 billion gallons does not need to be satisfied using strictly corn ethanol, however, at the time of writing, this ethanol production method remains the most cost efficient in the U.S., and until now has been responsible for fulfilling this non-specific component of the mandate.

Furthermore, although the mandates have been put into law, the future of U.S. renewable fuel standards is unknown. This is due to issues such as the ethanol blending wall, pertaining to usage in conventional motor vehicles and the lack of current availability of a large scale, cost effective, viable, cellulosic ethanol processing technology. In recent years, almost all of the required cellulosic ethanol has been waived due to the limited supply.



Source: Energy Independence and Security Act, 2007 .Office of Transportation and Air Quality - EPA Ruling 2012.
Note: Corn ethanol capped at 15 billion. Biomass diesel estimated to follow a linear upward trend.

Figure 4. U.S. renewable fuel standards, 2013

Agriculture and Uncertainty

An important facet of the relationship between current biofuel mandates and agricultural market variability is uncertainty. Agricultural production is heavily influenced by weather and other stochastic pressures that are unknown when the decision to plant takes place. Thus, players in the renewable fuel sector make decisions based on anticipated production levels and expected future commodity prices. On the other hand, renewable fuel policy is set *a priori*, for the most part unconditional on agricultural production and annual fluctuations in crop availability. As a consequence, prices sometimes rise quite high, for example during the 2012 drought, reaching above $7/bu, whereas pre-mandates they were about $2 per bushel. A waiver for corn ethanol production is a legally available option; however this option has not yet been exercised, even in the instance of the 2012 drought. An issue examined here will involve the effect of making renewable fuel mandates conditional on total production, perhaps reducing market volatility.

The 2012 Corn Belt drought greatly reduced total production, decreasing national production 13% from the previous year, sending corn price to a record high of $7.63 in August 2012 from a level of $6.88 in August 2011, and lowering national grain reserves. This occurred during a year where much of the crop land in the U.S. was dedicated to corn production, as was depicted in figure 1.

Market responses to the drought had impacts on non-ethanol users of commodities, particularly livestock producers. An issue is how much could this volatility have been reduced if the mandate was relaxed? Although there exists a policy mechanism to accommodate minor production fluctuations, the renewable identification number (RIN) credit system, the impact on corn prices in a drought year will continue to be a factor unless a waiver is implemented (Babcock 2012b). The legislation indicates that the Environmental Protection Agency (EPA) can only issue a waiver on conventional ethanol if 'economic harm' is evident in the market (Tyner 2013), an outcome not explicitly defined by the agency. The primary reason why a waiver was avoided during the 2012 drought was that the EPA assumed its use would cause unwanted agricultural market and ethanol blender actions (Tyner 2013). It is important to realize that long-run adjustments to improved policy have the potential to provide a less volatile market and those market participants' long-term actions would adjust, impacting planted acres, long-term commodity prices, and the subsequent welfare experienced by the various sectors.

Research Objectives

The current study attempts to contribute to this body of literature by investigating long- and short-run impacts of relaxing the RFS2 mandates in the face of production shortfalls.

Overall the objectives of this research are;

1. Investigate the short-run economic impact of relaxing of the RFS2 requirements under the production disruption as observed with the 2012 Corn Belt drought.
2. Investigate the long-run economic impact of implementing a blow-off valve relaxing the RFS2 requirements under various configurations of the relaxation.

Method Used

This work will be carried out in a three step process. The first step will involve the development of a stationary probability distribution for total US agricultural production and the subsequent identification of cases of production shortfalls. This will be done using a time series regression analysis on state and crop specific historical yields, focusing on the difference between expected and experienced levels of production. Then a stationary yield probability distribution for total production will be formed and cases of total production shortfall plus their probabilities identified.

Second, an examination of the short-run implications of mandate relaxation will be carried out using the data from the yield probability distribution that depicts the 2012 drought year. In this analysis, the effects of different degrees of waivers will be examined.

Third, the long-run implication of adopting a formal policy of mandate relaxation under total production shortfalls will be investigated. Currently, the implementation of such a mandate waiver is permitted by the legislation; however its implementation with respect to incidence and magnitude of production shortfalls remains uncertain. The certainty of this policy will allow producers to adopt long-run adaptation strategies. Thus, assuming rational expectations, producer choices will be impacted by changes in expected corn prices (i.e. reduced spikes during years of extreme drought) brought on by the altered policy before the planting period.

CHAPTER II

LITERATURE REVIEW

Previous literature has addressed various aspects of the relationships investigated in the current research. This chapter will outline the previous works concerning; statistical analysis of yield variation across time, the impact of drought and biofuel policy, and the implementation of biofuel policy dependent on crop yields.

Statistical Analysis of Crop Variation

Dated publications have explored how hybrid corn varieties, weather factors, and growing conditions explain yield change over time, leading to a plethora of more recent statistical analyses, explaining yield change using row crop observations (Griliches 1957; Shaw and Loomis 1950). These early studies set the groundwork for how statistical methods can aid in explaining crop variation in the past as well as improve our ability to anticipate crop yields in the future.

The weather component of crop yield variation is the most difficult aspect to account for, especially over long periods of time. Rainfall, although specific to certain regions and crop varieties is stated to account for over 50% of the yield variation in crop agriculture (Challinor et al. 2003). Future crop yield projection models have been employed during the growing season itself, and across multiple seasons. Monthly crop prediction models use real-time data to monitor various vegetation and weather indexes coupled with historical data (Prasad et al. 2006). These models employ remote sensing techniques to gain real-time insight into regionally specific water balance factors, being the first to bring news of an upcoming drought within a given season and provide insight concerning what regions will be most impacted (Horie, Yajima, and Nakagawa 1992). Researchers in the meteorological and crop science focused fields have stressed the importance of spatial scale for yield forecasting models, suggesting a regional upper limit as to not loose detail (Challinor et al. 2003). As it pertains to this analysis, regional analyses are important for both discrepancies in weather variability as well as broader economic factors.

The impacts of changing climate and weather trends on yields across crop years have also been investigated. This literature typically involves the deployment of global circulation models constructed by those in the atmospheric sciences field coupled with models depicting the processes of plant growth. Research in this field has found that future corn yields are expected to increase with climate change in areas where the temperature is less than 29 degrees Celsius and decrease in areas already above this threshold (Schlenker and Roberts 2009). In addition, the effects on yields of such factors as the El Niño Southern Oscillation have been analyzed (Potgieter, Hammer, and Butler 2002). These types of analysis are primarily focused on longer time horizons relative to that in the current study.

The use of yield forecasting models for use in agricultural sector models has traditionally used historical annual crop data. A recent study utilizing a long-run economic forecasting model found that in order to keep commodity prices at the 2010 level, corn yield growth rates need to increase by 100% by 2050 (Rosegrant, Tokgoz, and Bhandary 2013). The inclusion of yield variation into a stochastic agricultural modelling framework has created yield distributions based on historical variation incorporating exogenous factors (Thompson, Meyer, and Westhoff 2009a; Thompson 1986).

The Food and Agricultural Policy Research Institute (FAPRI) at Iowa State and the University of Missouri maintains a multi-commodity and multi-year partial equilibrium model to represent global and U.S. agricultural sector markets. This model provides the baseline values for numerous other models used in the U.S. ranging from large U.S. national models such as *POLYSYS* to smaller market-specific representations. The most recent versions of the FAPRI model includes crop prices, input costs, crop acreage, as well as a time trend in order to derive baseline yield projections. Restrictions are implemented on the econometric coefficients for price to reflect price elasticities. Also, adjustment factors are later incorporated based on other factors that may have impacted yields during the period. The coefficient for the time trend variable in the regression analysis is derived using at least 20 years of observations. In addition, an expert review panel is consulted on a yearly basis to make further adjustments. Previous versions of FAPRI used solely a linear time trend forecasting technique, similarly to that employed in this analysis due to the limited resources relative to the FAPRI modelling network (FAPRI 1999). Recent agricultural models have used annual percentage changes calculated from an average yield during a specific time period for a particular crop in a region (Tyner et al. 2010). The justification for using acres planted to predict future yields is based on the assumption that acres at the margin have lower yields.

RFS and Drought Analyses

There exists a reasonable body of literature whose goal is to better understand the relationship of biofuel policy and the impacts of a substantial drought. An analysis regarding the severity of the 1988 drought translated these impacts of the short-crop for the 2013 crop year (Tokgoz et al. 2008). The authors found that corn prices were expected to rise 44% above baseline levels and corn livestock feed to be reduced by 16%. Others have examined the impacts of renewable fuel standards in the U.S. and Brazil regarding global impacts (Fabiosa et al. 2010). It was found that shocks to the ethanol market in the U.S. have larger global land allocation impacts than similarly applying ethanol market shocks the Brazilian industry. Another recent study found that without considering supply shocks, the biofuel mandates were expected to increase the corn price by 24% and decrease U.S. gasoline price 8% by 2022 (Chen et al. 2012). This study also found that the resulting welfare impact was a $122 billion increase relative to a scenario without such mandates; however this was very sensitive to crop productivity, and the cost and production of bioenergy crops. On the other hand, research has also been critical to the biofuel programs, with one study claiming that the goal of energy independence has not and cannot be attained through current renewable fuel policy (Epplin and Haque 2011). These authors claimed that if all corn in the U.S. was converted to ethanol from the 2010 harvest, it would only attribute to 6.7% of the equivalent energy relative to current fossil fuel energy use, without accounting for non-renewable agricultural inputs. For a comprehensive meta-analysis of the long-run and short-run analyses of the impact of bio-fuel policy on corn prices in the U.S., see Condon et al. (2013).

Research conducted in the year following the 2007 Energy Independence and Security Act investigated what economic impacts would result given the mandates if corn yields were restricted to 'extreme drought levels' using a stochastic partial equilibrium model (McPhail and Babcock 2008). The authors concluded that corn prices would be increased from $6.59 a bushel without a mandate to $7.99 under the mandate. The research also determined that the variables most responsible for corn price variability included planted acreage, corn yield, export demand, gasoline prices, and ethanol production capacity. Another study that looked at corn price estimates without ethanol production, estimated that corn prices would currently be 30% lower from 2006-2010 had ethanol production not increased from 2005 levels (Carter, Rausser, and Smith 2012). In addition, Babcock (2012) examined the impacts of the 2012 drought and found the ethanol mandate causes corn prices to be a little over one dollar per bushel more expensive than without such policy. This preliminary analysis also found significant benefit to the renewable identification credit system, which allows ethanol blenders the flexibility to trade/sell/buy blending rights between two successive years, limiting the corn price spike. Babcock also found that ethanol plants could be strong buyers in the corn market without a mandate, especially in a high fuel price scenario.

Similarly to the methodology used in McPhail and Babcock (2008), additional research using a partial equilibrium analysis found that ignoring distortionary tax policies concerning ethanol could lead to misleading results (Taheripour and Tyner

2013). The authors combined the quantity control ethanol mandate to the tax credit that existed prior to 2011 and found agricultural output subsidies were reduced due to increased grain prices due to the mandates. The results indicated considerable land use changes are the result of ethanol mandates. These findings will be compared with the results of the current study.

Stochastic Yield and Flexible Biofuel Mandates

Several studies have investigated the general impacts of biofuel mandates on agricultural commodities, many of which are discussed earlier in this literature review. This section will review recent research on the effect of yield uncertainty and its economic impact on agriculture as influenced by biofuel mandates. The economic impact of including a conventional ethanol waiver in the biofuel policy framework has been more infrequently discussed. Recently however, the poor yields caused by the 2011 and 2012 growing conditions in the U.S. have prompted such analysis. This body of literature will be summarized by first covering the subject of yield uncertainty. The section concludes with the research regarding impacts of waiving the renewable fuel standards, both recent and most relevant to the current analysis.

Future crop yields are of great concern to blenders, agricultural producers, and policy makers regarding the attainment of the future biofuel mandates. Research has found that corn yield growth rates in the U.S. have fallen from 1940-2009, from a rate of 3.67% to 1.75% (Feng 2012). The research also notes that renewable fuel standards result in higher crop prices, bestowing strong short-run impacts such as the crowding out of other crops. When considering the land use changes outside of the US, the author found that 1.16 million hectares of agricultural land expansion would result. In addition to lower crop growth rates, variability in yields has also been investigated. Prior research has also found that climate change is affecting both the mean and variance of crop yields (McCarl, Villavicencio, and Wu 2008). This has substantial implications due to statistical considerations implying that yield cannot be considered a stationary variable. Research has investigated how uncertainty has impacted corn, soybeans, and switch grass prices from 1980-2006 (Mallory, Hayes, and Babcock 2011). The study found that the existence of a small chance of prices experiencing an upward spike resulted in higher mean commodity prices. Increasing the standard deviation for corn by 50% was found to increase corn prices by $0.48. This finding was evident among the major crops used for traditional and advanced biofuels. The research showed that using historical yields to reflect future agricultural production under climate change was unacceptable and regional and crop specific agricultural yields are changing. These findings influenced the method used to calculate the future yield states as described in the following chapter.

The assessment of the economic impacts on agriculture of a renewable fuel standard including a temporary waiver for corn ethanol has been previously studied. A recent study that included multiple scenarios with respect to production shortfalls, since at the time of the papers writing the full extent of the 2012 drought was unknown, this research chose an arbitrary negative production shock, finding a waiver on corn ethanol would have an impact on prices (Tyner, Taheripour, and Hurt 2012). For instance, one scenario utilized in the study assumed a drought cut corn production by 25%. This previous research found that reducing the blending requirements from the 2013 mandate of 13.8 billion gallons by 2 billion gallons, and assuming the economic incentives exist where blenders will stop purchasing ethanol, corn prices would fall approximately $0.66 a bushel. The current research will expand on this general framework by imposing actual drought yield scenarios that are state specific, also applying an ethanol mandate reduction of similar magnitude. The previous research had not analyzed the broad agricultural sector impacts, not including impacts on a heavily impacted industry, livestock.

Another quantitative study of this issue investigated the economic impacts of a program already in place to mitigate the impacts of between year production fluctuations, the renewable identification number system. This system allows ethanol blenders the ability to trade a portion of their blending requirement between blenders and between subsequent years. This system's details and drawbacks will be discussed in chapter 5 of this document, where the restrictiveness of the system leaves room for policy improvement, particularly regarding its performance during extreme drought situations. Previous research has compared the economic outcomes from three ethanol policy scenarios; the full RFS2 mandate as described earlier in this manuscript, the use of 2.4 billion gallons of RINs, and a full waiver (Babcock 2012a). The difference in corn price between having no biofuel mandate and the use of RINs was an extra $0.28 per bushel. Additionally, the difference between the RIN policy and the full mandate was an additional $0.91 more per bushel of corn. The author acknowledges that these estimated differences in price are sensitive to the specification of the ethanol demand curve to blenders. Also, a conceptual assessment was conducted using similar blender demand assumptions as Babcock (2012). The findings suggest that in the case where ethanol prices are below gasoline prices, a waiver would have no impact. As a result, blenders would want to purchase as much ethanol as they could up to the 10% blending limit; however the flexibility of both the refiners and the blenders is an important issue. The RIN system has been referred to in the European literature as the "Bellwether" of U.S. biofuel mandates, where its price signals the degree to which ethanol policy is distorting agriculture markets (Thompson, Meyer, and Westhoff 2009b). The recent increase in the RIN price has been associated with the concept often referred to as the "blend wall", where gasoline consumption bestows an upper bound limit on the quantity of ethanol available to blend (Tyner 2013; de Gorter, Drabik, and Just 2013). Research comparing fixed and variable biofuel policies using partial equilibrium analysis found that, although oil prices heavily influence the market, a flexible subsidy would have a lower impact on corn prices when oil prices are high (Tyner, Taheripour, and Perkis 2010). Similar to previous research, the authors also stressed the importance of the blend wall concept. This concept will be explored in more detail in regards to the current research in the final chapter of this document. Other partial equilibrium models have also been implemented to assess long-run implications of biofuel implementation on agricultural markets (Havlík et al. 2011).

CHAPTER III

AN ANALYSIS OF HISTORICAL CROP VARIABILITY

A statistical analysis of historical yield deviations is required in order to incorporate for the probability distribution for crop production risk that will be used in the subsequent analyses. Here, historical occurrences will be investigated, focusing on the probability and magnitude of major production shortfalls. In addition, the spatial scale of such an analysis, due to that used in the economic models later implemented, is required to be at the U.S. state and crop level. The objective of this analysis is to implement a yield regression model in order to construct stationary deviations from expected crop yields, ultimately constructing stationary probability functions for use in the final stochastic analysis.

Crop yields are difficult to forecast, incorporating both spatial and temporal variability, dominated by rainfall occurrence alongside other climatic and weather factors (Potgieter, Hammer, and Butler 2002). In addition, there are an array of other technological, economic, environmental, policy, and other factors that impact crop yields. When considering the estimation of a simple time trend with respect to yields, the associated factors must be categorized. The influences on yield that we assume will change with time, for better or worse, will be considered 'technical change' for this analysis. On the other hand, such influences associated with production variation within a single period, unexplained by changes between years, will be considered residuals or error terms.

When considering U.S. agricultural production, many factors, such as the influences from policy, plant genetics, equipment efficiency, access to inputs and labor, improvements in tillage and irrigation practices, and market signals, will end up in one of these categories. What is important to the current analysis is the assumption that all factors in the 'technical change' category are assumed to be known by farmers, given rational expectations and yield data availability. Also, the opposite must hold true of the factors in the residual or error term category, when after the trend factors are deduced, market participants cannot predict this effect on observed yields, most commonly associated with seasonal growing conditions.

Yield Analysis Objective

To develop a total and regional yield joint probability distribution for use in the other chapters of this thesis we need to create a stationary distribution. Such a distribution will consist of expected yields, obtained by the regressions fitted values for a subsequent year plus the unexplained errors from the regression. Thus, deviations from the expected yield in the form of residuals will be used to represent the production shortfalls and their geographically dependent severity. These results will be used in two ways for the subsequent chapters' analyses; enabling the creation of expected future yields as perceived by producers for modelling decision making, and for modeling the subsequent impacts of these decisions based on the realized yield conditions when they occur. The latter will be required in the next chapter to determine the impacts of a drought similar to 2012 occurring in the near future. The results from this regression analysis will also be used to derive states of nature pertaining to yields for the stochastic analysis explained in a subsequent chapter.

Regression Analysis

The statistical tool required for this analysis is the linear regression in linear and log form. Previous research investigating yield variability over time has also used regression (Reilly et al. 2003). Using statistical methods, this research examines variability in crop yields over time by factoring in technological change over time. Technological change is essential to this analysis because yields have increased over time due to the effects of crop breeding, increased management, and other factors. This analysis assumes technological change is constant in linear or logarithmic form during the study period, following recent research by Baker et al. (2013). Regressions were done over the complete 1950-2012 data set, in addition to sub sets of; 1975-2012, 1980-2012, and 1990-2012. The subsets were chosen based on prior research findings where decreased productivity improvements have been evident (Havlík et al. 2013; Feng 2012), and there exists “break points” when using basic linear and log regressions over such a substantial time horizon (Baker et al. 2013). The results of these regressions were compared, and then used in the analysis in the following chapter for the 2012 drought. Differences in slope coefficients in this case would be most pronounced because 2012 is the final observation in our data set, and large discrepancies in slope coefficients would result in significantly different residuals.

The residuals in this case can be interpreted as the difference between expected (fitted value from regression) and the actual experienced yield. The percentage difference of these values for each crop in each state is considered the exogenous shock to yields that defines each growing year and generates our subsequent states of nature. Although regression results for all periods, state-crop combinations, and regression periods cannot be presented, results for 2012 are presented for the most important agricultural producing U.S. regions, later in this section.

The farmers' decision with regard to crop and pasture acreage is a function of expected future yields, in addition to other factors and expected variables, some of which are not yet realized during the time the planting decision is made. In the current analysis, the relationship between crop and state specific yields and time is assumed to be either linear or log in form with respect to time (Griliches 1957; Hafner 2003; Tweeten 1998; Dyson 1999). Previous research has also included quadratic equations to explain this relationship, particularly when fertilizer data is included (Cerrato and Blackmer 1990). Using historical yield data ranging as far back as 1950, simple regressions with respect to time are conducted for each crop in each U.S. state, incorporating the spatial correlation inherent in expected crop yields. Equation (I) depicts the simple linear regression formula used to explain yields, *y*. This simple regression formula is used to determine the linear trend over subsequent crop years, for each crop, in each U.S. state. The residual, denoted as u, incorporates all variation in the yield not explained by the time trend. B_0 and B_1 are the intercept and time trend slope coefficient, respectively.

$$y = B_0 + B_1 Year + \mathrm{u} \qquad \text{(I)}$$

$$\log(y) = B_0 + B_1 \log(Year) + \mathrm{u} \qquad \text{(II)}$$

Equation (II) shows the log-log regression formula also implemented in the regression analysis, however the fitted and residual values were transformed using exponential functions in order for the statistically estimated yield growth parameters incorporated in the later structural models to reflect real values.

The issue of possible heteroscedasticity, omitted variable bias, stationarity and the appropriateness of the assumption regarding a constant yield growth rate (B_1) in the case of the linear regression are explained later in this chapter. We assume that the Gauss Markov assumptions hold in our instance, however testing for these conditions explicitly for all state-crop pairs was unrealistic; given over 5000 regressions were conducted. An important note is that only regression coefficients at the 90% level of statistical significance were incorporated into the further analyses, however the majority of the major agricultural producing states and crop pairs were significant at the 99% level, thus showing strong statistical evidence of a time trend.

States that share a similar growing climate due to their geographical closeness are expected to have correlated yields, whereas the relationship would be much weaker, negative, or non-existent for those in different climatic regions. Although the scale of this analysis is at the state level, there still exists significant within-state yield variability, especially when a large variation among soil types exists (Wendroth et al. 1992). Since these regressions produce state and crop specific growth rates, historical data can later be used to define the geographical characteristics of drought. The crops included for this analysis were corn, cotton, hay, rice, rye, oats, sorghum, soybeans, sugarcane, silage, sugar beets, potatoes, oranges, grapefruit, and the division of wheat categories. The functional form ultimately selected for each crop-state pair to represent how they are expected to change over time was chosen based off whichever had the highest goodness-of-fit relative to the historical yield data, specific to each of the time-frame scenarios.

Thus, the expectation of crop yields in the future is based on the expectation of these states reoccurring plus the incorporation of a long-term trend to take into account technological change, leaving all other variation to be picked up by the residual. The incorporation of this unexplained yield variation can then be used in the subsequent analyses to create states of nature that reflect this historical yield variation.

