THE EFFECT OF TECHNOLOGICAL PROGRESS, DEMAND, AND ENERGY POLICY ON AGRICULTURAL AND BIOENERGY MARKETS

A Dissertation

by

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ABSTRACT

Agricultural technological progress is a key factor in our ability to meet future demand growth for consumers and biofuel usage. This study investigates the consequences of agricultural technological progress, biofuel policy, and agricultural demand growth on crop, livestock, and bioenergy markets, as well as resource usage and greenhouse gas (GHG) emissions.

The study was done in three phases. In the first phase, estimates were constructed of the technological progress rates over time and their possible recent decline. The crop yield growth rate was estimated for six major field crops over U.S. crop yield data from 1950 to 2014. In the second phase, we formed scenarios for future technological progress, demand growth, and biofuel policy, where the technological progress scenarios were based on the estimates from the time series analysis. In the third phase, a dynamic simulation was carried out to investigate how the technological progress influenced markets, resource usage, and emissions.

The major findings are as follows: 1) A slowdown in technical progress was found in recent years, particularly for corn, cotton, and winter wheat; 2) Non-uniform technical progress was found across regions, especially for cotton and soybeans; 3) Technical progress across regions in most cases was found to be positively correlated; 4) Technological progress and biofuel policy were found to have significant impacts on U.S. cropland use where an increase in technological progress reduces cropland for biofuel and cropland pasture for livestock but increases cropland for crop production; 5)

Reducing corn ethanol requirements causes more cropland to move from cropping to pasture uses for livestock. However lowering ethanol from corn residue has minor effects on cropland use; 6) Lowering the requirement of ethanol from corn, lowers the price for most of the field crops and meat commodities, especially corn, hay, sorghum, and non-fed beef; 7) Technological progress and biofuel policy have significant effects of on GHG emissions. Increasing technical progress reduces overall GHG emissions. Lower corn ethanol level results in much larger GHG emissions as compared with the control case. This implies producing corn ethanol is effective in reducing emissions; and 8) technological improvement is a key factor in meeting growing global demand for food and energy and reducing emissions.

DEDICATION

I dedicate my dissertation to my beloved parents, Sarinya and Vudtechai Kapilakanchana and brother, Piyawat Kapilakanchana. I also dedicate my work to my grandparents, Somsong and Harn Haritavorn, and Pairoh and Aumphorn Kapilakanchana.

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CHAPTER I

INTRODUCTION

Besides the basic roles as a food supplier for mankind, the agricultural sector is playing an important role as a source of feedstocks for bioenergy production. Production and processing of agricultural commodities for bioenergy have gained a lot of attention because bioenergy is renewable and potentially beneficial in reducing greenhouse gas (GHG) emissions (IPCC 2007). In the United States, the production of bioenergy has increased with the implementation of the renewable fuel standard (RFS).

The RFS is a federal biofuel program the goals of which are to support a reduction in GHG emissions and improve U.S. energy stability and sustainability. The program sets a mandatory level of renewable fuel blended into transportation fuel. The eligible forms of renewable fuel in the program are required to have a lower level of GHG emissions compared to petroleum-based fuels. The RFS program was initially established under the Energy Policy Act (EPAct) of 2005 and then was extended by the Energy Independence and Security Act (EISA) of 2007. EISA raised the requirement for the amount of renewable fuel blended from 9 billion gallons in 2008 to 36 billion gallons by 2022 although progress toward this has been slower than anticipated. The RFS requirements for renewable fuel blending have stimulated increased biofuel production.

Up until now the main volume of biofuels used to satisfy the RFS requirement have been produced from corn which is also the primary U.S. feed grain for livestock (see figure 1), and , in turn, this affects human food supplies. The proportion of domestic corn used in the U.S. for producing alcohol for fuel use has greatly increased during the past fifteen years (see figure 2). More biofuel production as mandated under the RFS will either divert land from conventional crops, use substantial amounts of crop residues or require substantial volumes of new sources like forestry or water materials. These factors can potentially reduce conventional crop supplies. Thus, an increase in biofuel production competes with the human food supply.