The regression results will generate fitted yield estimates for each of the U.S. major crops in each state. The yield estimates for each crop year will be compared with actual yields to derive the deviation from the expected yields, or the supply shock as perceived by producers. This deviation from expected yield will then be converted to exogenous percentage shocks for better intuitive understanding and for future use to create a stationary yield distribution for the final analyses. The conversion of the linear regression results varied from the log regression case, whereas as explained, the regression model with the highest explanatory power was included.

Multiple regression periods in addition to the full 1950-2012 period were included for robustness of the results due to the strictness of the assumption that the rate of technological change of yields for each crop in each U.S. state has been constant over this time period. As mentioned, the alternative regression period scenarios included start dates of 1975, 1980 and 1990 until 2012. Goodness of fit parameter estimates were not compared over these scenarios whereas the results for each regression period scenario were investigated separately and the final results for each scenario were compared. As is detailed below, the regression results did vary between the time periods; however the results were consistent in regard to the nature of the relationship, showing only minor discrepancies in the magnitude of yield variation in the more recent periods relative to the predicted yield. In all, nearly 5000 separate yield regressions are required, specific to; crop, U.S. state, functional form, and regression period. The General Algebraic Modeling System (GAMS) software was utilized for these regressions due to the sheer number of regressions that need to be computed and sorted with respect to goodness-of-fit. GAMS provided the ability to automate these regression procedures. Due to the sheer number of regressions, tests for the existence of heteroscedasticity where therefore not conducted. Several studies have found that crop and region specific yield variability has been impacted over time due to climatic factors however the results have been mixed (Isik and Devadoss 2006; Chen, McCarl, and Schimmelpfennig 2004; Southworth et al. 2000; Reilly et al. 2003).

Yield Data

Yield data from the USDA National Agricultural Statistics Service (NASS) database was used for corn, cotton, hay, rice, rye, oats, sorghum, soybeans, sugarcane, silage, sugar beets, potatoes, oranges, grapefruit, and all categories of wheat. This yearly data was obtained at the state level in the case where the respective crop was grown in that jurisdiction during the years under investigation. Observations were obtained for the 1950-2012 timeframe, however not all data were utilized in every yield regression scenario. The USDA yield data were based on phone surveys with 5,500 to 27,000 participants. This data is publically available from the Quick Stats 2.0 database accessible from the USDA NASS website. Since not all crops are grown in each state, historical yields for many state-crop combinations were not available. Also, in the case of too few observations or substantial data lapses, the estimations for these U.S. state-crop combinations were disregarded. However, this was not the case for any major producing U.S. state-crop combination.

The economic model we use is primarily at the state regional level, although several important agricultural producing states are divided further, into districts consisting of several pieces of states, requiring heterogeneous modifications to county level data. Thus, we did our analysis at the state level. Future analysis could obtain county level yield data in order to produce increasing spatial accuracy in portraying production shortfalls although during preliminary analysis, it was found refining only the five major crop producing states in the U.S. to county level would increase the required yield regressions to over ten thousand.

2012 Production Shortfall Scenario

The results from this analysis will be displayed for 2012 and then for all years. Details will be provided as for how the states of nature were constructed, and how the corresponding probabilities were constructed. The yield regression results from the 2012 growing year presented detailed insight regarding the region specific impacts of the 2012 drought year. Shown below in table 1 are results on the key crops under investigation. Crops also included in the analysis but absent from the table are silage, sugarcane, sugar beets, potatoes, oranges, grapefruit, rye, and the division of wheat categories (durum, hard red spring, hard red winter, and soft red winter). Included are the top 10 U.S. agricultural producing states based on cash receipts and the major crops affected by the 2012 drought. As was explained previously, the results in the table below were calculated as the percent deviation of the realized yield from an expected yield calculated as the fitted value from a regression with respect to time (either linear or log).

Table 1 shows the yield deviations relative to an expected yield calculated using a 1950-2012 regression period. Additional tables are included in the appendix for the results generated from the 1980-2012 and 1990-2012 regression periods. Several of the U.S. state-crop pairs do not have a percentage deviation because the crop is not a major output of that particular area, thus no yield data was provided by NASS.

As was expected, realized corn yields in the states within the Great Plains and Corn Belt regions were significantly lower than the predicted yield values by any of the regression models for the 2012 crop year. According to the USDA Feed Grains Database for 2013, the top U.S. corn-producing states, Iowa and Illinois, produce more than one-third of all U.S. corn. As shown below, these states show a significantly lower yield than what was expected. Using the 1950-2012 regression period, the yield reduction averaged between 28-29% across all regression period scenarios. Other large corn producing states, Kansas, Indiana, Missouri, Wisconsin, Michigan, and Nebraska all showed similar decreases, with some states such as Missouri showing reductions as high as 45%. Minnesota was the only major corn producing state that did not experience a large deviation, shown in table 1 as a decrease by less than 1%. When comparing this to the results using the 1990-2012 regression period, this yield reduction increased to nearly 6%.

Table 1. Percentage Deviations from Expected Yield of Major U.S. State-Crop Pairs, 2012

	Corn	Cotton	Hay	Oats	Sorghum	Soybeans	Wheat
California	-7.0%	12.4%	-7.9%	-5.4%			-6.0%
Iowa	-20.2%		-33.4%	-12.6%		-12.2%	1.6%
Texas	-12.2%	-1.3%	-23.3%	-2.0%	-8.2%	-14.8%	-7.3%
Nebraska	-16.9%		-36.1%	-15.5%	-36.9%	-18.7%	-7.6%
Illinois	-36.7%		-26.6%	0.6%	-42.1%	-10.5%	0.4%
Minnesota	-0.6%		-25.5%	-6.1%		-2.2%	11.2%
Kansas	-38.9%	1.6%	-38.7%	-40.3%	-50.0%	-36.5%	-3.4%
North Carolina	4.2%	17.8%	3.2%	4.0%		25.8%	6.8%
Indiana	-37.6%		-31.0%	-3.5%		-10.7%	-1.3%
Missouri	-45.0%	13.9%	-28.6%	-11.1%	-40.5%	-23.7%	7.3%

Note: Expected yields are the fitted values found using a 1950-2012 linear/log regression.

A large agriculture producing state that displayed notable differences between the regression period scenarios was Texas, showing significant differences across all crops when comparing the 1950-2012 regression period relative to the other scenarios. For all crops except for cotton, the expected yields from the longer regression period were significantly higher than those obtained from only using more recent data intervals. This could suggest that technological change in crop yields in Texas have slowed in recent years, whereas cotton has shown the opposite effect. Yield regression results across regression periods showed that as the regression time period was shortened from 1950, the model predicted lower yield increases every year from technological change. This can be seen when comparing the percentage deviations from the expected yield tables for 2012, whereas using the 1950-2012 regression period, the largest deviations exists, and when this time span is shortened, these impacts are reduced. When comparing the corn yield percentage shock from the 2012 drought, it can be seen that using regression period 1950-2012, Kansas experiences a 39% negative supply shock, whereas if the expectations were used derived from 1990-2012, this shock is only 22%. Since all states could have adapted to technological advances at different times, this trend was sporadic across all crop-state pairs.

Table 2 depicts the same results presented earlier for the major state-crop combinations during the 2012 crop year however now the regression period from 1975-2012 is applied. As previously mentioned, the most notable difference is the percentage deviation differences for Texas when compared to the results in table 1 from the 1950 regression. For nearly all crops included in the table, the choice of regression period between 1975 and 1950 change the percentage deviations by nearly 10% as described earlier. In addition to the result discrepancies inherent in Texas, hay and cotton also depict some differences. These inconsistencies were to be expected, and addressed by means of multiple scenario analysis as described in this section, given the strictness of the assumption regarding a constant or log form of technical progress during the time period.

Table 2. Percentage Deviations from Expected Yield of Major U.S. State-Crop Pairs for 2012 Drought using 1975-2012 Regression

	Corn	Cotton	Hay	Oats	Sorghum	Soybeans	Wheat
California	-3.7%	8.6%	-5.1%	-5.5%			7.0%
Iowa	-21.0%		-25.6%	-8.3%		-11.8%	1.0%
Texas	0.9%	-11.4%	-6.6%	6.1%	2.7%	-5.6%	0.7%
Nebraska	-13.6%		-31.8%	-11.9%	-30.8%	-19.6%	-3.1%
Illinois	-35.4%		-18.7%	3.5%	-36.9%	-10.4%	1.2%
Minnesota	-3.7%		-18.8%	-2.4%		0.6%	14.2%
Kansas	-30.1%	-13.4%	-31.9%	-33.5%	-44.7%	-35.7%	2.5%
North Carolina	6.3%	18.2%	3.8%	5.8%		22.1%	5.1%
Indiana	-36.2%		-25.1%	-0.2%		-10.1%	-1.4%
Missouri	-44.7%	-2.4%	-25.9%	-7.6%	-34.4%	-24.7%	8.0%

Note: Expected yields are the fitted values found using 1975-2015 a regression period.

The results were compared to the most recent FAPRI baseline projections from 2013. The estimated corn yield from FAPRI was 166.3 bushels per acre for 2015, whereas the average yield projected by this regression model was approximately 177 bushels per acre. The FAPRI model incorporated several unique features and adjustment factors that were not used in this analysis. Also an important thing to note is that the FAPRI result is generated using the stochastic simulation average, whereas similar to the analysis in the final chapter in this paper, the model does correlated draws from the error terms of the yield equations to generate this result. Unlike our analysis in this manuscripts final chapter, FAPRI also incorporates several stochastic exogenous variables into the analysis as well. Since yield distributions are not symmetric, usually having larger negative tails, the smaller estimate relative yield estimate found by FAPRI is not surprising.

Stochastic Yield Scenarios

So far we have only displayed the regression results in percentage deviation form for 2012. This data is essential for the 2012 short run analysis discussed in the next chapter; however more information on historical crop variability is required for the long-run stochastic ag-sector analysis in chapter 5. The stochastic agricultural sector model analysis requires the incorporation of states of nature that reflect historical yield situations, observed only after the planting season. Future yield states are assumed to be equal in severity, frequency, and regional impacts as those previously witnessed within our 1950-2012 data set. These yield states are derived in a matter similarly to that for 2012, although now for the case of every previously experienced crop year within the data set. How this stochastic component will be implemented into the model will be discussed in detail in chapter 5, whereas this section will describe how such states of nature were derived.

In order to accurately include historical yields into a stochastic modeling framework that will have an ability to forecast future yields, refined state and crop specific data must be utilized, accounting for spatial correlation, technological change and across crop yield variability. It is important to note that each individual state of nature will reflect the yields for each crop grown within each state for each historical observation. It has been the case for many state-crop pairs that an individual crop is no longer grown in a region, however if data existed historically to generate a trend line, the information regarding the crops projected yield in the region will be incorporated. State-crop combinations with fewer than ten annual observations in addition to those with statistical significance below 10% were excluded; however the relative importance of these as a portion of total production is negligible. By including trended yield parameters for as many state-crop pairs as possible, we allow the agricultural sector model to incorporate every opportunity for cropping during the process of maximizing total welfare, even in the cases where current use is entirely different. In order to make the future yield states compatible across time, the deviations (calculated in the same fashion as described above for 2012) are also converted into percentage shocks, both positive and negative relative to the expected yield level.

Corn Production Deviations

Corn production variability from year-to-year is based on a number of factors, most notably; acreage, technological change, and growing conditions. These three factors were considered in order to deduce the relationship between years with respect to growing condition. Unlike the previous section that described the year-specific percentage shocks to yields, total corn production deviation calculations are required to rank each possible state in regard to the severity of the drought's impact on the total U.S. corn production. This ranking will allow for the construction of an empirical distribution of possible yield states as to identify drought and severe drought occurrences, thus enabling the stochastic analysis to apply RFS waivers solely to these instances.

This section outlines the method used for the construction of the total production deviation scenarios. Initially, a preliminary analysis calculated the percentage deviation from the expected yield for each year, using the difference between expected production levels (using projected yields from the regression analysis) described earlier in this chapter, and the actual experienced yield data. This analysis required the use of the fitted yield values from the regressions previously described and the actual yield data from NASS (United States Department of Agriculture 2014). Since our goal is to identify the most severe periods of decreased production, these state specific yield variations were multiplied by each states harvested acres. These calculations provided an estimate of the variation in production for each crop in each state, subsequently summed to attain a national production variation estimate. In order for the creation of our drought scenarios, we choose the impact on corn production to be the measure we would rank all subsequent growing years in order to construct a distribution of production variation. From the method above, the production variation in bushels of corn is calculated at a national level for all years within the dataset. In order to make this measure comparable across years with different levels of acres harvested, this variation in production was divided by the expected production for each year, creating a distribution in terms of percentage deviation from expected production in each year.

As expected, the probability density function of this distribution exhibited a long left-side tail, exhibiting the probability of, however low, severe negative production shocks. This can be seen in figure 5, depicting the US corn production deviation probability distribution function using the 1950-2012 regression data interval. The figure shows the corn crop has experienced production variation up to 25% less than average and upwards of 17% above average during the 1950-2012 time period. As is expected with a long negative tail, the majority of production experiences lay just above the expected production level, depicted at the 0% change mark.

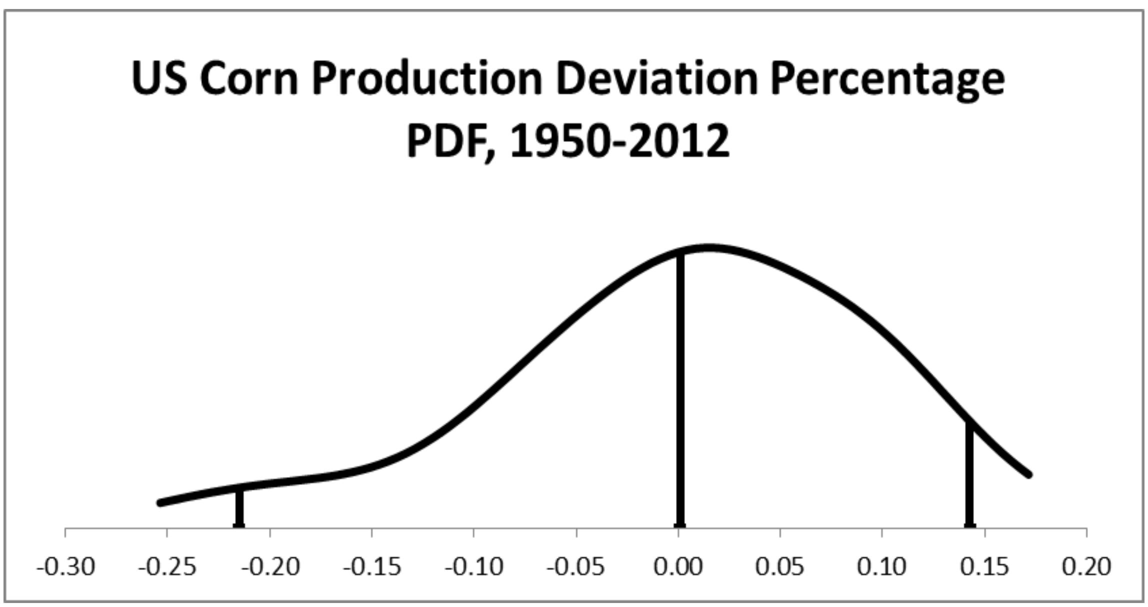


Figure 5. US corn production deviation probability distribution function, 1950-2012

The implementation of the initial method above, although suitable for historical analysis, lacks the forecasting ability relative to the method with an important modification. Results using the initially described method, and including the modification were compared in order to ensure a robust final analysis. Given the goal of the final analysis of ranking the severity of previous production variation in order to construct expected future states of nature, the previous analysis, although historically accurate, lacked the fact that the acreage distribution in more recent years in the U.S. better reflects the impacts of state yield specific variation on total production in future periods relative to those closer to 1950. Thus, given state and crop specific percentage shocks for each year, applying historical production shocks to a more recent distribution of crop acreage would portray future impacts of drought more accurately relative to a case where historical crop distributions are used.

Over time farmers have changed crop acreage in response to many economic, agronomic, and climatic factors (Mu, McCarl, and Wein 2013; Lambin and Meyfroidt 2011; Baker et al. 2013; Lambin et al. 2001). According to USDA acreage data, more than 10 million acres have migrated out of corn production from the Southeast U.S. since 1950, primarily in Mississippi, Georgia, Alabama, Tennessee, Arkansas, and North and South Carolina (United States Department of Agriculture 2014). In contrast, there have been increases in acreage over this timeframe in the northern states, primarily the Dakotas, Nebraska, Minnesota, Wisconsin, Iowa, and Illinois. An example of why the analysis described previously may not be suitable for assessing the production impacts of growing conditions is a drought in the Southeastern U.S. If a historical state of nature was constructed based on a drought of this nature, its relatively large corn acreage in that area would predict a larger percentage impact on corn production than would be the case given a more-recent distribution of acreage. The exogenous state specific growing conditions will occur regardless of the acres planted of any particular crop.

Due to regional crop shifts, the overall impact on corn production of historical yield deviations were not chosen to reflect crop acreage at the time, but redefined to the final year in our analysis as to better reflect a stationary distribution. Thus, instead of calculating production variation based on state-specific harvested acreage data in each corresponding year; these parameters were all normalized to reflect a 2012 acreage distribution across all states. Thus, for each state, harvested acres at 2012 levels were multiplied by yield in each respective period, then by one plus the percentage deviation specific to that growing year, as calculated previously. This allowed for the impact of previously experienced regional corn yield deviations on our dataset's most recent acreage distribution to be calculated and compared relative to one another. The normalized corn production percentage deviations from trend line values can be seen in figure 6, depicting the percentage deviation in corn production given an acreage distribution that reflects 2012. Using this metric, the 2012 drought is seen as the second most extreme, only less than 1988, corn production shortfall since 1950.

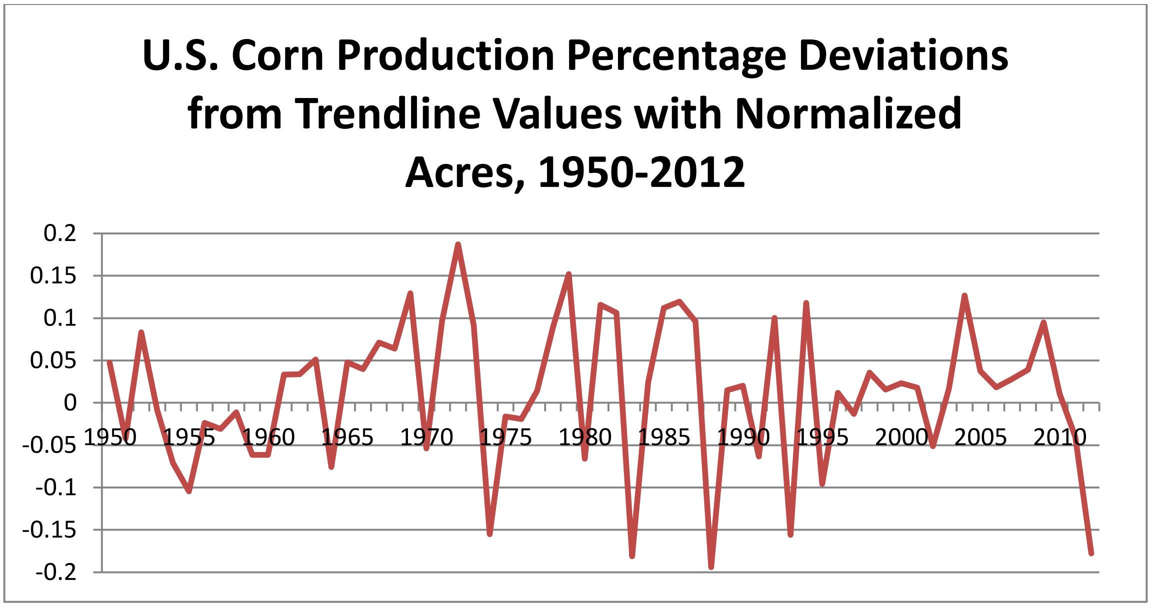


Figure 6. Corn production variation using normalized 2012 acres, 1950-2012

It would be preferred to include all states of nature into the subsequent stochastic analysis, however due to computational limits, it was required that representative years be selected from predetermined ranges of the displayed distribution. This process will be further detailed in chapter 5 of this manuscript.

Limitations

This analysis has important drawbacks than should be mentioned. Restricting technological growth to follow a linear or log function is a restrictive assumption due to the non-uniform nature of agricultural technology improvements over time, especially considering more-recent developments in biotechnology. This concern prompted the implementation of several time horizons in the analysis, incorporating the same functional form application using modern observations. Since the ultimate goal of this exercise was to compare crop yield variability over-time, including variables other than a simple time trend was not conducted, as the following analysis required all forms of yield variability be captured in the states of nature in order to best reflect potential future outcomes. Unlike yield forecasting models, the purpose of the regression analysis was not to explain the dependent variable through a regression of explanatory data; however it was to quantify the impact of the forces that caused yields to vary within a period. The issue of technological change regarding the relationship between these inter-annual affects and their subsequent impacts on yields over time will also be discussed. Given access to increased computing abilities, quadratic time trend terms could have also been incorporated in the regressions to alleviate the linear/log restrictions on technological growth.

Secondly, heteroscedasticity could exist in yield data, particularly for crops that have recently experienced multi-gene genetic improvements in drought resistance. This is also the case for recent developments in herbicide and pesticide resilience, and any crop whose stress tolerance has been improved. Although such improvements would result in higher yields (Tollenaar and Wu 1999), variability could also become reduced. Researchers have also found that since crop varieties have become increasingly similar and more spatially correlated, yield variance has actually increased (Hazell 1984). The recent release of a new variety of drought resistant corn, given commercial success, would limit the ability of past observations in crop variability to forecast future impacts on production. Given adequate time for data regarding these crops effectiveness against drought conditions to be investigated, future research should incorporate this into projections on future crop variability. Since such commercial level data over a number of years is currently unavailable, this research will utilize the scenario analysis framework, incorporating differing log and linear yield growth rates dependent on the regression period. Corn production data is shown in figure 7, although not used for the regression analysis; it shows a slight convergence in regard to variability ignoring the existence of the 2012 crop year, however this is not decisive. In order to visually inspect for heteroscedasticity in yields, the data for each state and crop would need to be separately tested rather than a test at the national and/or crop specific level.

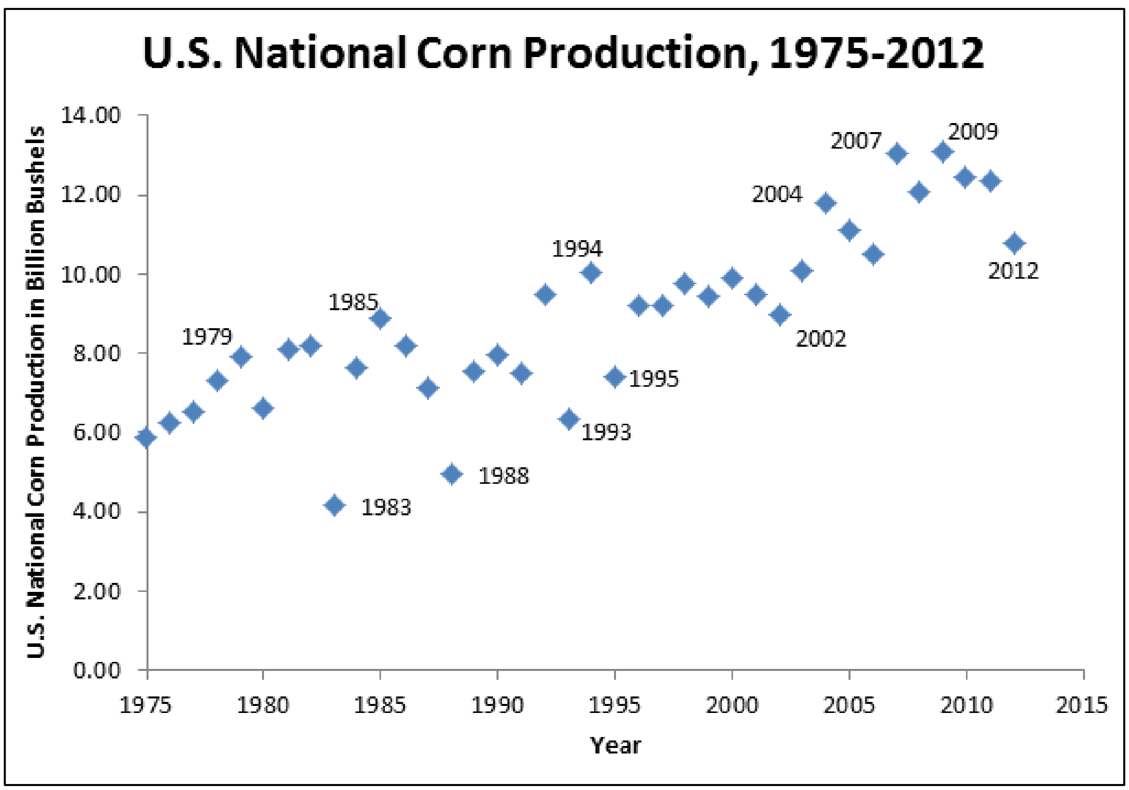


Figure 7. U.S. national corn production from 1975-2012 with labeled extreme years

CHAPTER IV

IMPACTS OF THE 2011-2012 CORN BELT DROUGHT

The occurrence of the 2011-2012 growing season Corn Belt drought had a substantial impact on production and subsequently agricultural commodity prices. The USDA reports that corn prices had risen to a record monthly average of $7.63 per bushel in August 2012 (up 10.9% from the previous year), while national production was estimated to be down from the previous year (despite the fact corn acreage was up 5%, the most acres of corn planted since 1937). Part of the price increase was due to the RFS2 mandate. This chapter will investigate the contribution of the mandate to the price increases and the short-run economic impact of mandate relaxations in the face of an unexpected supply shock of similar magnitude to the 2012 Corn Belt drought. Specifically, the analysis will examine the economic outcomes under the production shock of 2012 when various biofuel policy RFS relaxation scenarios are imposed. Also, sensitivity concerning mandates for cellulosic ethanol will be investigated.

Background

Climate-related events can have large impacts on agricultural production. In 2011, NOAA estimated that there were $14 billion in damages from climate-related disasters (National Oceanic and Atmospheric Administration 2012) with $10 billion attributed to the Texas drought effects on crops, livestock, and timber yields. Droughts are said to be one of the most costly natural disasters (Andreadis and Lettenmaier 2006).

The 2011-2012 crop season was a major climate event in the form of a drought in the US Midwest. By the end of September 2012, the USDA reported only 25% of the country's 2012 corn crop was either in 'good' or 'excellent' condition, down from 53% a year earlier. Corn in the 'very poor' category at the end of September 2011 was only 7% of the total, while in 2012, this was 26%. As shown earlier in figure 1, the acreage dedicated to corn for the 2011-2012 growing season was 96.9 million acres, constituting a 75 year high. Also depicted in the figure is the fact that corn acreage has been consistently increasing since 2008. The 2011-2012 U.S. Corn Belt drought brought the national average corn yield down nearly 20% relative to the previous growing season and 35% lower than the corn yield experienced in 2009. As the yield statistical analysis found, these decreases in corn yields occurred within states that produce the majority of U.S. corn, centered on the Corn Belt region.

The economic impacts of the drought are the result of both climate factors as well as policy choices; particularly renewable fuel mandates (Babcock 2012a). Despite the occurrence of drought, research estimated that in 2007, relative to 2005, consumers spent an additional $15 billion on food due to biofuel mandates (Alexander and Hurt 2007). However, what has been previously estimated, but still remains uncertain, is how the existence of ethanol mandates has impacted the economic outcome during the drought. Also, how alternative biofuel schemes, other than what is currently implemented, would fare in such situations. The current renewable fuel mandates have total quantity of ethanol increasing, until that resulting amount from grain reaches a cap of 15 billion gallons in 2015. It is expected that this increasing fuel requirement will further intensify the demand for corn, reflected in higher prices and thus put greater pressure on cropland, particularly under shortfalls. Although cattle producers and congress members requested a waiver from the conventional ethanol mandate for the 2012 season, the EPA choose to stick with the original requirements as mandated in 2007.

General Economic Framework

The economic impact of a binding government quota on ethanol is depicted in figure 8. The graphs in panel a) shows the situation where the corn clears at Qs with Qd going to the conventional market and Qs- Qd going to ethanol. Now if a larger mandated amount were required, the situation would be that in b), whereas now the corn price will increase as will the amount going to ethanol. This increase in ethanol use decreases the amount of corn consumed in the conventional corn market. These conclusions would still hold in the case were no corn would go to the ethanol market in the absence of a mandate.

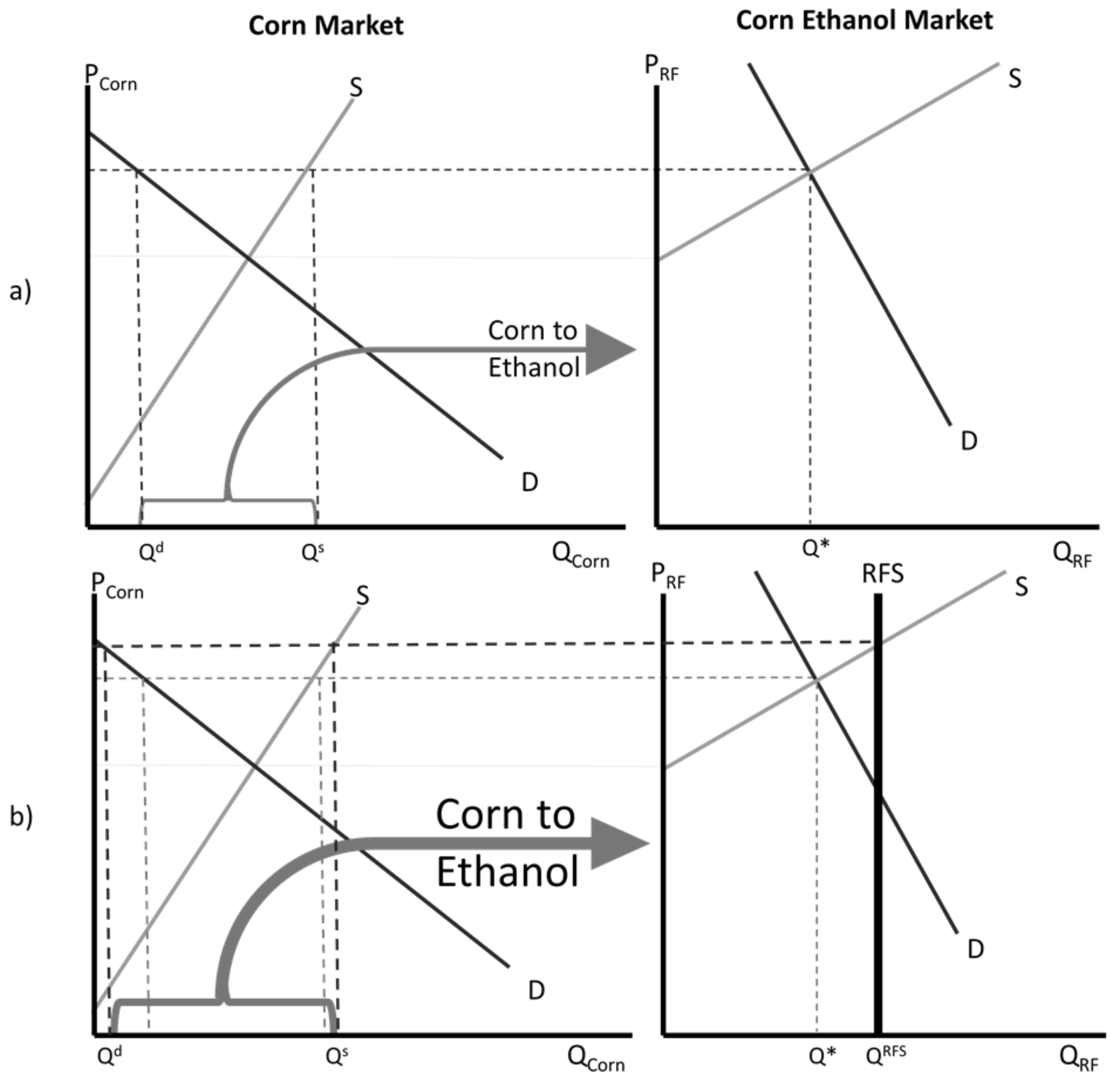


Figure 8. Economic representation of a binding corn ethanol mandate

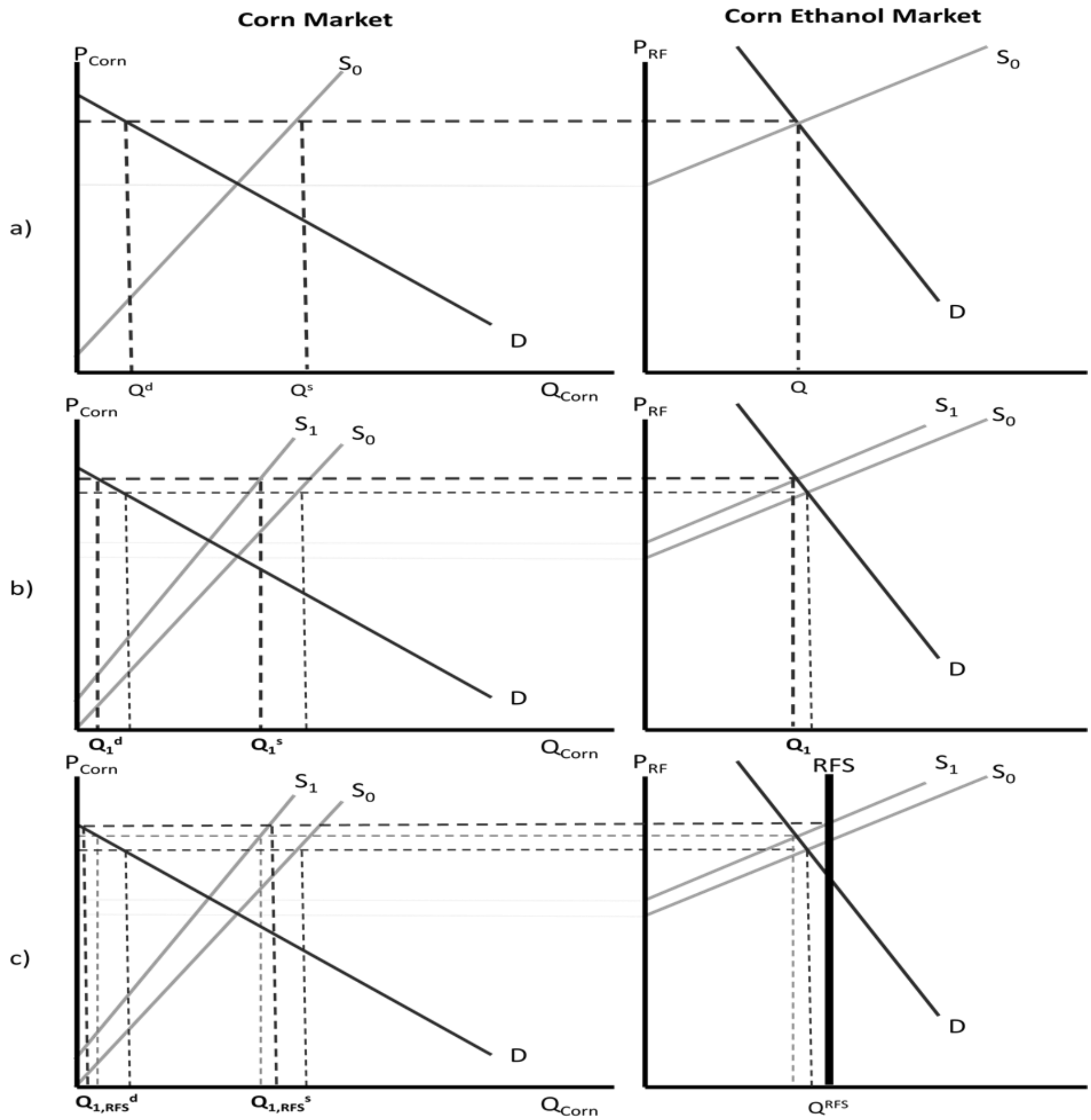


Figure 9. Economic representation of a corn ethanol mandate and drought

The basic economic effects of a negative supply shock in conjunction with a mandate can be seen in figure 9. The first set of graphs labeled a) depict the markets with certain production and ethanol production as determined purely by market forces.

The graphs in b) introduce a negative supply shock in the corn market, shown by the shift in supply from S_0 to S_1. Without a renewable fuel mandate in place, this is expected to shift ethanol production down (Q to Q_1), decrease the quantity supplied to conventional corn demand (Q^d to Q_1^d), and decrease total corn production (Q^s to Q_1^s). The final graphs shown in c) show the production reduction plus an ethanol mandate. In this case, the amount of corn that goes to conventional demand experiences a further decrease (Q_1^d to $Q_{1,RFS}^d$) and the amount of corn that goes to ethanol is unchanged due to the mandate ($Q_{1,RFS}^s$ - $Q_{1,RFS}^d > Q_1^s$ - Q_1^d). In the short-run analysis, as depicted in the above figures, supply cannot respond. The same framework will be extended in a later analysis using a stochastic and long run framework, where supply responses can occur.

Methods

The analysis will be implemented within a partial equilibrium modelling framework depicting the U.S. agricultural sector. The supply shock will be applied to the projected 2015 cropping and demand year, at a time when the conventional ethanol requirement reaches its peak upper-bound of 15 billion gallons. The economic impact will be investigated in regards to the effect on welfare, commodity prices, most notably corn, and impacts to the livestock sector. Trade implications will also be studied and the leakage effects of such policies on the rest of the world will be discussed, however, without any empirical analysis. Short-run impacts are derived due to the model assumption regarding no prior knowledge of either the drought occurrence, or the responding ethanol waiver. Subsequently, a long-run analysis is presented in the following chapter, where the assumptions regarding expectations are altered.

It is hypothesized that consumers of agricultural products will be made worse off in the short-run due to the inflated prices caused primarily by corn but also indirectly through a reduced supply of other agricultural commodities. In particular, ethanol policy has incentivized an increase in the total acres of corn, reducing the available acreage of other crops, thus having impacts on the production of all agricultural commodities. Since the drought is unexpected, the acreage is unable to respond to the negative supply shock, thus causing upwards pressure on commodity prices. In this short-run analysis we assume that acreage of a crop is fixed, for the policy waiver and drought occurrence is assumed to be realized after producers have planted.

Commodity prices, most notably corn, are predicted to rise due to the drought and the corn dedicated for use in ethanol production. Ranchers are expected to decrease their herd size and feeding due to high feed costs, causing mixed effects on beef prices. This will hurt beef producers while having a positive impact on consumers; however these impacts are highly dependent on the relative supply and demand elasticities. These effects are likely to be relatively large in the short-run compared to the long-run analysis due to the inherent inflexibilities in the supply chain. Based on rational expectation theory, the analysis assumes that producers did not expect an ethanol waiver.

The first procedure implemented for the following analysis, as described in the previous chapter, involves forming the 2015 yield distribution under an event of the magnitude of that which happened in 2012. This is done by extrapolating the yield regression analysis on state-specific crop yields to 2015 and applying the 2012 residuals. In turn, those yields are incorporated into the large-scale partial equilibrium framework of the U.S. agricultural sector using the model FASOM (Beach and McCarl 2010). As a result, the input data and results are dependent on the assumptions and model specifications within the regression analysis described in the previous chapter. The results were based on the regression model with the highest explanatory power with the linear model a better fit in most instances.

During each year's planting decision, farmers make choices on what crop mix to employ before future input and output prices as well as yields are realized. Other decisions can be made by the farmer following the discovery of these states of nature, such as harvesting and livestock feeding decisions. Other ex post decisions made by processors impact the final outcome, allowing for all participants in the agricultural industry to make decisions with recourse when the yield state is observed. This topic of expectations and its implementation within the modelling framework will be described later.

FASOM

The primary tool for the current analysis will be the FASOM mathematical programming model of the agriculture and forestry sectors in the U.S. (Adams et al. 2005; Beach and McCarl 2010). The complete model framework maximizes a function that reflects total welfare as a result of activities in the agricultural and forestry sector. The FASOM model has been recently employed to determine the impacts of the latest biofuel mandates on Agriculture and Forestry, particularly concerning the policy impacts on GHG emissions (Beach and McCarl 2010). FASOM is modular in nature, including such elements as land use, crop and livestock production, forestry production, commodity processing, greenhouse gas emission considerations, as well as renewable fuels. Although FASOM incorporates forestry and environmental quality components, as mentioned, these will not be included in the following analyses due to the focus of the current analysis. Key parameter projections from the USDA and EIA, in addition to the estimation of future parameters using historical data trends make short-run predictions from the modeling framework both reasonable and credible. The details of much of the model inputs are described in the data section. Because the drought scenario for 2015 is reflecting 2012-like percentage reductions in yields, assumptions regarding how farmer expectations at that time are important, also described below.

The FASOM model has not been employed to investigate the economic impacts of biofuel mandates in the event of this type of negative supply shock. This exogenous shock, combined with the additional upward pressure on corn prices from ethanol mandates, is expected to severely strain the supply of corn. Also, short-run impacts on market inputs and production activities will be evaluated.

The FASOM framework utilizes non-linear programming under the assumptions of perfect foresight in order to solve a societal welfare objective. However, the crop mix is fixed using constraints. The objective function computes the societal impact of processing, agricultural primary production (both livestock and crop), and ag-product consumption and trade. The model incorporates fixed production, specific to U.S. states (with certain key U.S. agricultural states being divided into sub-regions). There is also an ag-processing module, where alternative technologies can be employed for livestock feed and ethanol production among other items. Processed goods, in addition to primary agricultural commodities can also be traded, with the incorporation of interstate transfers, import, and export possibilities.

Although the overall construct of the model includes forestry and greenhouse gas emission accounting from agricultural activities, as mentioned, this research will only utilize and modify the agricultural framework. The most notable endogenous components of the FASOM model are commodity and factor markets. The specific crops, animal types, and final products will be mentioned throughout the following analyses as per their respective importance to the current investigation. Most notably, corn, livestock, and alternative uses for land otherwise grown on corn (i.e. soybeans) will be described. Factor markets concerning; irrigation, fertilizer, and labor are also included. Product markets are incorporated using production/supply, consumption/demand, and international trade. Specifically, production possibility frontiers are constructed using alternative production possibilities dependent on the endogenous input and output factors, various production technologies, as well as exogenous yield estimates based on previous literature or statistical methods of previously observed production. The model includes over 100 commodity types, including 40 crops, 25 livestock units, and over 50 processed goods.

The constraints of this maximization procedure are grounded in basic economic theory, whereas supply (determined by technological assumptions, available land, inputs, import markets, and alternative production options for the producer) and demand (determined by domestic demand, the intermediate product market, and export demand) determine the resulting prices. The model also allows for a certain degree of substitutability in demand for agricultural products, for instance, the closeness of beet sugar and cane sugar. The model constraints ensure a supply-demand balance holds for regional product supply, demand, processed commodities, trade, feeding, livestock markets, and transportation between U.S. states. Within the supply balance, total land constraints also exist for each U.S. state, treating production possibilities as heterogeneous across the state and sub-state regional scale.

Programs such as the Conservation Reserve Program are also implemented in the land constraint as a possible use, in addition to rangeland, pasture, urban, and cropland. Land of various types can also be idled depending on the incentives for production, determined by prices from the endogenous commodity markets incorporated in the model. Important constraints for the current analysis include bounds on the production of certain secondary market products due to government mandates, such as biofuels. By imposing such a constraint, the supply demand balance for ethanol producing crops, such as corn, is altered, resulting in an increased overall demand for corn, for instance. As mentioned previously, the expectation of this occurrence is of key importance, whereas depending on the assumptions regarding the flexibility of supply, producers could simply respond with an increase in corn acreage in response to the biofuel mandate’s upwards pressure on prices. Detailed descriptions of the entire model structure and parameter references can be found in several documentation papers (Adams et al. 2005; Beach and McCarl 2010). The data section within this chapter will outline some of this data used in the FASOM model most important to the current analyses.

Fixed Crop Mix – Model Lock-in

The inherent assumption within the general framework of the FASOM model is that market participants have perfect information of model parameters in the current period, and all future periods. This model characteristic makes determining short-run market behavior in the wake of an unexpected exogenous shock, either yield or policy related, difficult. The concept of perfect information and optimization given assumptions regarding agents' treatment of information is grounded on the widely accepted economic theory of rational expectations (Muth 1961). Although agricultural producers are aware that negative supply shocks inevitably exist, it would be unreasonable to expect producers to predict their occurrence for a given year with complete certainty. In order for the model to depict an unexpected drought for the 2015 crop year, adjustments need to be made to the model structure.