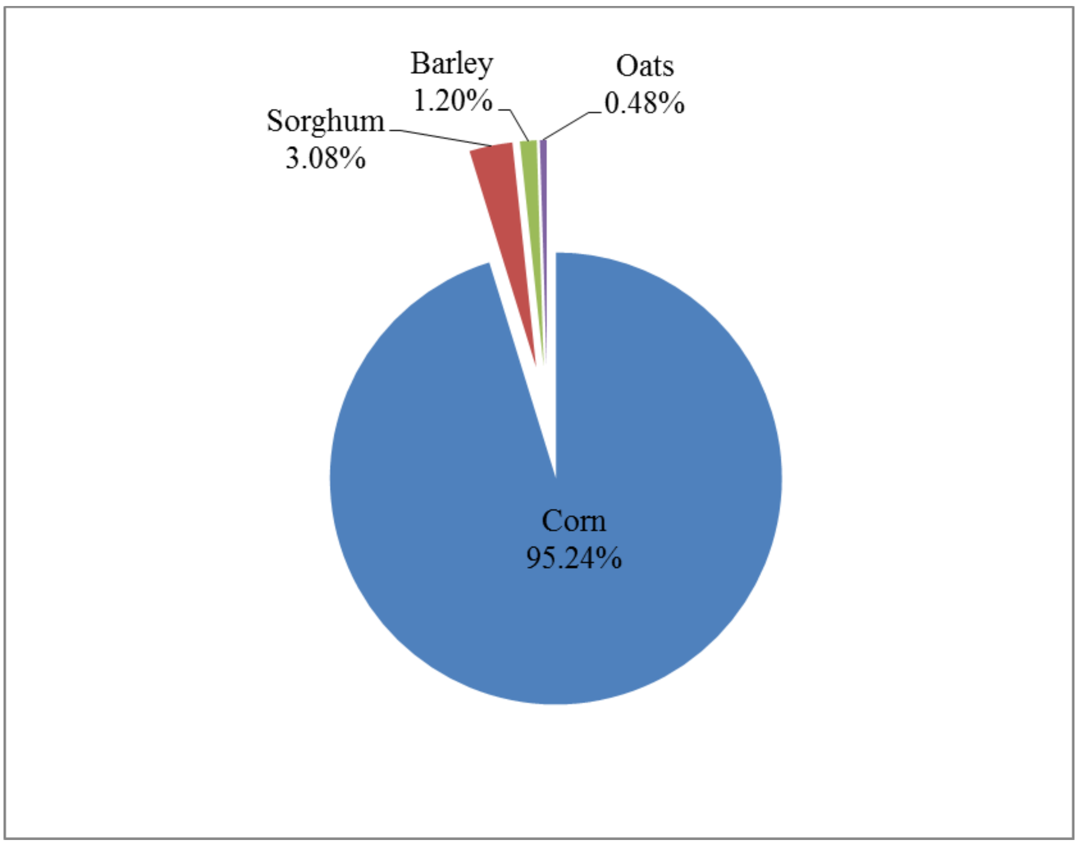

Figure 1. U.S. feed grain production, 2016/17
Source: Adapted from ERS (2016a)

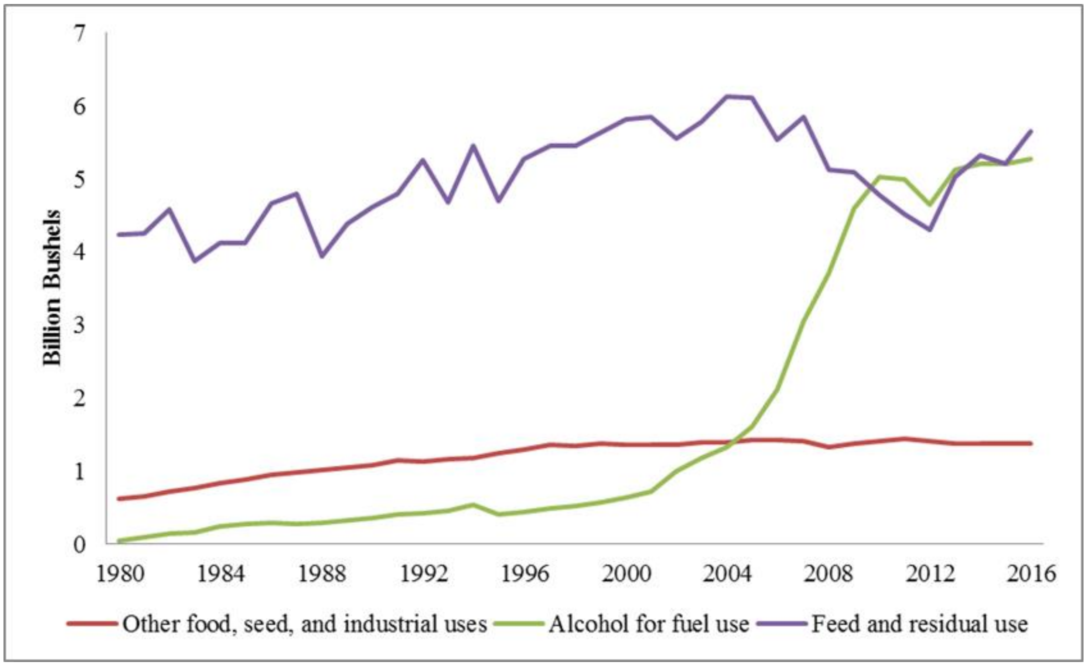

Figure 2. U.S. domestic corn use
Source: Calculated by USDA, ERS (2016b)

In order to satisfy demands on agriculture for food, feed, and energy feedstocks, agricultural technological progress is critical. A rapid growth of the world's population places challenges on meeting increasing global food demand and stresses resource availability such as land and water. During 1960 to 2010, the world's population grew from 3.0 to 6.9 billion people amounting to a 128 percent increase in the population, while global crop yield and cultivated land increased by 57 and 33 percent, respectively (Garibaldi 2011). According to a 2012 United Nations report (UN DESA 2013), the world's population in mid-2013 was 7.2 billion people and is projected to reach 8.1 billion in 2025 then 9.6 billion in 2050. In order to meet the projected demand, the

United Nations Food and Agriculture Organization (FAO) indicates that agricultural production will need to increase globally by 60 percent (FAO 2013).

Bioenergy demand is also expected to increase due to many possible reasons such as concerns on climate change mitigation, renewable energy policy action, energy stock depletion and energy security concerns. The International Energy Agency (IEA) projects that biofuel consumption will increase from 1.3 million barrels of oil equivalent per day (mboe/d) in 2011 to 2.1, and 4.1 mboe/d in 2020 and 2035, respectively (IEA 2013). Thus, over the next two decades, to meet the projected demand, biofuel production will have to increase by more than three times from its 2011 level.

Bioenergy production has to expand to meet expected increases in bioenergy demand, but government supports as incentives in investing on bioenergy may not result in an efficient outcome. Government supports such as credit subsidies have been criticized by some economists and political scientists (Gonzalez et al. 2012). Besides the government supports, the potential efficient drivers for an expanded bioenergy industry are agricultural technological progress. However, the studies on bioenergy investment are limited, and they do not cover the effect of agricultural technological progress.

Climate change is an additional complicating factor. Many studies project an altered mean and increased yield variability under climate change (Olesen and Bindi 2002; Chen et al. 2004; Torriani et al. 2007; McCarl et al. 2008; Xiong et al. 2009; Wang et al. 2011) with some projecting decreases in yields (IPCC 2014). Hence, agricultural technological progress is needed to meet the demand growth and overcome the negative consequences of climate change. Nevertheless, the studies on U.S. technological progress at the regional level relevant to this concern are limited.