Partial equilibrium analysis is based on agents in the model independently maximizing profit or utility given a known set of parameters and constraints. However, in our instance, farmers only have expectations of yields and RFS mandates rather than knowing these conditions with certainly. In a short-run analysis, as would have been the case in 2012, market participants had an expectation regarding yields and RFS mandates.

The issue of perfect knowledge coupled with rational expectations is overcome in the current analysis by first solving the programming model using the expected yield and mandate conditions. The crop mix and livestock breeding herd aspects of those decisions are 'locked-in' before we consider the impact of an exogenous shock occurrence. In turn, agricultural processing, livestock herd adjustments, and crop harvesting decisions that would normally be made ex-post are determined and market prices and welfare observed.

Relaxation of Renewable Fuel Standards

The model initially imposes the baseline renewable fuel blending requirements for 2015, following the RFS2 for convention ethanol of 15 billion gallons. In order to simulate the occurrence of a conventional ethanol waiver, the economic outcomes of this initial situation are compared to a scenario where the mandate is completely relaxed. In addition, the analysis is expanded to investigate the impacts of marginally reducing the 15 billion gallon conventional ethanol mandate rather than only providing results for the extreme relaxed case. Scenarios that reflect the conventional ethanol requirements dialed down in one billion gallon increments from 15 billion gallons to 7 billion gallons given such a drought occurrence are constructed. By comparing the economic conditions of the 15 billion gallon baseline to the alternative waiver scenarios, the economic impact created by such a waiver can be determined.

At the time of this manuscript's construction, the 'final rule' or RFS scenario one, pertaining to the treatment of cellulosic mandates given the latest EPA final ruling seems the most likely and closest to current biofuel mandate conditions. The inclusion of cellulosic ethanol within the modelling framework, however minor, requires that assumptions be made regarding the efficiency of energy crops into the future. These judgments have been a main point of criticism in the past concerning recent large scale agricultural modelling concerning ethanol production (Plevin 2010). This base scenario upholds the current RFS2 mandates for conventional ethanol, while relaxing the cellulosic ethanol requirements following EPA's annual rule making where 6.5 million ethanol equivalent gallons were assumed to be required in 2015. The amount of biodiesel was also mandated to be reviewed and updated each year, whereas in this baseline scenario, the requirement will also be equal to the amount stated in the 2013 final rule of 1.28 billion gallons of biodiesel. The RFS2 originally mandated biodiesel for this period to be at least 1 billion gallons, while the specific quantity would be made public on a yearly basis. This RFS structure will be compared to the corn ethanol relaxed requirements; however both the cellulosic and diesel quantity mandates remain in place. Biodiesel and final rule 2013 cellulosic mandates were kept due to the limited justification and backlash of the biodiesel and test scale cellulosic refiners in a drought situation.

Another renewable fuel standard scenario investigated used the cellulosic and conventional ethanol requirements as stated in the original RFS2 for 2015. Although this is not consistent with past actions through to 2013, this scenario was included solely to investigate model sensitivity and investigate the severity of a 2012-style drought given the full mandates that remain as law at the time of writing despite the final rulings made by EPA each year. As was the assumption in the first scenario, biodiesel is set at the 2013 final rule of 1.28 billion gallons. This quantity has been rising steadily over the past few years, and is expected to slowly increase until 2015; however from preliminary model results, these marginal changes seem to have minor effects on corn and other key commodity markets during the course of analysis, particularly when compared to the magnitude of the impact of conventional corn ethanol policy and drought on markets.

The relaxed version of the second RFS scenario drops RFS mandates for corn ethanol, while maintaining the RFS2 mandate for biodiesel and cellulosic ethanol.

The third and final renewable fuel scenario included in this analysis is similar to the first scenario, in which the final rule for 2013 is applied for biodiesel and the original 2015 RFS mandate is in place for corn ethanol. However, in this scenario, cellulosic ethanol is completely dropped from the model, leaving only the biodiesel and conventional ethanol based biofuel requirements. Since the final rule for 2013 included a relatively low requirement for cellulosic ethanol as compared to grain ethanol and biodiesel, the results from this scenario are expected to be similar to those found using scenario one. The inclusion of this scenario is deemed important to ensure robustness of the results given possible future changes to cellulosic requirements. In the relaxed variant of the third scenario, biodiesel mandates stay in place for the relaxed scenario, while similarly to the RFS case, cellulosic remains dropped. The scenarios described in this section are illustrated in table 3.

Table 3. Minimum Renewable Fuel Scenario Requirements for 2015 in Billion Gallons

Scenario		Final Rule	Full Cellulosic	No Cellulosic
RFS Scenario				
	Crop Ethanol	15	15	15
	Cellulosic Ethanol	0.0065	4.22	0
	Total Ethanol	15.01	19.25	15.00
	Biodiesel	1.28	1.28	1.28
Relaxed RFS Scenario				
	Crop Ethanol	0	0	0
	Cellulosic Ethanol	0.0065	4.22	0
	Total Ethanol	0.0065	4.22	0
	Biodiesel	1.28	1.28	1.28

In all of the above situations, and as mentioned in the previous section, farmer expectations are very important to the final result of this analysis. In the three RFS scenarios described above, farmers' expectations are equal to those in the respective RFS case, and similarly to the occurrence of drought. Since recent historical crop acreage and prices are used in the analysis, RFS scenario two is based on the producers' circumstance during a hypothetical situation, the inclusion of such scenarios that stray considerably from these baseline values will show larger variation from those more in-line with recent conditions. However unrealistic from today's prospective, the fulfillment of this requirement, although subject to waiver from the EPA, remains the legal standard. Thus, this scenario was included for the purpose of gauging the importance of the cellulosic mandate waivers given current cellulosic ethanol supply conditions. In addition, if the cellulosic ethanol industry was to be developed in the near future, the impacts on conventional ethanol policy would be of great importance to policy design. This discrepancy between expected and actual yield conditions, ethanol mandates, and subsequent market conditions will be further exacerbated given the case of a negative supply shock.

In conjunction with the RFS scenarios described, state specific rates of yield change since 1950 have not been constant. Therefore, results from multiple regression periods were conducted for each analysis, in addition to the full 1950-2012 timeframe. These model runs were conducted for robustness of the partial equilibrium model results, as well as to gauge model sensitivity to these parameter assumptions. The regression periods used included start dates of 1975, 1980 and 1990 until 2012. Using the percentage yield shocks generated from the four regression periods, each individual supply shock was then applied to the RFS scenarios.

Data

There is a considerable amount of data required for this analysis due to the large scope of the FASOM framework. Processing costs for conventional and advanced ethanol were obtained from the data appendix included in the EPA's final rule for 2009 (U.S. Environmental Protection Agency 2009). Most notably, processing cost for ethanol was parameterized as $0.71 cents per gallon.

Incorporating the expected future change of key macroeconomic variables is also essential for construction of a large optimization framework for 2015. In particular, expected GDP growth, oil prices, and the rate of return on a 10 year U.S. government bonds are all essential components for decision makers in the period. These projections were obtained from the USDA Long-Term Agricultural Projection Tables released February 2013. In addition, data on corn ethanol production and demand were also required from the U.S. Energy Information Administration (U.S. Energy Information Administration 2014).

Most of the future baseline values were drawn from the 2013 USDA baseline (U.S. Department of Agriculture, Office of the Chief Economist, World Agricultural Outlook Board 2013).

Results

This section will summarize the results from the FASOM model. The economic results generated for the 2012-style production shock are discussed first for prices, market wide activities, and impacts on the livestock, meat, and crops, concerning both prices and production levels followed by an analysis of the subsequent welfare effects of the various biofuel policy alternatives.

Price Results

Table 4 shows the corn and soybean price results. In the absence of drought, given the various RFS scenarios, the base case projected corn and soybean prices for 2015 to range between $5.91-$6.07 and $12.29-$12.38 per bushel, respectively. Due to the similarities in the results among regression periods, only the 1950-2012 tables are presented. Given RFS2 mandates are fully in place, and 15 billion gallons of corn ethanol is being produced, the 2012-like production shortfall caused corn prices to nearly double, increasing between 91%-95%, to $11.66-11.82 a bushel. This increase in corn price is higher than found in a previous study when a negative supply shock similar to the 1988 drought under an ethanol mandate scenario saw corn prices increase 43.8% (Tokgoz et al. 2008). On the other hand, corn prices increase only 6%-12% when relaxing the RFS mandate in the same drought situation to $6.36-$6.65. This shows that a RFS waiver is expected to have significant short-run price consequences, reducing the severity of the positive spike in corn price.

The impact of the drought on soybean prices was found to be relatively small. In addition, relaxing the corn ethanol mandates actually had minor positive impacts on soybean prices. This is most likely because the biodiesel mandates were not altered.

Something of interest is the lack of price difference given the three RFS scenarios. This was a significant result, particularly in the case of scenario two, where over four billion gallons of cellulosic ethanol was produced to satisfy the original RFS2 requirement for 2015. Since the results show that there is no real effect of the cellulosic ethanol scenarios, we will not discuss those further.

Table 4. Corn and Soybean Price Results for 2015 under a 2012-like Supply Reduction

			Production Short-fall Scenarios			
	RFS Cellulosic Scenario	Base	Full RFS and Short-fall	%Δ from Base	Relaxed RFS and Short-fall	%Δ from Base
Corn Price /bu	Final Rule	$5.92	$11.66	97%	$6.62	12%
	Full Cellulosic	$6.01	$11.66	94%	$6.46	8%
	No Cellulosic	$5.98	$11.82	98%	$6.36	6%
Soybean Price /bu	Final Rule	$12.17	$12.50	3%	$13.93	14%
	Full Cellulosic	$12.26	$12.70	4%	$14.10	15%
	No Cellulosic	$12.24	$12.61	3%	$14.19	16%

Notes: Base scenario depicts the situation in which no drought occurred. Prices in 2014 US Dollars.

The basic results across the RFS cellulosic relaxation scenarios is that the production shortfall coupled with the RFS leads to a substantial rise in prices with them raising from $5.92-$6.01 per bushel to $11.46-$11.82. This found that given a drought occurrence, current RFS standards would increase corn prices by almost $6, or a near doubling, whereas relaxing the corn ethanol mandates by 50% dampens this price spike to $6.36-$6.72, less than a one dollar increase.

Price Indices

Weighted fisher production and price indices were computed given each yield regression scenario and corresponding RFS situation. The indices presented in this section represent the weighted average of price changed received by farmers at the "farm gate" for crop, livestock, and meat products relative to the reference case without a drought.

Table 5 depicts the results obtained using the 1950-2012 yield shock, whereas the no drought scenario values are the base at 100. The general results show crop, livestock, and meat prices are all increase in the drought situation and production declines. Again large differences in price shifts were found when corn ethanol mandates were relaxed.

Table 5 shows that weighted crop prices are expected to increase between 34-36%, under the production shortfall mostly driven by higher corn prices, when the corn ethanol standards are set to 15 billion gallons. In contrast, this increase is expected to be only 8.6-9.6% when this ethanol requirement is relaxed by 50%. Livestock prices are also expected to increase between 30-34%, while interestingly, relaxing the corn ethanol mandate only reduces this price shock marginally, to 28-32% increase. This could be attributed to a higher demand for feed, due to the relative production adjustments described later in this section.

Table 5. Production and Price Indices Following 2015 Drought

Commodity Index	Price Index Full RFS	Price Index RFS Relaxed	Production Index Full RFS	Production Index RFS Relaxed
Crop	134.7	109.6	85.9	86.7
Livestock	133.4	132.0	91.0	97.9
Meat	119.6	106.1	87.2	93.2

Notes: Index values are relative to the baseline expected yield scenario without short-fall at 100.

The weighted price index for meats is also depicted in table 5, denoting a near 20% increase when corn ethanol mandates remain in place. This is relative to a 5-6% increase when such RFS standards are relaxed.

Production across all commodity categories decreases relative to the drought free situation. Crop production declines 13-14%, with very little difference regarding the status of the corn ethanol mandate due to the model lock-in. Livestock production declines 8.5-9.1% given adjustments made in response to higher feeding costs. Given a relaxed RFS mandate and the subsequent less expensive feed, this decline is smaller, at 2.1-2.3%. Lastly, meat production decreases 12-13% given RFS mandates and 6.4-6.8% when such mandates are relaxed. This is a difference of nearly half between the policy alternatives.

Meat Product Results

As the fed beef, pork and chicken product price results were highly consistent among yield shock scenarios and RFS scenarios, 1950-2015 regression period results are displayed. Similarly to the other results displayed, complete tables including all other results can be found in the appendix. Table 6 shows the major U.S. meat product prices given RFS scenario 1. 2015 fed beef prices are projected to be $533.50 in the drought-free base case, experiencing a 14% increase given a drought of relative magnitude to that witnessed in 2015. Similar results were found for chicken prices; however pork is seen increasing a substantial 50% given the drought and RFS standards. As is expected, when corn ethanol mandates are relaxed, these prices still increase as a result of the drought but at a reduced magnitude. Most notably is the pork price, reducing the shock tenfold. Figure 10 depicts why the relationship between corn price and meat product prices is so strong, with over 95% of all feed grain production in 2013 in the form of corn. Prices for silage, hay, distillers' grains from corn and non-corn sources, and feed corn were found to be all higher in RFS scenario than in the relaxed case. Regardless of the RFS scenario, as expected, the drought caused feed prices to increase.

Table 6. Major U.S. Meat Product Prices per 100 lbs. for the 2015 Drought

	Base	Full RFS	%Δ from Base	RFS Relaxed	%Δ from Base
Fed Beef Price	$533.50	$606.30	14%	$590.32	11%
Pork	$84.17	$125.84	50%	$88.33	5%
Chicken	$134.47	$152.39	13%	$136.73	2%

Notes: Feedlot fed beef in 100lbs of carcass weight, for pork in 100lbs after dressing, and for chicken in 100 lbs. on a ready to cook basis. Prices in 2014 US Dollars.

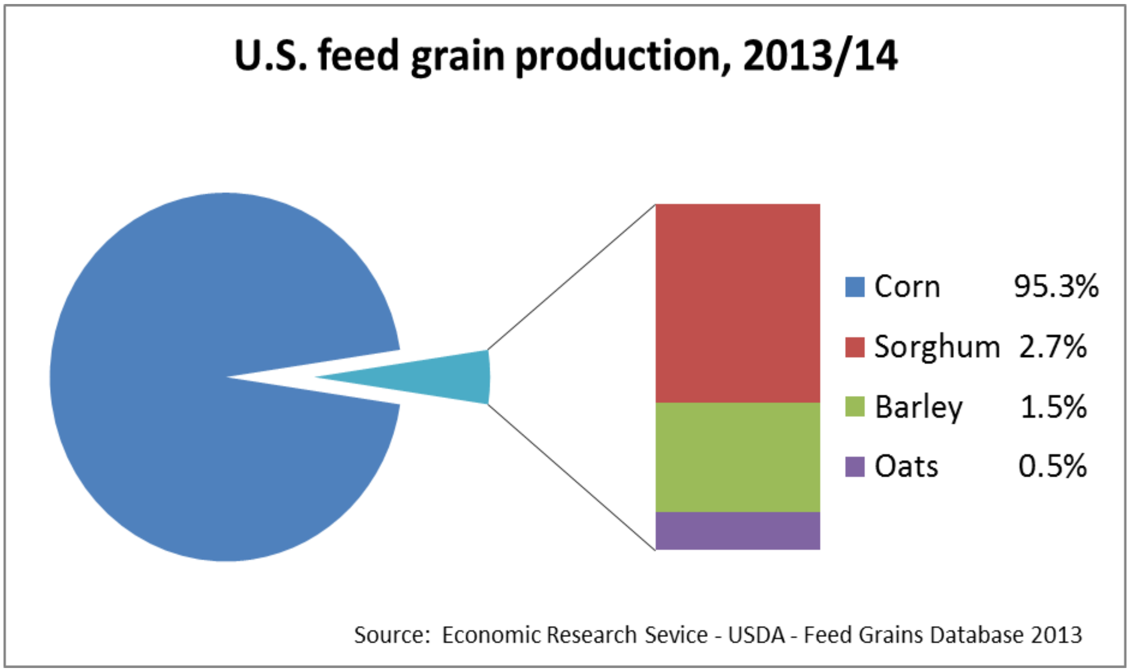


Figure 10. U.S. feed grain production for 2013/2014

Crop Ethanol Mandate Sensitivity

The results depicted so far display select cases for ethanol mandate waivers, while in practice; it is valuable to know the marginal impacts of such a reduction. The data presented in table 7 shows the resulting corn price of marginally decreasing the mandate for the 2015 drought simulation plus under base yields. Under the base yields we see corn prices show little response to changes in the mandate after decreasing the mandates by only a few billion gallons. This result shows that crop ethanol mandates, given the 2015 yield projections, do not positively impact corn price until after 13 billion gallons given this production situation. A meta-analysis of previous biofuel and corn price studies given unexpected short-run implementation of ethanol waivers where each additional billion gallons of ethanol is associated with a 5 to 10 percent increase in corn prices on average (Condon 2013). This was the case in our model findings, until a lower bound corn price is reached; a price influenced my other factors not directly associated with biofuel mandates.

Table 7. 2015 Corn Price in dollars/bu Sensitivity to Crop Ethanol Mandates Given 2012 Drought

Crop Ethanol Mandate (billion gallons)	Normal Yields	2012 Drought Regression Scenario
15	$5.92	$11.65
14	$5.69	$10.83
13	$5.65	$10.30
12	$5.65	$9.76
11	$5.65	$9.33
10	$5.65	$8.69
9	$5.65	$8.21
8	$5.65	$7.84
7	$5.65	$7.53
Relaxed (0)	$5.65	$6.61

Note: Prices shown in 2014 US Dollars.

However, the situation is dramatically different under the 2012 imposed drought yields, where we see the mandate has large impacts on corn price. The table shows that given a 1 billion gallon decrease in crop ethanol mandates in the drought situation, corn prices would decrease from their $11.65, on average 50 cents, however, this effect is marginally decreasing as the size of the waiver increases, as depicted in figure 11.

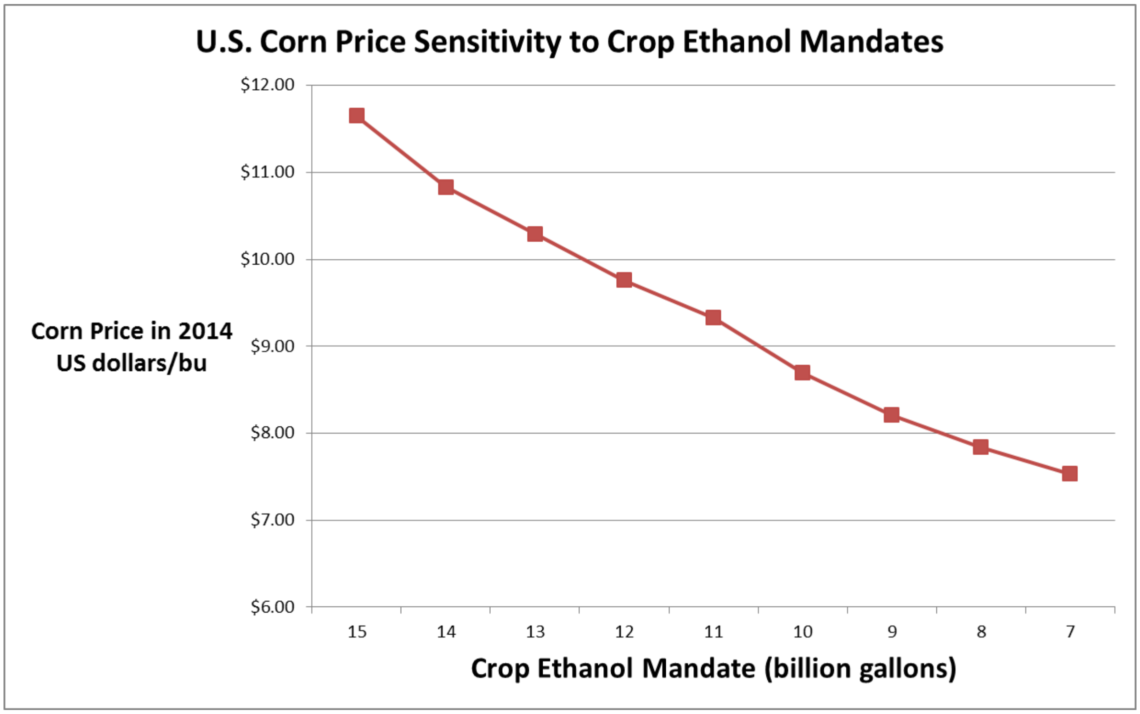


Figure 11. 2015 U.S. corn price given 2012 drought sensitivity to marginal decreases in crop ethanol mandates

Welfare Results

Lastly, the welfare results of the partial equilibrium analysis are presented. Included in this section are the producer and consumer and total welfare effects by U.S. region as depicted in table 8. Although the optimization model allowed for welfare computations at the state level, regional results are presented to allow summary comparisons and conclusions to be drawn. Incorporated in the welfare analysis is a comparison of the baseline, no drought 2015 welfare situations, relative to drought situations with and without RFS mandates. The difference between RFS policy is highlighted for this short-run analysis, assuming no expectations existed regarding its implementation. Consumer surplus with respect to agricultural related products is calculated as the area underneath the demand curve and above the endogenously determined price. Since 2015 demand must be forecasted, it includes the previously discussed macroeconomic assumptions taken from the 2013 USDA baseline projection report. Producer surplus, or farm income, is determined as the revenue generated from the sale of outputs minus the cost of production. All welfare amounts are calculated in 2014 U.S. dollars for the 2015 crop year under investigation using the 'Final Rule' cellulosic ethanol scenario.

Table 8. Definition of U.S. Welfare Regions

Regions	Included States and Sub-regions
Corn Belt	Illinois, Indiana, Iowa, Missouri, Ohio
Lake States	Michigan, Minnesota, Wisconsin
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
Northern Plains	Kansas, Nebraska, North Dakota, South Dakota
Pacific Northwest	Oregon and Washington
Pacific Southwest	California
Rocky Mountains	Arizona, Colorado, Idaho, Montana, Eastern Oregon, Nevada, New Mexico, Utah, Eastern Washington, Wyoming
South Central	Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Eastern Oklahoma, Tennessee, Eastern Texas
Southeast	Virginia, North Carolina, South Carolina, Georgia, Florida
Southwest	Western and Central Oklahoma, All of Texas but the Eastern Part -- Texas, High Plains, Texas Rolling Plains, Texas Central Blacklands, Texas Edwards, Plateau, Texas Coastal Bend, Texas South, Texas Trans Pecos

Table 9 illustrates the consumer welfare implications of the hypothetical drought. This calculation includes all ag-related consumption across the U.S. divided into regions. Consumer surplus, in this instance, does not incorporate heterogeneous consumption across regions, thus commodity price changes are expected to impact consumer welfare uniformly in this model. Therefore, the discrepancies of consumer welfare between regions solely reflect differences in population.

Imposing policy that relaxes the biofuel mandate causes consumer surplus to be higher than in the case RFS remained, due a relief to the positive pressures on commodity prices. In this case, short-run consumer welfare would be $29.2 billion USD higher given the relaxation of conventional biofuels during the drought.

Table 9. Consumer Welfare in 2015 from Short-run Analysis

Region	BASE	Full RFS	RFS Relaxed	% Change of Relax
Southwest	261.74	256.10	258.36	
Corn Belt	493.13	482.51	486.77	
Northern Plains	74.88	73.27	73.92	
Lake States	252.50	247.06	249.24	
Northeast	792.09	775.02	781.88	
Rocky Mountains	189.16	185.09	186.72	
Pacific Southwest	396.59	388.05	391.48	
Pacific Northwest	101.21	99.03	99.90	
South Central	331.67	324.52	327.39	
Southeast	484.40	473.96	478.15	
Total	3,377.37	3,304.59	3,333.81	0.88%

Notes: Values shown in 2014 billions of US dollars.

The consumer welfare results presented above show that an unanticipated waiver on conventional ethanol in a drought situation has positive short-run welfare effects on consumers.

The alternative side of the welfare analysis is the welfare impacts on producers. Since drought occurrence combined with tight ethanol mandates cause agricultural output prices to increase, it was initially expected that relaxing such mandates during drought years would negatively impact producers, because they would now face lower market prices for outputs. Table 10 depicts how the producer welfare changes from the initial non-drought, base level, with respect to a 2012-like drought given both full RFS and a relaxed situation. In both policy situations, the drought's impact on price for most regions increases producer income, thus the price rise is exceeding the negative impact on production through reduced yields.

However, the regional dependence of the results is interesting when looking at the producer welfare analysis. Specifically, since certain regions are highly specialized in the production of corn, the relaxation of ethanol mandates can actually cause a reduction in producer surplus relative to the non-drought base case. This is most evident in the Corn Belt region, a region comprising of nearly one third of all farm income in the base scenario. Given a drought situation with the full 15 billion gallon RFS, farm income from this region is expected to nearly double, whereas given the immediate relaxation of RFS mandates, this would be cut two thirds, to an amount below the base case. In contrast, the relaxation of ethanol mandates actually positively impacts agricultural producers, most notably in the southwestern regions, due to the limited field crop production and existence of livestock operations. For instance, California is well known for its dairy industry, a market that would benefit in a situation of reduced feeding costs.

Table 10. Producer Welfare in 2015 from Short-run Analysis

Region	BASE	RFS	Relax	% Change of Relax
Southwest	3.26	7.57	8.92	17.85%
Corn Belt	20.43	37.35	12.33	-66.98%
Northern Plains	11.51	23.17	9.68	-58.23%
Lake States	6.26	20.83	8.90	-57.28%
Northeast	1.14	3.88	3.42	-11.83%
Rocky Mountains	7.59	16.29	15.43	-5.27%
Pacific Southwest	3.03	5.07	5.59	10.20%
Pacific Northwest	1.57	4.65	4.11	-11.68%
South Central	3.38	9.26	6.70	-27.64%
Southeast	3.51	7.44	6.80	-8.62%
Total	61.67	135.53	81.89	-39.58%

Notes: Values shown in 2014 billions of US dollars.

The final welfare analysis for this chapter looks at the combination of both consumer and producer effects to determine the impact on total welfare. It was found that relative to the baseline total welfare, a drought situation given RFS mandates would cause a negligible effect on national welfare. This implies that the positive impact on producers would be counterbalanced by the negative impacts felt by consumers. In contrast, when RFS mandates are relaxed, the short-run total welfare effects were found decrease between five and seven tenths of a percent. As shown in table 11, the relative impact on each region was dependent on the ratio of agricultural production to population. For instance, the Northeast, where many people live relative to the region's agricultural production, the area actually experiences negative welfare impacts. This is also the same for regions where corn is not a major source of agricultural income such as the southwest regions. With respect to the impact of ethanol relaxation, regions that depend heavily on corn as a source of farm income experience larger negative welfare changes relative to those with limited dependence on grain. In all, due to the relatively larger negative impact on producer welfare relative to consumer welfare, the mandate relaxation scenario across all regressions shows relaxation would result in an \$18-\$25.4 billion dollar decrease in total surplus during a 2012-sytle drought occurrence in 2015. The total welfare results for the alternative regression scenarios can be found in the appendix.

Table 11. Total Welfare in 2015 from Short-run Analysis

Region	BASE	RFS	Relax	% Change of Relax
Southwest	265.00	263.66	267.28	1.37%
Corn Belt	513.56	519.86	499.10	-3.99%
Northern Plains	86.39	96.44	83.60	-13.32%
Lake States	258.76	267.89	258.14	-3.64%
Northeast	793.23	778.91	785.30	0.82%
Rocky Mountains	196.75	201.38	202.16	0.39%
Pacific Southwest	399.62	393.12	397.07	1.00%
Pacific Northwest	102.78	103.68	104.01	0.32%
South Central	335.05	333.78	334.09	0.09%
Southeast	487.91	481.40	484.95	0.74%
Total	3,439.03	3,440.12	3,415.70	-0.71%

Note: Values shown in 2014 billions of US dollars.

Discussion

Here we analyzed the short-run economic ramifications of imposing both a full relaxation and marginal reduction of conventional crop ethanol mandates given a hypothetical drought occurrence. Short-run impacts on key markets were investigated from this unexpected policy implementation, showing substantial impacts exist, across both livestock and crop related sectors. Implications of such policy range from effects on welfare distributional considerations, trade, environmental considerations, and future expectations.

The price results depicted above showed complete relaxation of ethanol mandates decreased corn prices substantially relative to a full mandate scenario, nearly reducing the short-run corn price increase caused by drought by one half. Cellulosic ethanol assumptions were found to have little impact on the effectiveness of such policy. Full relaxation of the mandate also was found to decrease prices for livestock and meats relative to the RFS scenario. In comparison to the full relaxation policy, marginal reductions in the mandates continued to impact corn price, however at a decreasing rate. Decreases in livestock and meat production were also mitigated when subject to RFS relaxation. This can be attributed to changes in feed costs.

As presented above, the resulting welfare implications of the relaxation of ethanol waivers during a drought bestows positive impacts on consumers while affecting producers negatively. Although the empirical trade implications were not explicitly detailed in the previous analysis, the substantial corn price rise shows the possibility that such a policy would also have impacts in other parts of the world. This concept that price signals can create undermining effects relative to the policy goals, elsewhere in the world, is of great importance in respect to the biofuel issue, due to its environmental underpinnings. This issue, in the context of GHG mitigation and forestry, has been discussed previously in the literature (Murray, McCarl, and Lee 2004).

It is important to mention that the welfare results presented earlier in the chapter were only calculated with respect to agricultural commodity production and consumption. The relaxation of ethanol mandates would also be expected to impact liquid fuel markets in the U.S., particularly gasoline (McPhail 2011). Since there is a discrepancy between ethanol and liquid gasoline price, substituting gasoline for ethanol no longer mandated could result in significant welfare implications for consumers. Ethanol has lower energy content relative to gasoline, with approximately two thirds of the equivalent energy relative to gasoline. Given adequate supply conditions, prices tend to reflect this difference, however per unit of energy, gasoline has historically been cheaper. If we assumed a perfectly elastic gasoline supply, a waiver implemented on ethanol would result in a replacement by gasoline. From the model results presented earlier in a 2015 scenario, RFS relaxation was expected to decrease ethanol consumption 10 billion gallons, requiring the replacement of two thirds of that quantity in gasoline to make up the lost energy. This will alter the ratio of bending, resulting in a different final blended price for the consumer. The 2015 projections for gasoline equivalent ethanol and gasoline prices depict that gasoline is expected to be $0.37 less expensive than per gasoline equivalent gallon of ethanol (U.S. Department of Agriculture, Office of the Chief Economist, World Agricultural Outlook Board. 2013, Long-term Projections Report OCE - 2013). This relationship was also found in the historical data during the 2012 year drought.

Although the difference in the resulting blends with and without a waiver only results in $0.06 difference in fuel cost, when considered for the entire U.S. gasoline market, significant welfare impacts result. Using a simple Hicks calculation to estimate the change in consumer welfare, a gain of $2.4 billion dollars is calculated due to lower blended fuel costs. This estimate is highly sensitive to the ethanol-gasoline price ratio, dependent on corn production and the projections for 2015. Even when a waiver is implemented for 1 billion gallons of ethanol, a welfare impact is still evident, depicting a consumer gain of $250 million dollars. When comparing these calculations to the consumer benefits determined by the agricultural sector model, the consideration of fuel markets and ethanol waivers is important. In addition to the impacts of fuel substitution, blenders also increased their dependence on the renewable identification number (RIN) system inherent in the RFS2 system. Prices in this market following the corn short crop of 2012 rose drastically during 2013. For the first time, 600 million RINs were retired during 2013 in order to satisfy the 13.2 billion gallon requirement and the RIN price rose from near-zero in 2012 to $1 during late 2013. This drawdown of banked RINs combined with a price increase was expected to have further consumer welfare impacts in addition to those presented previously mentioned (U.S. Environmental Protection Agency 2014). Although detailed publically available RIN price data could not be obtained, this caused blenders costs to increase in order to comply with the RFS2 regulation an approximated average of $300 million dollars during the year. Much of this increase in RIN price increase was attributed to the approaching blend wall, where this and the RIN market will be described in detail within the following chapter.

The discussed mandate relaxation policy is also expected to alter market participants' future decision making. This issue was not incorporated in this analysis but will be in the next chapter.

CHAPTER V

'BLOW OFF VALVE' POLICY FOR U.S. RENEWABLE FUEL STANDARDS

Renewable fuel mandates in the U.S. have limited flexibility considering their fulfillment depends on a highly variable supply of agricultural products. While the *Energy Independence and Security Act of 2007* mandates that renewable fuel blending requirements are to strictly increase until 2022, agriculture experiences substantial variability (Congress 2007). Recently, both the Texas drought of 2011 and the U.S. Corn Belt drought of 2012 have caused commodity prices to reach record highs, while at the same time lowering the U.S. national grain stocks. During 2011, Texas, the third largest agricultural producer in the US, experienced the hottest growing conditions in 116 years of observational data and extremely dry conditions with resultant impacts on agricultural production (Hoerling et al. 2013). Researchers from both the U.S. and Great Britain have found that these extreme heat events have become twenty times more likely to occur relative to other La Niña years due to the effects of climate change (Rupp et al. 2012). An unchanging ethanol mandate in the face of such variability may not be desirable. This chapter investigates the long-run consequences of establishing a policy that relaxes the mandates under production shortfalls.

Mandates and Uncertain Yields

A degree of flexibility exists in the current renewable fuel mandates through a mechanism called the 'renewable identification number' system. This allows for the commoditization of renewable fuel, allowing for trade among the production and use of renewable fuel in order to achieve the standard at the lowest cost, at least from a theoretical resource economics perspective. The system is also used to track and ensure compliance, including quantity, type of biofuel, and production date (Schnepf and Yacobucci 2011). This system, similar to tradable permits, represents the right to sell gasoline up to an appropriate ethanol blending limit that corresponds with the specific type of renewable fuel that was produced to create the RIN. The governing body for the RIN market is the EPA, who have also allowed for a restricted transfer of these permits overtime. A RIN produced in any given year must be used in either the year it was created or the subsequent year, and at the time of this document's writing, a maximum of 20% of the current year's renewable volume obligation can be satisfied with RIN's from the previous year. It is of interest to note that the variability of the U.S. corn yield given extreme event situations can be quite large as shown in this research, and these effects can become compounded when bad crop years occur in succession. This circumstance instigates increased corn price volatility, resulting in negative welfare effects both domestically and abroad when risk aversion is assumed**.**

In addition to the RIN market, the EPA also has the right to implement yearly waivers for all forms of ethanol. In the case of cellulosic mandates, a waiver has been implemented in each year since the mandates took effect due to the unavailability of cellulosic ethanol in the market. With respect to conventional ethanol mandates, a waiver from the EPA is warranted only in a situation where 'economic harm' would be created. This option has not been implemented since the creation of the biofuel mandates, and market participants remain unsure regarding what constitutes 'economic harm'. The current analysis assumes that the EPA would consider impacts on both consumers and producers when evaluating such an occurrence resulting from decreased corn production.

Background on Mandates

The use of biofuel mandates has rapidly become a worldwide phenomenon, with world ethanol production increasing from 16.9 to 72 billion liters, and biodiesel production increasing from 0.8 to 14.7 billion liters from 2000-2009 (Sorda, Banse, and Kemfert 2010). This international adoption amplifies the impact of this growing trend on world food supply and markets. U.S. corn production dedicated to non-ethanol uses, peaking in 2005, has decreased continuously (with the exception of 2007) since the adoption of the government ethanol mandates. In 2005, 7.25 billion bushels of corn were consumed by non-ethanol sources, whereas that number in 2012 was slightly over 5 billion bushels, a 30% decrease (United States Department of Agriculture 2014). This creates a much tighter supply environment.

An expected partial relaxation of the biofuel mandates in years of restricted corn supply has the potential for welfare improvement. In the case for relaxing mandates during periods of limited crop supplies, New Mexico, Georgia, North Carolina, Arkansas, Virginia, and Texas petitioned the EPA in favor of an ethanol mandate waiver for 2011-2012 with the expected response in late 2012. Many studies that were reviewed in chapter II have investigated the impacts of an ethanol waiver in this circumstance, however, to my knowledge; no prior research has looked into the possibility of the adoption of a production dependent RFS policy shift. This policy would alleviate policy uncertainty now faced by both agricultural and energy markets, allowing market participants an opportunity to know with certainly the conditions of a conventional ethanol waiver *a priori* and respond to such expectation.

Objective

The objective for this chapter is to assess the long-run economic impact of adding an explicit production dependent 'blow off valve' to the renewable fuel standard policy that relaxes the mandate under large production shortfalls. Rather than conducting a short run analysis of an 'unexpected' waiver, here we look at long-run consequences of an *a priori* specified policy. To do this the magnitude of historical drought and short crop experiences for U.S. corn will be analyzed with future scenarios of shortfalls formulated. Also in the face of such shortfalls alternative relaxations will be imposed. Comparing the long-run effects of such relaxations will provide insight regarding the impacts of an announced policy of mandate relaxations.

The hypothesis is that such a policy would reduce corn price fluctuations decreasing the expected and extreme corn prices. Also, since this study focuses on long-run impacts of a known policy shift, it is expected that one would see producer adaptations.

Method

The methodology used here follows that presented in chapter IV with several key differences. The FASOM model is again used but with a distribution of yield outcomes following the work in Lambert et al. (1995) and Butt et al. (2005). Namely, rather than only utilizing the yield profile for 2012, we incorporate yield data from 1950-2012. In doing this concerns of model size arise and we use a 10 state empirical distribution that reflects the 1950-2012 yield events. Secondly, unlike the short run analysis employing the ‘model-lockin’ mechanism in the previous chapter, this analysis will assume that the model is solved using the probabilistic yield distribution, with a specified renewable fuel mandate scenario possibly varying by state of nature (i.e. a possible relaxed mandate under the more sever production shortfalls). For instance, in a particular example of a policy scenario, during ‘extreme’ shortfalls or ‘moderate’ shortfalls, RFS conventional ethanol mandates will be reduced 2 billion gallons or 1 billion gallons, respectively. Such an approach will yield a long-run analysis as will be discussed below.

Construction of Yield States

In order to derive long-run implications of a hypothetical yield-dependent renewable fuel standard, the regression analysis results from chapter 3 are utilized. This study first creates a country-wide yield distribution for all crops with 10 states of nature. The states of nature will be defined based on results for total U.S. corn production. The estimation of these state specific yield parameters as described previously will be conducted at the state level, in order to incorporate both spatial and inter-crop correlation within the mathematical framework, requiring a considerable amount of data due to the number of parameters to be estimated (Chen, McCarl, and Hill 2002). This process, as described in more detail in chapter 3, generated yield scenarios that are conditional to a particular climate scenario, similarly to those derived in Chen and McCarl (2000), Chen, McCarl, and Adams, (2001), and Chen, Gillig, and McCarl (2001).

Unfortunately, the inclusion of all yield states of nature, as defined by our 1950-2012 data is computationally difficult given we want to incorporate yield data into the partial equilibrium framework to calculate impacts at the state level. To address this problem, the 63 yield states of nature were divided into 10 discrete categories, and a representative year was chosen from each category. Since corn is the major ethanol crop produced, production variation among years was categorized using only corn production but the subsequent representative years incorporated production characteristics for all crops in all U.S. states.

In turn, the distribution depicted earlier in figure 5 was broken into ten sections, and the most recently observed year in each section was chosen as the representative year. A representation of this distribution can be seen from the histogram in figure 12. The relative frequency of these years occurrence was calculated from the number of years within each corresponding interval relative to the full 1950-2012 data set. It is important to note that this yield variation does not only reflect drought, but also many other possible factors such as pests, diseases, frosts, snow and flooding. For instance, yields from 1993 were impacted from the combination of flooding in the Midwest and a drought in the US Southeast, causing an estimated $16 billion dollars in damage (Lott 1994). The most recent year was chosen as a representative growing season in order to reduce the effect of technology impacting yield variability, an issue discussed at length in the limitations section.

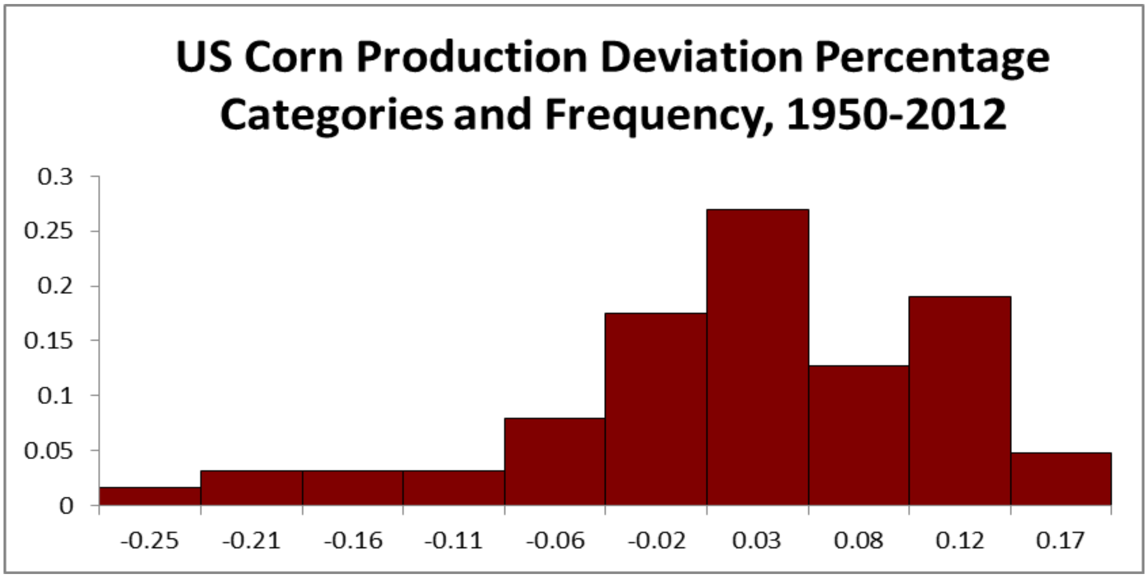


Figure 12. An empirical distribution of yearly corn production variability in percentage deviations, 1950-2012

Table 12 shows the representative growing years from ten intervals based on the percentage variation from the expected corn production of each season. Also depicted in the table is the deviation in real terms, frequency of this interval occurring from the 1950-2012 data set, and the number of years observing corn production in the respective interval. It is interesting to note that although 2012 experienced a more substantial production shortcoming than in 1988, as a percentage of total expected production, 1988 was computed as more severe with respect to percentage deviation from expected. The frequency of each interval is simply computed as the number of years observed within each interval divided by the number of years (63) included in the total data set.

Table 12. Representative Years of U.S. Corn Production Variability Distribution, 1950-2012

Growing Season	Percentage Variation from Expected Production	Deviation from Expected in Billion Bu	Frequency of Occurrence	Years within Interval
1988	-25.36%	-1.67	1.59%	1
2012	-20.82%	-2.83	3.17%	2
1993	-17.74%	-1.36	3.17%	2
1995	-10.31%	-0.97	3.17%	2
1991	-8.48%	-0.69	7.94%	5
2011	-5.04%	-0.65	17.46%	11
2010	-0.26%	-0.03	26.98%	17
2008	3.22%	0.37	12.70%	8
2009	8.98%	1.07	19.05%	12
2004	12.68%	1.32	4.76%	3

Production Dependent Renewable Fuel Standard Scenarios

Current RFS policy allows the EPA to employ an arbitrary waiver on corn ethanol in the case of economic harm. Here we condition such a policy on total corn production. Figure 13 presents the final distribution of corn production variability developed via the residuals from chapter 3 using normalized 2012 acres. The production shortfall years are assumed to be the dark grey (shortfall) and black (extreme shortfall) boxes in figure 13. These years, represented by the 1993 and 1995 crop years, also through their relative probability of occurrence, represent the dust bowl years of the 1950's, 1964, and 1974 and thus has a probability of 6 years out of 63. In the case of the 'extreme' shortfall case, 2012 is also representative of 1988 and 1983, thus has a probability of 3 years out of 63.