An ambitious and challenging question now is how to meet growing food and energy global demands, while preserving environmental quality. The suggested solutions are sound public policy, technological improvement, and global collaboration (Karp and Richter 2011; Tilman et al. 2009). The technological progress possibility is the main focus of this dissertation.

Objectives

This dissertation primarily focuses on agricultural technological progress and its' influences on agricultural and bioenergy sectors, and environment especially climate change. The two objectives will be pursued:

1. To investigate U.S. technological progress at the regional level and its future.
2. To examine the influences of technological progress, demand growth, and energy policy on field crops, livestock, and bioenergy markets and resource usage examining land use and price. In addition, the influence on environmental concerns including greenhouse gas emissions is also explored.

CHAPTER II

A TIME SERIES APPROACH TO ESTIMATING TECHNOLOGICAL PROGRESS

Introduction

To date, the largest share of biofuels used to meet the RFS requirement comes from the biofeedstock corn which is also one of the major feed grains for livestock which in turn becomes human food. Thus bioenergy usage affects human food supplies. The future increases in the RFS are largely in the cellulosic ethanol category, but this may well involve reductions in the land used to produce conventional crops or an expansion in crop residue usage plus may stimulate increased land use elsewhere or increased U.S. deforestation (Hertel et al. 2010; Searchinger et al. 2008).

There has been a debate about bioenergy effects on food security. Some raise the issue of increasing food prices and food shortage possibilities due to rising demand for biofuel (Alexander and Hurt 2007, Mitchell 2008). However, some argue that with technological improvements, the agricultural sector will be able to provide an adequate supply of both food and biofuel (Alexander and Hurt 2007) and that bioenergy production has no significant impact on feedstock prices i.e. those for corn, wheat, barley, sugarcane, soybeans, etc. (Ajanovic 2011). In order to meet the growing demand for both food and energy with a limited resource base, technological progress is crucial.

There are different findings involving the degree of technological progress. Alston et al. (2009) found that the productivity growth of the agricultural sector decreased in the past two decades as did Feng (2012), Baker et al. (2013), and

Villavicencio et al. (2013). On the other hand, Arizen et al. (2008) found no evidence of decreased crop yield growth. This dissimilarity of the results is likely caused by the different approaches to measuring the extent of technical progress, and no clear consensus result has emerged. This brings our attention to a study of the degree of technological progress.

Many studies as mentioned above concentrate on technological progress at the national level representing the whole country agricultural improvement. Besides this technological progress, technological progress at the regional level is crucial and interesting, especially in large countries like the U.S. whose agricultural production system choices vary substantially across the landscape depending on available resources, geography, and climate. Investigating technological progress at the national level may not deliver enough insight into this subject. A study on regional technological progress will provide a further understanding of technological progress and also shed light on absolute regional advantage. However, the studies on regional technological progress in the U.S. are limited. Hence, U.S. agricultural technological progress at the regional level will be explored in this chapter using an econometric approach.

Literature Review

Technological progress for the agricultural sector is difficult to estimate since it is associated with many factors. A common effort involves estimating crop yield growth over time. Different approaches have been used to estimate yield growth. Generally, these approaches fall into the estimation methods based on crop production functions, a yield probability distribution, and a time series technique.

The crop production function approach which identifies the influence of time and climate factors on both mean and variance of yield based on historical data. Examples of research used this approach include Adams et al. (2001); Isik and Devadoss (2006); McCarl et al. (2008); and Barnwal and Kotani (2010). When using this approach, it is difficult to determine an appropriate production function in order to avoid generating omitted-variable bias (Li and Ker 2013).