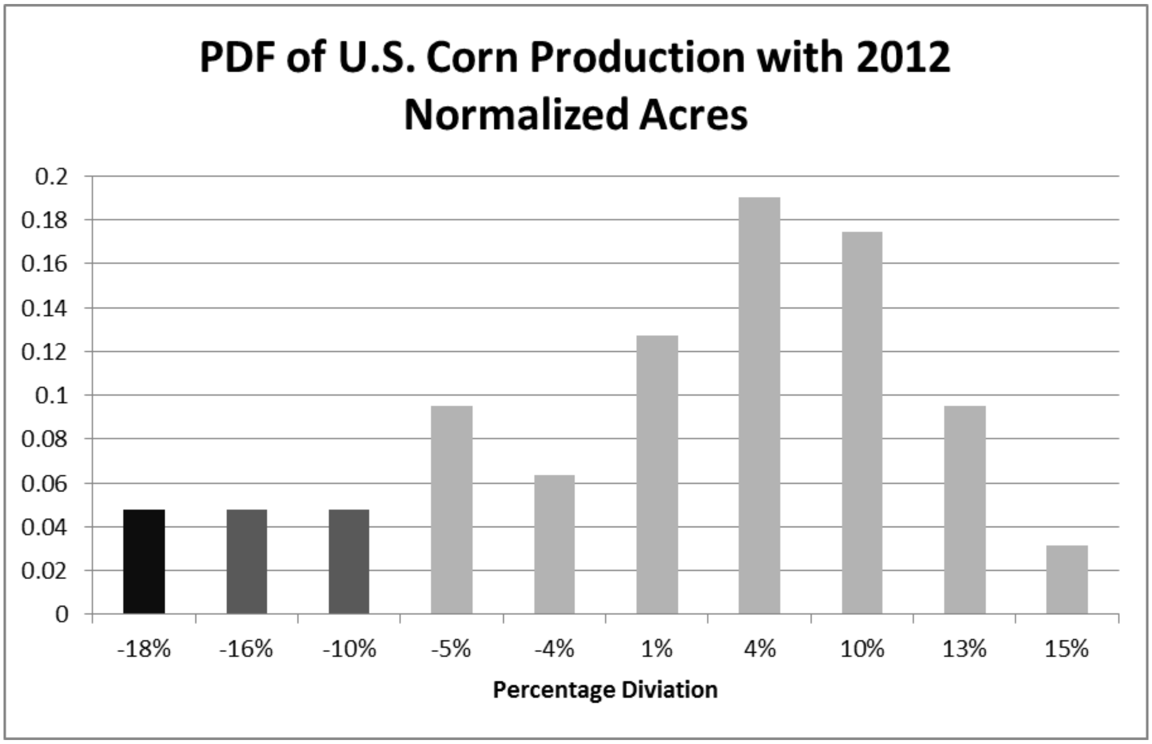


Figure 13. Discreet representation of the PDF of U.S. corn production, depicting short-fall triggers

Twelve RFS mandate reduction scenarios are incorporated, ranging from no reduction to up to 50%. Cases 2-6 have smaller reductions of 1-2 billion gallons while cases 7-12 are larger with 3-7.5 billion gallons. Table 13 outlines the mandate reduction scenarios, where in a non-shortfall experience, no waiver is implemented, and a 15 billion gallon requirement is upheld. The mandate reductions can vary across the either the ‘moderate’ or ‘extreme’ shortfall circumstances.

Table 13. Production-Dependent Conventional Renewable Fuel Standard Scenarios

	Conventional Ethanol Mandate in Billion Gallons		
Scenario	Normal	Moderate Shortfall	Extreme Shortfall
Baseline - 1	15	15	15
2	15	15	14
3	15	15	13
4	15	14	14
5	15	14	13
6	15	13	13
7	15	15	12
8	15	15	10
9	15	15	7.5
10	15	12	12
11	15	12	10
12	15	12	7.5

Although agents will be unaware of the specific yield state of nature that will occur, they know the distribution with certainly, and given the assumption of rational expectations (Muth 1961), act accordingly based on this knowledge. Outcomes are then calculated across all states of nature and policy scenarios.

Multiple scenarios concerning RFS policy and yield distributions are constructed for comparison and robustness. Given the long-run characteristics of the current analysis, this enables an exploration into the potential shifts in cropping patterns within and across regions in response to changing RFS waiver policy. Since the partial equilibrium model incorporates uncertainty by including historical state specific crop yields as possible states of nature, the expectation of crop yields in the future will be based on the expectancy of these states reoccurring in addition to the incorporation of a long-term trend to take into account technological change. Also incorporated, and detailed further below, is the normalization of crop acreage to reflect a recent U.S. acreage distribution, allowing for an improved ability to gauge the impact of previous regional yield shocks on future levels of production.

Long Run vs. Short Run Agricultural Sector Model Implementation

The primary difference between the chapter IV short-run and the long-run model here is that crop acreage will change based on the probability distribution of yields and the producer responses to changes in expected waiver policy. The potential conventional ethanol waiver, expected to impact acreage because the knowledge of its implementation is now assumed to be known *a priori*.

In the long-run framework, the empirical yield distribution will be incorporated into the FASOM framework to provide stochastic yield scenarios and compare alternative biofuel policies over a range of possible outcomes. The model baseline would first be run based on farmers' initial expectations of yields without a waiver.

Therefore, in order to determine acreage, the yield probability distribution acts both to give expectations to farmers to determine the initial crop acres that would be irreversible, and then to establish the economic outcome given each possible yield state.

Stochastic Long-Run Modelling Framework

Modification to the general deterministic partial equilibrium framework used in the previous chapter is required to incorporate market outcomes under alternative states of nature. This research wishes to integrate stochastic yield states into the model. The objectives for this modified model are to allow certain model participants the ability to respond to stochastic outcomes, while restricting the ability of others. In this circumstance, it is assumed that crop production decisions are based on yield distributions and demand curves, without realizing actual yields or prices. Thus, producers choose to maximize expected revenue based on expectations. On the other hand, consumers, livestock feeders, and processors are assumed to be able to alter their production and consumption decisions based on the realized yield outcomes. This implies yield risk must also be incorporated into the markets for intermediate goods, such as the corn available for ethanol processing. Therefore, the ethanol mandate needs to be incorporated in such a way that its implementation can be conditional on states of nature, while only the distribution of such nature states are known *a priori*.

Stochastic programming with recourse was originally portrayed and generalized within the management sciences (Dantzig 1955; Cocks 1968). The agricultural application of this framework has developed considerably since this time (Rae 1971; Lambert and McCarl 1985), generally finding that results differ relative to deterministic models using mean values. The framework used in the current analyses follows research from the agricultural economics literature (Lambert et al. 1995), incorporating adaptive behavior and derived demands in the agricultural setting.

The model is as follows:

Max

$$\textit{Total surplus} = \mathrm{E}\left(\int \mathrm{p(q)dq} - \mathrm{g'y}\right) - c'x$$

$$= \sum_{s=1}^{N} \left(\theta_s \int \mathrm{p}(\mathrm{q}_s)\mathrm{dq}_s - \mathrm{g'y}_s\right) - c'x \qquad \text{(IIIa)}$$

Subject to:

$$q_s + Hy_s - N_s x \le 0 \; for\ all\ s, \qquad [\pi_{1s}] \qquad \text{(IIIb)}$$

$$My_s \le e \; for\ all\ s, \qquad [\pi_{2s}] \qquad \text{(IIIc)}$$

$$Dx \le b \qquad [\pi_{3s}] \qquad \text{(IIId)}$$

$$q_s,\ y_s,\ x \ge 0 \qquad \text{(IIIe)}$$

where θ_s is the probability of each state of nature occurring s, p(q_s) is the inverse demand curve where q_s is a vector of final goods, g is a vector of processing costs, H a matrix of production activity, y_s is the state dependent vector of processing using primary production, consuming goods when H>0 and producing when H<0. M is the matrix of resource usage of processing, where the processing resource endowments are defined by e. Primary agricultural production levels are denoted deterministically as x, given resources b, and the resource usage matrix D. The stochastic effect on the model is represented through N_s, the matrix of all yields under each state of nature. The shadow prices from the constraints are depicted as π_{1s}, π_{2s}, and π_{3s}. In all, producer and consumer surplus is maximized given each state of nature (IIIa) subject to supply balance constraints for each state (IIIb), processing resource endowment given each states production (IIIc), primary agricultural production resource endowments (IIId), and non-negativity constraints.

In addition to the general structure of the Lambert et al. model depicted above, a further constraint is required to incorporate biofuel policy. Model bounds depicting biofuel processing were included on the relevant elements of the y_s vector to force a minimum amount of processing of corn into ethanol with the per unit yield EY to meet the RFS requirements. Since the biofuel constraints in the current analysis are state dependent, the right hand side values of these constraints also is dependent on s. This constraint is depicted as follows:

$$EY y_s \geq m_s \quad [\pi_{4s}] \tag{IIIf}$$

Equation (IIIf) presents the additional constraint where final production is set to be greater than a certain mandate, denoted m_s, and π_{4s} is the shadow price of the RFS constraint. This analysis assumes that the RFS upper bound of 15 billion gallons on corn ethanol does not constrain production. Below, p_s is the state-specific demand curve, defined as $p_s = a - Bq_s$, where a is the intercept and B is the slope coefficient. The first order conditions of the Lagrangian depicted from equations (IIIa-f) with respect to final output q_s when $q_s > 0$ is as follows:

$$\frac{\partial L}{\partial q_s} = \theta_s[a - Bq_s] - \pi_{1s} \leq 0 \tag{IV}$$

This simplifies to:

$$\pi_{1s} = \theta_s[a - Bq_s] \qquad \text{(V)}$$

The first order condition with respect to state dependent processing levels y_s from the Lagrangian is:

$$\frac{\partial L}{\partial y_s} = -\theta_s g + H\pi_{1s} - M'\pi_{2s} - EY\,\pi_{4s} \leq 0 \qquad \text{(VI)}$$

If we look at the ethanol processing activity only, assuming it is zero, the expression becomes an equality, plus adopting the assumption that the corn use is 1 unit where EY is the ethanol yield from processing, this becomes:

$$-\theta_s g + \pi_{1s} - M'\pi_{2s} - EY\,\pi_{4s} = 0 \qquad \text{(VIIa)}$$

or,

$$\pi_{1s} = \theta_s\, g + M'\pi_{2s} + EY\,\pi_{4s} \qquad \text{(VIIb)}$$

Therefore, the commodity price also equals the cost of producing ethanol (g) plus the cost of the resources used, plus the cost of mandate times the ethanol yield.

In turn simultaneously solving the equations (V) and (VII), we see the price under the sth state of nature we get:

$$[a - Bq_s] = \ g + M'\pi_{2s}/\theta_s + EY\ \pi_{4s}/\theta_s \qquad \text{(VIII)}$$

Equation (VIII) shows that the equilibrium price and associated quantity from the processing market includes the mandate requirement, as would be expected.

The first order condition with respect to primary agricultural crop production levels x from the Lagrangian is:

$$\frac{\partial L}{\partial x} = -c + \textstyle\sum_s N_s\pi_{1s} - D'\pi_3 \ \leq 0 \qquad \text{(IVa)}$$

From (V):

$$\frac{\partial L}{\partial x} = -c + \textstyle\sum_s \theta_s N_s[a - Bq_s] - D'\pi_3 \ \leq 0 \qquad \text{(IVb)}$$

Substituting in equation (VIII), this equals:

$$\frac{\partial L}{\partial x} = -c + \textstyle\sum_s \ \theta_s N_s(g + M'\pi_{2s}/\theta_s \ + EY\ \pi_{4s}/\theta_{s)} - D'\pi_3 \ \leq 0 \qquad \text{(IVc)}$$

From equation (IVc), we can see that the production decision responds to the expected demand curve price, also involving the state specific cost of the biofuel mandate, represented by π_{4s}. Assuming that the mandate m_s is binding, thus $\pi_{4s}>0$, increasing m_s would impact the level of crop production x, irrespective of the state of nature. Therefore, if state specific mandates were introduced into the model, the decisions made prior to yield realization would be affected.

The stochastic programming framework originally presented by Lambert et al., with minor modification presents a formulation that allows explicit outcomes for each state of nature to be depicted, enabling the yield distribution data to be incorporated in its raw form. In addition, risk for such intermediate commodities as corn can be determined since processing, ethanol constraints, and consumption both depend on the state of nature.

Results

This section outlines the long-run model results given alternative RFS policy expectations.

Price Results

Generally, the corn price was found to increase given waivers during years in which no production shortfall was experienced (table 14). This can be seen by the representative states of nature 2002, 2004, 2008, 2009, 2010, and 2011, due to decreasing production levels. These price increases are relatively small; however these years represent the portions of the production distribution with the highest probability. The reasons for this increase involve reductions outlined in the acreage results section below. On the other hand, during the representative year that depicts the largest production shortfall, 2012, corn price experiences a relatively large decrease in price under the mandate relaxations.

The variance of the price distribution however does show a considerable change, represented by the coefficient of variation, with larger waivers exhibiting less corn price variance across all yield possibilities.

Table 14. U.S. Corn Price by Representative State of Nature Given the Smaller Waiver Scenarios, 1-6

	Conventional Ethanol Waiver Scenarios					
State of Nature	Base	2	3	4	5	6
son1979	3.13	3.13	3.14	3.14	3.14	3.14
son1993[1]	7.86	7.89	8.09	7.33	7.59	7.04
son1995[1]	6.40	6.54	6.74	5.97	6.04	5.55
son2002	6.63	6.64	6.76	6.75	6.83	6.93
son2004	3.48	3.49	3.50	3.50	3.51	3.59
son2008	4.76	4.75	4.78	4.77	4.81	4.80
son2009	3.52	3.59	3.61	3.62	3.62	3.64
son2010	3.82	3.91	3.95	3.95	4.07	4.14
son2011	4.98	4.98	5.01	5.01	5.05	5.11
son2012[2]	11.56	10.74	9.50	11.16	9.86	10.09
Mean*	4.61	4.61	4.60	4.60	4.59	4.58
COV**	50.92%	48.57%	46.11%	48.78%	45.72%	45.43%

Notes: Values are in 2014 USD. [1]Shortfall scenario. [2]Extreme shortfall scenario. *Weighted mean based on representative probabilities. **Coefficient of variance.

Comparing the price results between waiver scenarios 3 and 4 provides an excellent opportunity to compare the relative impacts between a large waiver, implemented in the worst production years and smaller waivers implemented in the years experiencing minor production setbacks. For instance, scenario 3 waives 2 billion gallons only in the 2012 state of nature, while scenario 4 implements a 1 billion gallon waiver in both the 'shortfall' and 'extreme shortfall' situations. Table 15 shows the nearly 20% reduction in corn price given an 'extreme shortfall' occurrence in scenario 3, when a 2 billion gallon waiver is implemented only in the 2012 representative state of nature. On the flipside, in the 'moderate shortfall' situations, 1993 and 1995, prices increase 3% and 6%, respectively. Comparing this situation to the scenario 4 waiver of a 1 billion gallon reduction in all 'shortfall' and 'extreme shortfall' conditions, prices in each representative 'moderate shortfall' year fall substantially, both over 7%. As noted, the waiver is still implemented for the 'extreme shortfall' case for 2012; however the price relative to no waiver is only reduced 3.8%.

Table 15 shows that average overall price when comparing scenarios 3 and 4 are essentially identical. Thus, when considering the probability of each states occurrence relative to the magnitude of the price movement, the price changes described earlier are offsetting in regards to the expected levels. The variability of corn price was measured by the coefficient of variation (COV) for each scenario, presenting a noteworthy difference between scenarios 3 and 4 in table 14. Due to the increased sensitivity of the corn price in 'extreme shortfall' situations relative to the 'shortfall' occurrences, the COV was found to be lower in the case where the waiver amount is only applied to the worst shortfall year. Additionally, comparing scenarios 5 and 6 show that the waiver impact on the ‘severe shortfall’ corn price is actually diminished as the waiver on ‘shortfall’ states is increased.

Table 15. Percent change from Base of U.S. Corn Price by Representative State of Nature given Smaller Waiver Scenarios, 2-6

State of Nature	Conventional Ethanol Waiver Scenarios				
	2	3	4	5	6
son1979	0.0%	0.3%	0.3%	0.3%	0.3%
son1993[1]	0.3%	3.2%	-7.5%	-3.8%	-11.4%
son1995[1]	2.4%	5.9%	-7.3%	-6.1%	-14.5%
son2002	0.2%	2.1%	2.0%	3.4%	5.0%
son2004	0.3%	0.7%	0.7%	0.9%	3.4%
son2008	-0.3%	0.5%	0.3%	1.2%	1.0%
son2009	2.0%	2.6%	2.9%	2.9%	3.7%
son2010	2.6%	3.9%	3.7%	7.4%	9.3%
son2011	0.0%	0.6%	0.6%	1.4%	2.7%
son2012[2]	-7.7%	-19.4%	-3.8%	-16.0%	-13.9%

Note: [1]Shortfall scenario. [2]Extreme shortfall scenario.

It is interesting to note than many of the relationships found in using the relatively small waiver scenarios, of 2 billion gallons or less, began to change when larger waivers were considered. The significance of the ‘extreme shortfall’ waiver relative to a waiver also conditional on the ‘shortfall’ occurrence represented by scenarios 9 and 10 show this. Both scenarios have the same expected price, however in this instance our results when comparing the effectiveness of each scenario in reducing corn price variability becomes obscured. Table 16 presents the corn prices in all representative states of nature given the larger RFS waiver scenarios 7-12, previously outlined in table 13. As was the case earlier, the 1979 representative yield scenario was unresponsive to waiver changes due to excess corn production. As was the case with the prior scenarios, the COV continually decreased with the implementation of larger waivers, thus representing decreasing corn price variance. At the same time, expected corn price experienced a slight decline as the magnitude of the waivers increased. This minimal change causes the future long-run welfare change to be almost zero. Table 17 is included to better represent the impacts of implementing a waiver relative to the baseline case without waivers.

Comparing scenarios 7 and 10 in regard to the ‘extreme shortfall’ circumstance further shows that the impact of a waiver is diminished given the addition of waivers conditional on the ‘moderate shortfall’ production occurrence. This was also the case found in the smaller waiver scenarios. When a 3 billion gallon waiver is implemented solely in the 2012 state, 2012 state of nature prices are expected to be reduced almost 30%, relative to 25% in the same situation but with a possible 3 billion gallon waiver also employed for the 1993, and 1995 states of nature. This interesting finding shows that the effectiveness of decreasing corn price by employing waivers in the extreme cases is reduced given additional waiver possibilities in less-extreme conditions.

Table 16. U.S. Corn Price by Representative State of Nature given Waiver Scenarios, 7-12

State of Nature	Conventional Ethanol Waiver Scenarios						
	Base	7	8	9	10	11	12
son1979	3.13	3.14	3.14	3.14	3.15	3.15	3.15
son1993[1]	7.86	8.21	8.38	8.49	6.38	6.45	6.62
son1995[1]	6.40	6.94	7.09	7.17	5.29	5.48	5.54
son2002	6.63	6.84	6.95	7.09	7.09	7.17	7.26
son2004	3.48	3.50	3.57	3.62	3.67	3.69	3.73
son2008	4.76	4.80	4.80	4.87	4.91	4.95	4.95
son2009	3.52	3.62	3.64	3.65	3.73	3.79	3.85
son2010	3.82	4.06	4.17	4.26	4.30	4.40	4.53
son2011	4.98	5.01	5.02	5.10	5.17	5.22	5.26
son2012[2]	11.56	8.46	7.09	5.61	8.82	7.26	5.88
Mean*	4.61	4.59	4.57	4.56	4.56	4.54	4.53
COV**	50.92%	44.42%	42.89%	42.22%	41.73%	39.07%	37.91%

Notes: Values are in 2014 USD. [1]Moderate shortfall scenario. [2]Extreme shortfall scenario. *Weighted mean based on representative probabilities. **Coefficient of variance.

Table 17. Percent change from Base of U.S. Corn Price by Representative State of Nature given Waiver Scenarios, 7-12

State of Nature	Conventional Ethanol Waiver Scenarios					
	7	8	9	10	11	12
son1979	0.3%	0.3%	0.3%	0.4%	0.5%	0.6%
son1993[1]	4.8%	7.2%	8.6%	-20.6%	-19.6%	-17.3%
son1995[1]	9.2%	11.7%	13.1%	-18.9%	-15.6%	-14.7%
son2002	3.5%	5.3%	7.5%	7.5%	8.8%	10.4%
son2004	0.7%	2.8%	4.5%	5.9%	6.6%	8.0%
son2008	0.8%	1.0%	2.5%	3.5%	4.5%	4.5%
son2009	2.9%	3.6%	3.8%	6.5%	8.4%	10.2%
son2010	6.9%	10.0%	12.7%	13.7%	16.8%	20.4%
son2011	0.6%	0.9%	2.5%	4.0%	5.1%	6.1%
son2012[2]	-29.3%	-42.2%	-56.2%	-25.8%	-40.6%	-53.6%

Note: [1]Moderate shortfall scenario. [2]Extreme shortfall scenario.

Since corn prices are dependent on the actions of producers in the market, both effects should be simultaneously assessed. A previous meta-analyst was conducted; evaluating 18 long-run ethanol studies to decrease on the ethanol mandates (Condon 2013). Although such analyses did not consider production dependent waiver policy implications, producer response to changes in mandates given all future production instances were found. Comparing the predicted long-run price changes found in this research to the results of this previous research finds both similarities and differences. The researchers found long-run implications of ethanol mandates have smaller impacts relative to short-run cases. Comparing the current results to those in the previous chapter verifies this intuitive result. Also, the meta-analysis found that on average each billion gallon increase in biofuel mandates increase the long-run corn price by 2-3%. Our results and waivers were dependent on the stochastic yield framework, and the magnitude of this relationship was seen to be impacted by production levels. The mean price was not found to increase at the 2-3% rate given 1 billion gallon reductions to the mandate, although in our instance, these were only implemented during poor crop years. In good crop years, when waivers were not implemented, resulting corn acreage reductions from producer reaction actually caused corn price to increase.

Acreage Results

Producer response to policy and future production expectations are pivotal in this analysis. This section presents the key findings in terms of acreage adjustments. Table 18 shows the planted acres in millions of acres for the important U.S. crops by scenario. It is important to point out that crop acres are determined before the yield state of nature is determined, thus are constant across all of the stochastic yield states. They are however impacted by the changes in future expectations, in this case, affected by the ethanol waiver policy. If corn producers expect large ethanol waivers in years of a poor corn crop, the expected future corn price is reduced, limiting the incentive for production. Most evident from this table is the steady decline in corn acreage given RFS policy alternatives with increasing waiver size. This cropland is then allocated to alternative uses, including those included in the table, as well as cropland pasture, rangeland, and an assortment of other crops.

Table 18. Stochastic Model U.S. Crop Acreage in Millions of Acres from 1975 Regressions

	Conventional Ethanol Waiver Scenario											
Crop	Base	2	3	4	5	6	7	8	9	10	11	12
Corn	96.1	95.7	95.4	95.2	94.8	94.6	94.9	94.5	94.3	93.9	93.4	93.3
Soybeans	92.3	92.3	92.3	92.2	92.2	92.3	92.4	92.3	92.5	92.3	92.4	92.6
Wheat*	44.7	44.9	45.3	45.9	46.2	46.4	45.9	46.4	46.5	47.1	47.3	47.6
Cotton	22.9	22.5	22.2	22.0	21.6	21.2	21.4	20.8	20.6	20.9	20.4	20.3
Sorghum	7.3	7.4	7.3	7.3	7.5	6.9	7.9	7.6	7.2	7.6	7.6	7.5

Note: *Includes hard red winter, soft red winter, durum, and hard red spring varieties.

Producer response to decreased expected future corn price primarily shows an increased utilization of wheat to replace the corn acreage. Soybean acreage shows a surprising decrease in acreage as the waivers become more substantial likely due to rotation concerns. The results for cotton also show declines. Sorghum was found to have conflicting results between the two regression scenarios, as shown in table 19, decreasing relative to the waiver size in the 1975 instance and increasing in the 1980 case. The 1980 case also found an absence of production response to the 1 billion gallon waiver used in scenario 1, relative to the four hundred million corn acre response using the 1975 regression.

Table 19. Stochastic Model U.S. Crop Acreage in Millions of Acres from 1980 Regressions

	Conventional Ethanol Waiver Scenario											
Crop	Base	2	3	4	5	6	7	8	9	10	11	12
Corn	97.5	97.5	97.2	97.0	97.1	96.7	96.6	96.0	95.7	96.0	95.5	95.0
Soybeans	91.2	91.2	91.1	91.2	91.2	91.1	91.2	91.4	91.7	91.0	91.0	91.5
Wheat*	43.7	43.7	43.6	43.7	43.7	43.8	43.8	43.5	43.6	43.9	44.0	44.7
Cotton	23.0	23.0	23.0	23.2	23.1	23.2	23.3	22.5	23.0	23.3	22.9	22.8
Sorghum	6.8	6.8	6.8	6.6	6.7	6.6	6.7	6.5	6.4	6.6	6.4	6.4

Note: *Includes hard red winter, soft red winter, durum, and hard red spring varieties.

Concluding Comments

Expected 2015 corn prices were found to slightly decrease with the implementation of larger waiver policies. However, the coefficient of variation in expected long-run 2015 corn price decreased consistently with larger waiver implementations. With respect to small waivers, implementing only in extreme production shortfall conditions was found to reduce corn price variance more effectively relative to a waiver implemented also in less-extreme cases. This is an important finding due to the non-included administrative burden of a policy option enacted more frequently. Larger waiver implementation, in regards to enacting such policy only under extreme conditions, created similar production responses, however presented mixed results relative to a situation where a less extreme waivers were implemented more often. These results depict the market sensitivity towards production variability, presenting a wide range of supply and demand balance circumstances attributed to the stochastic nature of yields. Conventional ethanol mandates, relatively unimportant during years of high yields, present major challenges during production short-fall events. The policy options in this chapter present tools in which we can use ethanol policy to mitigate the economic risk caused by variable crop production.

CHAPTER VI

CONCLUSIONS

According to the USDA, as of 2012, almost half of the U.S. corn crop was being used to produce ethanol with further expansion in the biofuel mandate expected although only a small amount pertaining to conventional ethanol. With the highly fluctuation nature of total U.S. corn crop production but the relatively fixed amount of corn ethanol required, the economic impacts caused by the current RFS policy is of importance to domestic and international stakeholders. Food production sustainability, food security and food affordability should be kept in high regard when assessing the impacts of renewable fuel programs.

This research was designed to investigate the short- and long-run economic implications of the EPA using conventional ethanol waiver policy during large production shortfalls. In order to conduct this research, the first step involved construction of a stationary yield distribution that is assumed to characterize the future with identification of production shortfall conditions. This was done using an econometric procedure over historical yield data. . Subsequently that distribution was used in modeling to analyze short- and long-run RFS relaxation implications. The short-run analysis was based on a shortfall of similar magnitude to that experienced during the drought of 2012, under the RFS requirements as contemplated for 2015, when conventional RFS ethanol mandates reach their upper-bound of 15 billion gallons. In the short run analysis we assume the corn crop is known and fixed so there is no producer response to mandate changes. In that case, significant impacts on prices, production levels, linked markets, and welfare were observed. The mandate relaxations greatly limited the magnitude of price spikes and livestock feeding costs plus redistributed welfare from producers to consumers. The waiver policy was found to reduce short-run total welfare \$18-\$25.4 billion USD.

Although previous research has found that biofuels can be associated with 40% of the increase in corn prices, it is important to note that in the short-run and long-run analyses herein, the results did not suggest elimination of biofuels completely from the market (Searchinger et al. 2008). In the short-run analysis across all scenarios, corn ethanol production was reduced to levels between 4.1-4.9 billion gallons, signaling that production would continue in shortfall conditions without government mandates, but at a much reduced level.

The implications of implementing such a policy over the long run were also investigated. In this instance, market participants would anticipate that waivers would occur when production was low. This was done using a stochastic model that simulated the market under a distribution of yields. In that model, producer decisions were assumed based on the full yield distribution and associated prices. Also, constraints reflecting mandate requirements were altered, conditional on yield shortfalls, with less required under 'shortfall' and 'severe shortfall' years. The primary findings of the long-run analysis illustrated that potential welfare gains could result from such a policy. Price spikes were reduced while expected prices were found to be minimally impacted due to the producer response of decreasing corn acreage. The long-run economic results present a potential for economic gains, stressing the importance of RFS policy risk on agricultural markets.

Across all of these results a philosophical question arises. The U.S. RFS legislation states goals of independence and security in its fuel source. The question is should a similar requirement be in place for the caloric energy needs of the U.S. populace? Moreover, should this be protected under production shortfalls?

Limitations and Future Analysis

There are several limitations to the current analysis, including future ethanol mandates, refining industry, political, environmental, and modelling considerations.

The results generated by this analysis show upcoming corn ethanol mandates induce farmer acreage allocation and impact price spikes. Oil companies and livestock groups are jointly lobbying the US government for a reduction in RFS standards due to a 'blending wall' caused by a natural ethanol consumption limit when only E10 gasoline is considered which limits ethanol consumption to about 13.2 billion gallons without structural or technological changes in the industry (Babcock 2013). Gasoline with ethanol content in excess of 10% (E10) is argued by car manufacturers and oil companies to have adverse effects on many vehicles. Such factors were not considered herein and could be in future research.

Second, relaxations in mandates while benefiting livestock producers and consumers are not viewed favorably by the refining and vehicle manufacturing industries. Such companies do not want to make large capital investments in ethanol related infrastructure if they are unsure of whether mandate relaxations will remove demand for their product or alter the need for vehicles that are capable of using fuels like E85. Agents within the ethanol industry were primarily overlooked in the current analysis. Particularly, in a situation where ethanol mandates become either market driven or dependent on corn production, significant supply risk will be experienced by refiners in an already immature and politically unstable marketplace. This research focused on the implications on agricultural based entities. In order for such a waiver to be considered as an effective policy, impacts on other industry stakeholders must be considered. Such factors were not examined herein and could be in further research.

Additionally, much of the biofuel debate relates to U.S. fossil fuel dependency as well as environmental considerations. Neither of these important aspects were incorporated in the analysis. Although this analysis focused solely on economic implications, RFS policy is dependent on these issues as well. Ethical considerations in regards to impacts towards global food prices and hunger are also important when considering such policy would noticeably affect world food supplies in shortage situations.

In regards to the statistical approaches employed to determine yield variations, a more complex analysis could have been done over the historical data improving the predictions of the future corn production distribution. The sheer number crop-state combinations and number of factors impacting this important production measure renders the inclusion of all possible influences difficult. A balance between data requirements and predictive power must be realized in this instance. However simplistic, the single linear and log method outlined in the above section provides an estimate at the same level of spatial resolution as is employed by the subsequent economic analysis. The inclusion of a yield distribution framework of increased complexity would have made this level of regional precision unattainable, however could have improved the statistical representation of regional impacts. The statistical methods for future yield prediction are an ever-evolving science, as shown by the recent evolution of the techniques used by the USDA and FAPRI in their baseline modelling approaches (FAPRI 1999) and more advanced techniques could be used in future work.

Model Sensitivity

Many of the results presented in this study could be further evaluated for sensitivity of model parameters. Herein, a sensitivity analysis was implemented on regression projections for estimating the future yield distribution. We found the key economic outcomes of the analysis were unaffected by this choice more could be done on these and other assumptions.

Also, the stochastic component of this analysis was limited. Incorporation of the full 1950-2012 historical yield distribution could have provided the stochastic results with increased robustness, particularly concerning regional impacts. Elements that captured the impacts of climate change could have also been used to reflect future yields. As yield variability increases, it can be expected that the incentives for adaptive behavior with respect to cropping technologies will also change. Risk aversion could have also incorporated rather than simply looking at an expected value measure.

Lastly, alternative data assumptions could be used. The baseline prices adopted from the USDA projections could be replaced with other projections as could factors like future demands and oil prices. Additionally, technical production and cost parameters concerning cellulosic ethanol could be varied and these in turn might replace reliance on corn and provide a buffer from production shortfalls. In addition, the impact of the RIN market on the relationship between crop shortfalls and price variability needs to be incorporated into the framework. Although RIN prices remained relatively flat throughout much of the 2012 year, 2013 RIN prices experienced a significant increase due to the pervious supply conditions. This price impact would have implications on future consumer welfare. Future analysis could investigate such factors.

REFERENCES

Adams, D., R. Alig, B. A. McCarl, B. C. Murray, L. Bair, B. Depro, G. Latta, H. Lee, U. A. Schneider, and J. M. Callaway. 2005. "FASOMGHG Conceptual Structure, and Specification: Documentation." *Unpublished Paper. College Station, TX: Texas A&M University, Department of Agricultural Economics*. Available at: http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers/1212FASOMGHG_doc.pdf. (Accessed September 14, 2012).

Alexander, C. and C. Hurt. 2007. *Biofuels and their Impact on Food Prices*. Purdue University Cooperative Extension Service, West Lafayette, IN. ID-346-W. Available at: http://www.ces.purdue.edu/extmedia/ID/ID-346-W.pdf. (Accessed September 1, 2012).

Anderson, D., J. D. Anderson, and J. Sawyer. 2008. "Impact of the Ethanol Boom on Livestock and Dairy Industries: What are they Going to Eat?" *Journal of Agricultural and Applied Economics* 40 (2): 573-579.

Andreadis, K. M. and D. P. Lettenmaier. 2006. "Trends in 20th Century Drought Over the Continental United States." *Geophysical Research Letters* 33(10): L10403, 1-4.

Babcock, B. 2012a. "Preliminary Assessment of the Drought's Impacts on Crop Prices and Biofuel Production." *CARD Policy Brief 12-PB* 7, Iowa State University, Ames, Iowa. Available at: http://www.card.iastate.edu/publications/dbs/pdffiles/12pb7.pdf (Accessed October 20, 2013).

Babcock, B. 2012b. "Updated Assessment of the Drought's Impacts on Crop Prices and Biofuel Production." *CARD Policy Brief 12-PB* 8, Iowa State University, Ames, Iowa. Available at: http://www.card.iastate.edu/publications/dbs/pdffiles/12pb8.pdf. (Accessed December 22, 2013).

Babcock, B. A. 2013. "RFS Compliance Costs and Incentives to Invest in Ethanol Infrastructure." *CARD Policy Brief 13-PB* 13, Iowa State University, Ames, Iowa. Available at: http://www.card.iastate.edu/publications/DBS/PDFFiles/13pb13.pdf (Accessed October 19, 2013).

Baker, J. S., B. C. Murray, B. A. McCarl, S. Feng, and R. Johansson. 2013. "Implications of Alternative Agricultural Productivity Growth Assumptions on Land Management, Greenhouse Gas Emissions, and Mitigation Potential." *American Journal of Agricultural Economics* 95 (2): 435-441.

Beach, R. H. and B. A. McCarl. 2010. "US Agricultural and Forestry Impacts of the Energy Independence and Security Act: FASOM Results and Model Description."

Research Triangle Park, NC: RTI International. Available at: https://rti.org/pubs/fasom_technical_report_-_rfs2_frm.pdf. (Accessed September 19, 2011).

Butt, T. A., B. A. McCarl, J. Angerer, P. T. Dyke, and J. W. Stuth. 2005. "The Economic and Food Security Implications of Climate Change in Mali." *Climatic Change* 68 (3): 355-378.

Carter, C., G. Rausser, and A. Smith. 2012. "The Effect of the US Ethanol Mandate on Corn Prices." *Department of Agricultural and Resource Economics, UC Davis, CA.* Available at: http://Agecon.Ucdavis.Edu/People/Faculty/Aaronsmith/Docs/Carter_Rausser_Smith_Ethanol_Paper_submit.Pdf. (Accessed January 29, 2013).

Cerrato, M. E. and A. M. Blackmer. 1990. "Comparison of Models for Describing; Corn Yield Response to Nitrogen Fertilizer." *Agronomy Journal* 82(1): 138-143.

Challinor, A. J., J. M. Slingo, T. R. Wheeler, P. Q. Craufurd, and D. I. F. Grimes. 2003. "Toward a Combined Seasonal Weather and Crop Productivity Forecasting System: Determination of the Working Spatial Scale." *Journal of Applied Meteorology* 42 (2): 175-192.

Chen, C., B. McCarl, and H. Hill. 2002. "Agricultural Value of ENSO Information Under Alternative Phase Definition." *Climatic Change* 54(3): 305-325.

Chen, C., D. Gillig, and B. A. McCarl. 2001. "Effects of Climatic Change on a Water Dependent Regional Economy: A Study of the Texas Edwards Aquifer." *Climatic Change* 49(4): 397-409.

Chen, C. and B. A. McCarl. 2000. "The Value of ENSO Information to Agriculture: Consideration of Event Strength and Trade." *Journal of Agricultural & Resource Economics* 25(2): 368-385.

Chen, C., B. A. McCarl, and R. M. Adams. 2001. "Economic Implications of Potential ENSO Frequency and Strength Shifts." *Climatic Change* 49(1-2): 147-159.

Chen, X., M. Khanna, H. Huang, and H. Önal. 2012. "Meeting the Mandate for Biofuels: Implications for Land use, Food, and Fuel Prices." Paper presented at NBER Agricultural Economics conference, March 4–5, Cambridge, MA. Available at: http://www.researchgate.net/publication/228285699_Meeting_the_Mandate_for_Biofuels_Implications_for_Land_Use_Food_and_Fuel_Prices/file/3deec526934f9af7a1.pdf. (Accessed October 19, 2013).

Chen, C., B. A. McCarl, and D. E. Schimmelpfennig. 2004. "Yield Variability as Influenced by Climate: A Statistical Investigation." *Climatic Change* 66(1-2): 239-261.

Cocks, K. D. 1968. "Discrete Stochastic Programming." *Management Science* 15(1): 72-79.

Dantzig, G. B. 1955. "Linear Programming Under Uncertainty." *Management Science* 1(3-4): 197-206.

de Gorter, H., D. Drabik, and D. R. Just. 2013. "Policy Update: Policy Implications of High RIN Prices and the'Blend Wall'." *Biofuels* 4(4): 359-361.

Dyson, T. 1999. "World Food Trends and Prospects to 2025." *Proceedings of the National Academy of Sciences of the United States of America* 96(11): 5929-5936.

Elobeid, A., S. Tokgoz, D. J. Hayes, B. A. Babcock, and C. E. Hart. 2006. *The Long-Run Impact of Corn-Based Ethanol on the Grain, Oilseed, and Livestock Sectors: A Preliminary Assessment*, Center for Agricultural and Rural Development, Iowa State University. Available at: http://www.card.iastate.edu/publications/synopsis.aspx?id=1029. (Accessed February 19, 2013).

Epplin, F. M. and M. Haque. 2011. "Policies to Facilitate Conversion of Millions of Acres to the Production of Biofuel Feedstock." *Journal of Agriculture and Applied Economics* 43: 385-398.

Fabiosa, J. F., J. C. Beghin, F. Dong, A. Elobeid, S. Tokgoz, and T. Yu. 2010. "Land Allocation Effects of the Global Ethanol Surge: Predictions from the International FAPRI Model." *Land Economics* 86(4): 687-706.

FAPRI. 1999. "Trend Yield Analysis and Yield Growth Assumptions." *Agricultural Policy Research Institute,(1999) FAPRI-UMC Report# 06-99, June. FAPRI at the University of Missouri*. Available at: http://www.fapri.missouri.edu/outreach/publications/1999/FAPRI_UMC_Report_06_99.pdf. (Accessed October 4, 2013).

Feng, S. 2012.*Three Essays on Agricultural and Forestry Offsets in Climate Change Mitigation*. PhD Dissertation, Texas A&M University, Department of Agricultural Economics, College Station, Texas.

Golub, A. A., T. W. Hertel, A. D. Jones, M. O'Hare, R. J. Plevin, and D. M. Kammen. 2010. "Effects of US Maize Ethanol on Global Land use and Greenhouse Gas Emissions: Estimating Market- Mediated Responses." *Bioscience* 60(3): 223-231.

Griliches, Z. 1957. "Hybrid Corn: An Exploration in the Economics of Technological Change." *Econometrica* 25(4): 501-522.

Hafner, S. 2003. "Trends in Maize, Rice, and Wheat Yields for 188 Nations Over the Past 40 Years: A Prevalence of Linear Growth." *Agriculture, Ecosystems & Environment* 97(1–3): 275-283.

Havlík, P., H. Valin, A. Mosnier, M. Obersteiner, J. S. Baker, M. Herrero, M. C. Rufino, and E. Schmid. 2013. "Crop Productivity and the Global Livestock Sector: Implications for Land use Change and Greenhouse Gas Emissions." *American Journal of Agricultural Economics* 95(2): 442-448.

Havlík, P., U. A. Schneider, E. Schmid, H. Böttcher, S. Fritz, R. Skalský, K. Aoki, et al. 2011. "Global Land-use Implications of First and Second Generation Biofuel Targets." *Energy Policy* 39(10): 5690-5702.

Hazell, P. B. R. 1984. "Sources of Increased Instability in Indian and U.S. Cereal Production." *American Journal of Agricultural Economics* 66(3): 302-311.

Hertel, T. W., W. E. Tyner, and D. K. Birur. 2010. "The Global Impacts of Biofuel Mandates." *Energy Journal* 31(1): 75-100.

Hoerling, M., A. Kumar, R. Dole, J. Nielsen-Gammon, J. Eischeid, J. Perlwitz, X. Quan, T. Zhang, P. Pegion, and M. Chen. 2013. "Anatomy of an Extreme Event." *Journal of Climate* 26(9): 2811-2832.

Horie, T., M. Yajima, and H. Nakagawa. 1992. "Yield Forecasting." *Agricultural Systems* 40(1–3): 211-236.

Isik, M. and S. Devadoss. 2006. "An Analysis of the Impact of Climate Change on Crop Yields and Yield Variability." *Applied Economics* 38(7): 835-844.

Lambert, D. K. and B. A. McCarl. 1985. "Risk Modeling using Direct Solution of Nonlinear Approximations of the Utility Function." *American Journal of Agricultural Economics* 67(4): 846-852.

Lambert, D. K., B. A. McCarl, Q. He, M. S. Kaylen, W. Rosenthal, C. Chang, and W. I. Nayda. 1995. "Uncertain Yields in Sectoral Welfare Analysis: An Application to Global Warming." *Journal of Agricultural and Applied Economics* 27(2): 423-236.

Lambin, E. F. and P. Meyfroidt. 2011. "Global Land use Change, Economic Globalization, and the Looming Land Scarcity." *Proceedings of the National Academy of Sciences* 108(9): 3465-3472.

Lambin, E. F., B. L. Turner, H. J. Geist, S. B. Agbola, A. Angelsen, J. W. Bruce, O. T. Coomes, et al. 2001. "The Causes of Land-use and Land-Cover Change: Moving Beyond the Myths." *Global Environmental Change* 11(4): 261-269.

Lott, J. N. 1994. "The US Summer of 1993: A Sharp Contrast in Weather Extremes." *Weather* 49(11): 370-383.

Mallory, M. L., D. J. Hayes, and B. A. Babcock. 2011. "Crop-Based Biofuel Production with Acreage Competition and Uncertainty." *Land Economics* 87(4): 610-627.

McCarl, B. A., X. Villavicencio, and X. Wu. 2008. "Climate Change and Future Analysis: Is Stationarity Dying?" *American Journal of Agricultural Economics* 90 (5): 1241-1247.

McPhail, L. and B. A. Babcock. 2008. *Ethanol, Mandates, and Drought: Insights from a Stochastic Equilibrium Model of the US Corn Market*. Working Paper 08-WP 464 ed. Center for Agricultural and Rural Development.

McPhail, L. 2011. "Assessing the Impact of US Ethanol on Fossil Fuel Markets: A Structural VAR Approach." *Energy Economics* 33(6): 1177-1185.

Mu, J. E., B. A. McCarl, and A. M. Wein. 2013. "Adaptation to Climate Change: Changes in Farmland use and Stocking Rate in the US." *Mitigation and Adaptation Strategies for Global Change* 18(6): 713-730.

Murray, B. C., B. A. McCarl, and H. Lee. 2004. "Estimating Leakage from Forest Carbon Sequestration Programs." *Land Economics* 80(1): 109-124.

Muth, J. F. 1961. "Rational Expectations and the Theory of Price Movements." *Econometrica: Journal of the Econometric Society* 29(3): 315-335.

National Oceanic and Atmospheric Administration. 2012. "Extreme Weather 2011." United States Department of Commerce. Available at: http://www.noaa.gov/extreme2011/. (Accessed October 11, 2013).

Plevin, RJ. 2010. "Review of Final RFS2 Analysis." *Energy and Resources Group, University of California, Berkeley, CA, USA.*

Potgieter, A. B., G. L. Hammer, and D. Butler. 2002. "Spatial and Temporal Patterns in Australian Wheat Yield and their Relationship with ENSO." *Australian Journal of Agricultural Research* 53 (1): 77-89.

Prasad, Anup K., Lim Chai, Ramesh P. Singh, and Menas Kafatos. 2006. "Crop Yield Estimation Model for Iowa using Remote Sensing and Surface Parameters."