Another approach is a yield probability distribution approach derived by using nonparametric, semi-parametric, or parametric methods. Li and Ker 2013 claimed that this approach has the advantage of generating yield probability distributions without assuming a fixed form for the yield probability function. Since any given fixed parametric form for the yield function may be unable to represent a general pattern of crop yield (Li and Ker 2013). Examples of studies used this approach in estimating crop yield probability distribution include Goodwin and Ker (1998) using nonparametric method, Ker and Coble (2003) using semi-parametric method, and Gallagher (1987); Nelson and Preckel (1989); Just and Weninger (1999); and Li and Ker (2013) employing parametric methods. Even though this estimation approach has an advantage as was being claimed by Li and Ker (2013), it does not mean that it is the best way in estimating crop yield. Additionally, this approach is also complicated.

The third approach analyzes the historical data using time series techniques to examine the crop yield growth rate. The historical crop yield data is estimated over time by using the best fitting model with a time trend function. The best fitting model is chosen from the best fitting functional form such as a linear function, an exponential function, or the possible combination function, and the condition of whether there is a structural break point or not. After the best fitting model is selected, a correlation of residuals from the model will be tested to determine whether further modeling is required.

Examples of this line of research include Feng (2012) and Baker et al. (2013). Feng (2012) estimated the crop yield growth rate of eight main U.S. crops using time series techniques and investigated the relationship between the RFS policy and the crop yield by simulation using the optimization model. Baker et al. (2013) obtained the productivity growth using time series techniques to estimate both crop and livestock yields as a function of time (linear and log-linear functional forms). Then the yield growth estimates were used in dynamic simulation analysis to explore the implications of future agricultural productivity growth on land use and management, GHG emissions, and GHG mitigation potential (Baker et al. 2013). Like the studies as mentioned above, we aim to examine how crop yields have progressed over time to represent agricultural technological progress and then use the estimates in a dynamic simulation. Thus, the time series approach suits our study's purposes. However, this study delves into the regional level instead of the national one to gain an in-depth view of technological progress.

Objectives

The basic objective of this chapter is to examine the magnitude of technological growth and estimate likely futures for agricultural technological progress comparing results. Furthermore, the estimated crop yield results are used to form technological progress scenarios in the next chapter.

Data

Data were gathered for six major field crops in the U.S. including corn, cotton, hay, sorghum, soybeans, and winter wheat. State level yield data were drawn using the Quick Stats 2.0 tool from United States Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) Database (2015) from 1950 through 2014. For technical progress estimation, this study focuses on the regional level because the crop yield data in some states have a few or no observations. The regions were constructed based on the old USDA Farm Production Regions, which followed state boundaries:

1. Northeast (NE): Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, District of Columbia
2. Lake States (LS): Michigan, Minnesota, Wisconsin
3. Corn Belt (CB): Indiana, Illinois, Iowa, Missouri, Ohio
4. Northern Plains (NP): Kansas, Nebraska, North Dakota, South Dakota
5. Appalachian (AC): Kentucky, North Carolina, Tennessee, Virginia, West Virginia

6. Southeast (SE): Alabama, Florida, Georgia, South Carolina
7. Delta States (DS): Arkansas, Louisiana, Mississippi
8. Southern Plains (SP): Oklahoma, Texas
9. Mountains (MT): Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming
10. Pacific (PA): California, Oregon, Washington.

Summarizing and Displaying Data

The crop yield data for most of the regions have 65 annual observations for each crop (see table 1). However, for some regions and crops, the data have less or no observations as some crops are not grown there. For example, there are no observations for cotton in the Northeast and the Lake States regions. These cases were not analyzed. The cases without data are the Northeast and the Lake States regions for cotton and sorghum, and the Mountains and the Pacific regions for soybeans.