International Journal of Applied Earth Observation and Geoinformation 8(1): 26-33.

Rae, A. N. 1971. "Stochastic Programming, Utility, and Sequential Decision Problems in Farm Management." *American Journal of Agricultural Economics* 53(3): 448-460.

Reilly, J., F. Tubiello, B. McCarl, D. Abler, R. Darwin, K. Fuglie, S. Hollinger, et al. 2003. "U.S. Agriculture and Climate Change: New Results." *Climatic Change* 57 (1-2): 43-67.

Rosegrant, M. W., S. Tokgoz, and P. Bhandary. 2013. "The New Normal? A Tighter Global Agricultural Supply and Demand Relation and its Implications for Food Security." *American Journal of Agricultural Economics* 95(2): 303-309.

Rupp, D. E., P. Mote, N. Massey, C. Rye, R. Jones, and M. Allen. 2012. "Did Human Influence on Climate make the 2011 Texas Drought More Probable?" *Bulletin of the American Meteorological Society* 93(7): 1052-1067.

Schlenker, W. and M. J. Roberts. 2009. "Nonlinear Temperature Effects Indicate Severe Damages to U.S. Crop Yields Under Climate Change." *Proceedings of the National Academy of Sciences* 106(37): 15594-15598.

Schnepf, R. and B. D. Yacobucci. 2011. *Renewable Fuel Standard (RFS): Overview and Issues*. Congressional Research Service Report, R40155. DIANE Publishing Co.

Searchinger, T., R. Heimlich, R. A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T. Yu. 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-use Change." *Science* 319(5867): 1238-1240.

Shaw, R. H. and W. E. Loomis. 1950. "Bases for the Prediction of Corn Yields." *Plant Physiology* 25(2): 225-244.

Sorda, G., M. Banse, and C. Kemfert. 2010. "An Overview of Biofuel Policies Across the World." *Energy Policy* 38(11): 6977-6988.

Southworth, J., J. C. Randolph, M. Habeck, O. C. Doering, R. A. Pfeifer, D. G. Rao, and J. J. Johnston. 2000. "Consequences of Future Climate Change and Changing Climate Variability on Maize Yields in the Midwestern United States." *Agriculture, Ecosystems & Environment* 82(1–3): 139-158.

Suttles, S. A., W. E. Tyner, G. Shively, R. D. Sands, and B. Sohngen. 2014. "Economic Effects of Bioenergy Policy in the United States and Europe: A General Equilibrium Approach Focusing on Forest Biomass." *Renewable Energy* 69(0): 428-436.

Taheripour, F., T. W. Hertel, W. E. Tyner, J. F. Beckman, and D. K. Birur. 2010. "Biofuels and their by-Products: Global Economic and Environmental Implications." *Biomass and Bioenergy* 34(3): 278-289.

Taheripour, F. and W. E. Tyner. 2013. "Welfare Assessment of the Renewable Fuel Standard: Economic Efficiency, Rebound Effect, and Policy Interactions in a General Equilibrium Framework." Paper prepared for presentation at the 15th Annual Conference on Global Economic Analysis, Geneva, Switzerland June 27-29, 2012. Available at: https://www.gtap.agecon.purdue.edu/resources/download/6001.pdf. (Accessed March 11, 2014).

Thompson, L. M. 1986. "Climatic Change, Weather Variability, and Corn Production." *Agronomy Journal* 78(4): 649-653.

Thompson, W., S. Meyer, and P. Westhoff. 2009a. "How does Petroleum Price and Corn Yield Volatility Affect Ethanol Markets with and without an Ethanol use Mandate?" *Energy Policy* 37(2): 745-749.

———. 2009b. "Renewable Identification Numbers are the Tracking Instrument and Bellwether of US Biofuel Mandates." *EuroChoices* 8(3): 43-50.

Tollenaar, M. and J. Wu. 1999. "Yield Improvement in Temperate Maize is Attributable to Greater Stress Tolerance." *Crop Science* 39(6): 1597-1604.

Tweeten, L. 1998. "Dodging a Malthusian Bullet in the 21st Century." *Agribusiness* 14 (1): 15-32.

Tyner, W. E. 2013. "Policy Update: The US Renewable Fuel Standard Up Against the Wall." *Biofuels* 4(5): 475-477.

Tyner, W. E., F. Taheripour, and C. Hurt. 2012. "Potential Impacts of a Partial Waiver of the Ethanol Blending Rules." Farm Foundation, Purdue University. Available at: http://www.farmfoundation.org/news/articlefiles/1841-wiaver%20impacts3%20FINAL.pdf. (Accessed November 19, 2013).

Tyner, W. E., F. Taheripour, Q. Zhuang, D. Birur, and U. Baldos. 2010. "Land use Changes and Consequent CO2 Emissions due to US Corn Ethanol Production: A Comprehensive Analysis." *Technical Report, Department of Agricultural Economics, Purdue University, April*. Available at: https://ethanol.org/pdf/contentmgmt/Purdue_new_ILUC_report_April_2010.pdf. (Accessed August 19, 2013).

Tyner, W. E., F. Taheripour, and D. Perkis. 2010. "Comparison of Fixed Versus Variable Biofuels Incentives." *Energy Policy* 38(10): 5530-5540.

U.S. Congress. 2007. "Energy Independence and Security Act of 2007." *Public Law, H.R. 6, 110th Congress, December 19 2007,* (110-140). Available at: http://frwebgate.access.gpo.gov/cgibin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6eas2.txt.pdf. (Accessed March 12, 2013).

———. 2005. "Energy Policy Act of 2005." *Public Law, 109th Congress, August 8th 2005,* (109-58). Available at: http://www.gpo.gov/fdsys/pkg/PLAW-109publ58/html/PLAW-109publ58.htm. (Accessed March 12, 2013)

U.S. Energy Information Administration. 2014. "Monthly Energy Review." Available at: http://www.eia.gov/totalenergy/data/monthly/#renewable. (Accessed March 19, 2014).

U.S. Environmental Protection Agency. 2013. "40 CFR Part 80. Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program; Proposed Rule." Available at: http://www.epa.gov/otaq/renewablefuels/rfs2_1-5.pdf. (Accessed March 20, 2014).

U.S. Environmental Protection Agency. 2014. "2013 RFS2 Data.", Available at: http://www.epa.gov/otaq/fuels/rfsdata/2013emts.htm. (Accessed March 22, 2014).

United States Department of Agriculture, Office of the Chief Economist, World Agricultural Outlook Board. 2013. "USDA Agricultural Projections to 2022." Prepared by the Interagency Agricultural Projections Committee. Available at: http://usda.mannlib.cornell.edu/usda/ers/94005/2013/OCE131.pdf. (Accessed March 9, 2013).

United States Department of Agriculture. 2014. "National Agricultural Statistics Service - Quick Stats - Corn Condition." Available at: http://quickstats.nass.usda.gov/. (Accessed March 19, 2014).

Wallander, S., R. Claassen, and C. Nickerson. 2011. "The Ethanol Decade: An Expansion of US Corn Production, 2000-09." *USDA-ERS Economic Information Bulletin* (EIB-79). Available at: http://www.ers.usda.gov/ersDownloadHandler.ashx?file=/media/121204/eib79.pdf. (Accessed March 22, 2014).

Wendroth, O., D. R. Nielsen, A. M. Al-Omran, C. Kirda, and K. Reichardt. 1992. "State-Space Approach to Spatial Variability of Crop Yield." *Soil Science Society of America Journal* 56(3): 801-807.

APPENDIX

Table A1. Percentage Deviations from Expected Yield of Major U.S. State-Crop Pairs for 2012 Shortfall using 1980-2012 Regression

	Corn	Cotton	Hay	Oats	Sorghum	Soybeans	Wheat
California	-2.11%	9.67%	-3.87%	-3.66%			9.72%
Iowa	-21.23%		-25.11%	-8.46%		-11.94%	-0.02%
Texas	-0.47%	-10.72%	-5.49%	8.73%	4.54%	-5.96%	3.34%
Nebraska	-13.49%		-30.58%	-13.49%	-30.10%	-19.57%	-2.20%
Illinois	-36.29%		-17.61%	4.70%	-36.02%	-10.83%	2.43%
Minnesota	-5.18%		-16.52%	-2.40%		0.99%	13.76%
Kansas	-27.59%	-12.10%	-30.25%	-31.59%	-43.47%	-34.92%	3.50%
North Carolina	6.18%	18.99%	4.42%	5.94%		21.20%	5.78%
Indiana	-36.66%		-23.23%	1.70%		-10.67%	-1.01%
Missouri	-44.20%	-2.11%	-24.89%	-6.23%	-33.49%	-25.27%	8.31%

Note: Expected yields are the fitted values found using 1980-2015 a regression period.

Table A2. Percentage Deviations from Expected Yield of Major U.S. State-Crop Pairs for 2012 Shortfall using 1990-2012 Regression

	Corn	Cotton	Hay	Oats	Sorghum	Soybeans	Wheat
California	-0.2%	9.3%	-3.3%	-3.0%			6.8%
Iowa	-22.5%		-24.9%	-9.5%		-11.6%	-2.6%
Texas	0.2%	-11.9%	-0.9%	9.6%	5.2%	-1.8%	6.4%
Nebraska	-14.0%		-28.8%	-12.9%	-29.2%	-19.2%	-7.1%
Illinois	-35.6%		-13.8%	1.9%	-32.3%	-9.6%	-1.7%
Minnesota	-5.8%		-13.1%	-5.7%		1.0%	4.9%
Kansas	-22.2%	-15.7%	-25.9%	-28.8%	-40.0%	-32.5%	3.6%
North Carolina	6.2%	18.3%	11.7%	6.5%		22.3%	6.6%
Indiana	-35.8%		-18.6%	-0.1%		-8.6%	-2.6%
Missouri	-41.5%	-3.3%	-20.3%	-3.9%	-29.4%	-23.1%	6.3%

Note: Expected yields are the fitted values found using 1990-2015 a regression period.

Table A3. Corn and Soybean Price Results for 2015 using the 1975-2015 Regression

	RFS Scenario	Base	RFS	%Δ from Base	RFS Relaxed	%Δ from Base
Corn Price /bu	Final Rule	$5.92	$11.46	94%	$6.65	12%
	Full Cellulosic	$6.01	$11.45	91%	$6.47	8%
	No Cellulosic	$5.98	$11.64	95%	$6.36	6%
Soybean Price /bu	Final Rule	$12.17	$12.61	4%	$14.05	15%
	Full Cellulosic	$12.26	$12.77	4%	$14.19	16%
	No Cellulosic	$12.24	$12.70	4%	$14.28	17%

Notes: Results are calculated using the 2012 yield residuals from the 1975-2012 regression period. Prices in 2014 US Dollars.

Table A4. Shortfall Condition Corn and Soybean Prices for 2015, 1980 Regression

	RFS Scenario	Base	RFS	%□ from Base	RFS Relaxed	%□ from Base
Corn Price /bu	Final Rule	$5.92	$11.47	94%	$6.69	13%
	Full Cellulosic	$6.01	$11.48	91%	$6.50	8%
	No Cellulosic	$5.98	$11.63	95%	$6.39	7%
Soybean Price /bu	Final Rule	$12.17	$12.70	4%	$14.10	16%
	Full Cellulosic	$12.26	$12.81	5%	$14.31	17%
	No Cellulosic	$12.24	$12.80	5%	$14.31	17%

Notes: Results are calculated using the 2012 yield residuals from the 1980-2012 regression period. Prices in 2014 US Dollars.

Table A5. Shortfall Condition Corn and Soybean Prices for 2015, 1990 Regression

	RFS Scenario	Base	RFS	%□ from Base	RFS Relaxed	%□ from Base
Corn Price /bu	Final Rule	$5.92	$11.64	97%	$6.72	13%
	Full Cellulosic	$6.01	$11.67	94%	$6.61	10%
	No Cellulosic	$5.98	$11.72	96%	$6.44	8%
Soybean Price /bu	Final Rule	$12.17	$12.55	3%	$14.08	16%
	Full Cellulosic	$12.26	$12.70	4%	$14.19	16%
	No Cellulosic	$12.24	$12.70	4%	$14.31	17%

Notes: Results are calculated using the 2012 yield residuals from the 1990-2012 regression period. Prices in 2014 US Dollars.

Table A6. Production and Price Indices Following 2015 Shortfall, 1975-2012 Regression Period

		Price Index		Production Index	
Commodity Index	Scenario	RFS	RFS Relaxed	RFS	RFS Relaxed
Crop	Final Rule	134.2	110.2	87.1	88.1
	Full Cellulosic	133.6	109.0	87.3	88.3
	No Cellulosic	134.5	109.1	86.9	88.0
Livestock	Final Rule	123.3	119.1	93.6	98.2
	Full Cellulosic	124.2	117.2	93.8	98.7
	No Cellulosic	122.4	117.4	93.4	98.6
Meat	Final Rule	117.4	104.0	89.6	95.9
	Full Cellulosic	117.2	103.8	89.8	96.3
	No Cellulosic	117.5	103.4	89.6	96.2

Notes: Index values are relative to the baseline expected yield scenario. Results are calculated using the 2012 yield residuals from the 1975-2012 regression period.

Table A7. Production and Price Indices Following 2015 Shortfall, 1980-2012 Regression Period

Commodity Index	Scenario	Price Index RFS	Price Index RFS Relaxed	Production Index RFS	Production Index RFS Relaxed
Crop	Final Rule	134.7	110.6	87.1	88.2
	Full Cellulosic	134.2	109.6	87.3	88.3
	No Cellulosic	134.9	109.3	86.9	88.1
Livestock	Final Rule	120.7	115.1	93.7	98.1
	Full Cellulosic	120.5	116.1	93.9	98.5
	No Cellulosic	120.1	116.0	93.4	98.3
Meat	Final Rule	117.4	104.0	89.7	96.3
	Full Cellulosic	117.3	103.6	89.9	96.6
	No Cellulosic	117.5	103.1	89.7	96.8

Notes: Index values are relative to the baseline expected yield scenario. Results are calculated using the 2012 yield residuals from the 1980-2012 regression period.

Table A8. Production and Price Indices Following 2015 Shortfall, 1990-2012 Regression Period

Commodity Index	Scenario	Price Index RFS	Price Index RFS Relaxed	Production Index RFS	Production Index RFS Relaxed
Crop	Final Rule	134.8	110.6	87.4	88.7
	Full Cellulosic	134.6	109.8	87.5	88.7
	No Cellulosic	136.8	109.4	87.2	88.5
Livestock	Final Rule	116.8	109.6	93.3	98.2
	Full Cellulosic	118.5	109.6	93.5	98.4
	No Cellulosic	118.5	109.0	93.2	98.7
Meat	Final Rule	117.0	103.5	89.9	96.9
	Full Cellulosic	116.9	103.2	90.1	97.2
	No Cellulosic	117.0	102.6	89.8	97.6

Notes: Index values are relative to the baseline expected yield scenario. Results are calculated using the 2012 yield residuals from the 1990-2012 regression period.

Table A9. Alternative Regression 2015 Corn Price in dollars/bu Sensitivity to Crop Ethanol Mandates Given 2012 Shortfall

Crop Ethanol Mandate (billion gallons)	Normal Yields	2012 Drought Regression Scenarios		
		1975-2012	1980-2012	1990-2012
15	$5.92	$11.46	$11.47	$11.64
14	$5.69	$10.69	$10.74	$10.88
13	$5.65	$10.00	$10.03	$10.22
12	$5.65	$9.70	$9.75	$9.86
11	$5.65	$9.10	$9.26	$9.34
10	$5.65	$8.57	$8.66	$8.81
9	$5.65	$8.15	$8.21	$8.32
8	$5.65	$7.77	$7.85	$8.02
7	$5.65	$7.46	$7.55	$7.72
Relaxed (0)	$5.65	$6.64	$6.69	$6.72

Notes: RFS scenario 1 with final rule cellulosic of 6.5 million gallons. Prices shown in 2014 US Dollars.

Table A10. Corn Price in dollars/bu Sensitivity to Crop Ethanol Mandates with full RFS2, 2015 Estimates from 1950-2012 Regression

Crop Ethanol Mandate (billion gallons)	Normal Yields	2012 Drought Yields
15	$6.07	$11.57
14	$5.76	$10.80
13	$5.73	$10.08
12	$5.47	$9.80
11	$5.18	$9.19
10	$5.12	$8.67
9	$5.12	$8.28
8	$5.12	$7.88
7	$5.12	$7.58
Relaxed (0)	$5.12	$6.53

Note: RFS Scenario with full RFS2 cellulosic mandates from 1950-2012 regression.

Table A11. Corn Price in dollars/bu and Crop Ethanol Mandates with Full Cellulosic, 2015

2015 Crop Ethanol Mandate (billion gallons)	Normal Yields	2012 Drought Yields
15	$6.01	$11.45
14	$5.70	$10.69
13	$5.67	$9.98
12	$5.42	$9.70
11	$5.13	$9.10
10	$5.07	$8.58
9	$5.07	$8.20
8	$5.07	$7.80
7	$5.07	$7.50
Relaxed (0)	$5.07	$6.46

Notes: RFS Scenario 2 with RFS2 cellulosic mandates. Results are calculated using the 1975-2012 drought regression scenario. Prices in 2014 US Dollars.

Table A12. Consumer Welfare in 2015 using 1975-2012 Regression

Region	BASE	RFS	Relax	% Change of Relax
Southwest	261.74	257.57	259.88	
Corn Belt	493.13	485.27	489.63	
Northern Plains	74.88	73.69	74.35	
Lake States	252.50	248.47	250.70	
Northeast	792.09	779.47	786.46	
Rocky Mountains	189.16	186.15	187.82	
Pacific Southwest	396.59	390.27	393.78	
Pacific Northwest	101.21	99.59	100.49	
South Central	331.67	326.38	329.31	
Southeast	484.40	476.68	480.96	
Total	3,377.37	3,323.55	3,353.37	0.90%

Note: Values shown in 2014 billions of US dollars.

Table A13. Consumer Welfare in 2015 using 1980 and 1990 Regression

Region	BASE	1980 RFS	1980 LAX	1990 RFS	1990 LAX
Southwest	261.74	257.71	260.03	258.00	260.37
Corn Belt	493.13	485.54	489.92	486.10	490.56
Northern Plains	74.88	73.73	74.39	73.81	74.49
Lake States	252.50	248.61	250.85	248.89	251.18
Northeast	792.09	779.91	786.94	780.79	787.97
Rocky Mountains	189.16	186.25	187.93	186.46	188.18
Pacific Southwest	396.59	390.49	394.01	390.94	394.53
Pacific Northwest	101.21	99.65	100.55	99.76	100.68
South Central	331.67	326.56	329.51	326.93	329.94
Southeast	484.40	476.95	481.25	477.49	481.88
Total	3,377.37	3,325.40	3,355.39	3,329.19	3,359.78

Notes: Values shown in 2014 billions of US dollars. LAX represents the relaxed biofuel scenario.

Table A14. Producer Welfare in 2015 using 1975-2012 Regression

Region	BASE	RFS	Relax	% Change of Relax
Southwest	3.26	5.81	6.91	19.09%
Corn Belt	20.43	37.07	12.64	-65.89%
Northern Plains	11.51	24.00	10.17	-57.64%
Lake States	6.26	18.52	7.52	-59.38%
Northeast	1.14	2.50	2.13	-14.70%
Rocky Mountains	7.59	12.30	11.26	-8.48%
Pacific Southwest	3.03	3.51	3.93	11.97%
Pacific Northwest	1.57	3.38	2.79	-17.50%
South Central	3.38	7.42	4.67	-37.04%
Southeast	3.51	6.32	5.40	-14.56%
Total	61.67	120.82	67.43	-44.19%

Note: Values shown in 2014 billions of US dollars.

Table A15. Producer Welfare in 2015 using 1980 and 1990 Regression

Region	BASE	1980 RFS	1980 LAX	1990 RFS	1990 LAX
Southwest	3.26	5.62	6.57	4.84	5.78
Corn Belt	20.43	36.59	12.58	36.97	12.45
Northern Plains	11.51	23.81	10.53	24.06	10.62
Lake States	6.26	18.36	7.56	18.34	7.48
Northeast	1.14	2.23	2.02	1.76	1.74
Rocky Mountains	7.59	9.34	10.73	8.34	9.80
Pacific Southwest	3.03	3.32	3.79	2.96	3.53
Pacific Northwest	1.57	3.25	2.66	2.99	2.40
South Central	3.38	7.02	4.32	6.83	4.03
Southeast	3.51	4.51	5.21	4.35	4.92
Total	61.67	114.05	65.99	111.44	62.74

Notes: Values shown in 2014 billions of US dollars. LAX represents the relaxed biofuel scenario.

Table A16. Total Welfare in 2015 using 1975-2012 Regression

Region	BASE	RFS	Relax	% Change of Relax
Southwest	265.00	263.37	266.79	1.30%
Corn Belt	513.56	522.34	502.27	-3.84%
Northern Plains	86.39	97.69	84.52	-13.48%
Lake States	258.76	267.00	258.23	-3.29%
Northeast	793.23	781.97	788.59	0.85%
Rocky Mountains	196.75	198.45	199.08	0.32%
Pacific Southwest	399.62	393.79	397.71	1.00%
Pacific Northwest	102.78	102.97	103.27	0.29%
South Central	335.05	333.80	333.98	0.05%
Southeast	487.91	483.01	486.36	0.70%
Total	3,439.03	3,444.37	3,420.80	-0.68%

Note: Values shown in 2014 billions of US dollars.

Table A17. Total Welfare in 2015 using 1980 and 1990 Regression

Region	BASE	1980 RFS	1980 LAX	1990 RFS	1990 LAX
Southwest	265.00	263.33	266.61	262.85	266.15
Corn Belt	513.56	522.13	502.50	523.07	503.02
Northern Plains	86.39	97.54	84.93	97.87	85.11
Lake States	258.76	266.97	258.41	267.23	258.66
Northeast	793.23	782.13	788.96	782.55	789.71
Rocky Mountains	196.75	195.59	198.67	194.80	197.97
Pacific Southwest	399.62	393.82	397.80	393.90	398.05
Pacific Northwest	102.78	102.90	103.21	102.75	103.08
South Central	335.05	333.58	333.83	333.77	333.97
Southeast	487.91	481.46	486.46	481.84	486.80
Total	3,439.03	3,439.46	3,421.37	3,440.63	3,422.52

Notes: Values shown in 2014 billions of US dollars. LAX represents the relaxed biofuel scenario.