Table 1. Number of Observations and Observation Period Available in Each Region of Each Crop Yield Data

Region	Number of Observations (Observation Period)					
	Corn	Cotton	Hay	Sorghum	Soybeans	Winter Wheat
Northeast	65	0	65	0	65	65
Lake States	65	0	65	11 (1979-1980, 2000-2008)	65	65
Corn Belt	65	65	65	65	65	65
Northern Plains	65	33 (1982-2014)	65	65	65	65
Appalachian	65	65	65	59 (1950-2008)	65	65
Southeast	65	65	65	65	65	65
Delta States	65	65	65	65	65	65
Southern Plains	65	65	65	65	65	65
Mountains	65	65	65	65	0	65
Pacific	65	55 (1950-1963, 1974-2014)	65	49 (1950-1989, 2000-2008)	0	65

Note: If the number of observations is 65, the observation year period is 1950 to 2014.

To get a preliminary perspective on how crop yields have grown, the scatter plots are provided showing how yields have evolved by crop and region (figure 3 to figure 8). Here we notice that for most of the crops, the yields seem to exhibit a linear rate of growth – see the data for corn in the Lake States and the Northern Plains regions; sorghum in the Delta States; soybeans in the Northeast and the Corn Belt regions; and winter wheat in the Northeast and the Lake States region. However, for some yield data such as corn, cotton, and soybeans in the Delta States region, their crop yield growth patterns seem to correspond to exponential growth. In some regions, it is difficult to determine the yield patterns. For example, the sorghum yield data in the Corn Belt and the Northern Plains regions and the soybean data in the Southern Plains region have more fluctuation and dispersion. Hence, two potential functional forms are considered in estimating crop yield growth rate, which are linear and exponential. Not only is the crop growth trend considered but also a possible shift in the trend. For the hay yield data, in general, there is an increasing trend of yield at the beginning part of the data while a decreasing trend starts in the after part (see figure 5). Especially, in the Lake States and the Northeast regions, one peak is observed during the 1980s in the graph of each region. To examine the possible shift in the growth trend, a structural break point is allowed in the study.

Figure 3. US historical corn yield from 1950 to 2014 at the regional level

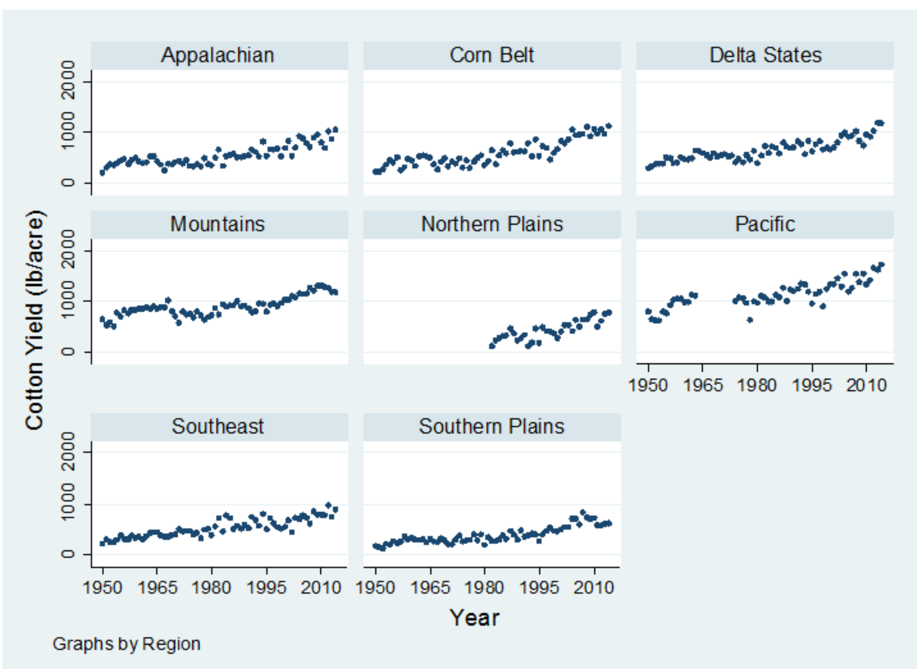

Figure 4. US historical cotton yield from 1950 to 2014 at the regional level

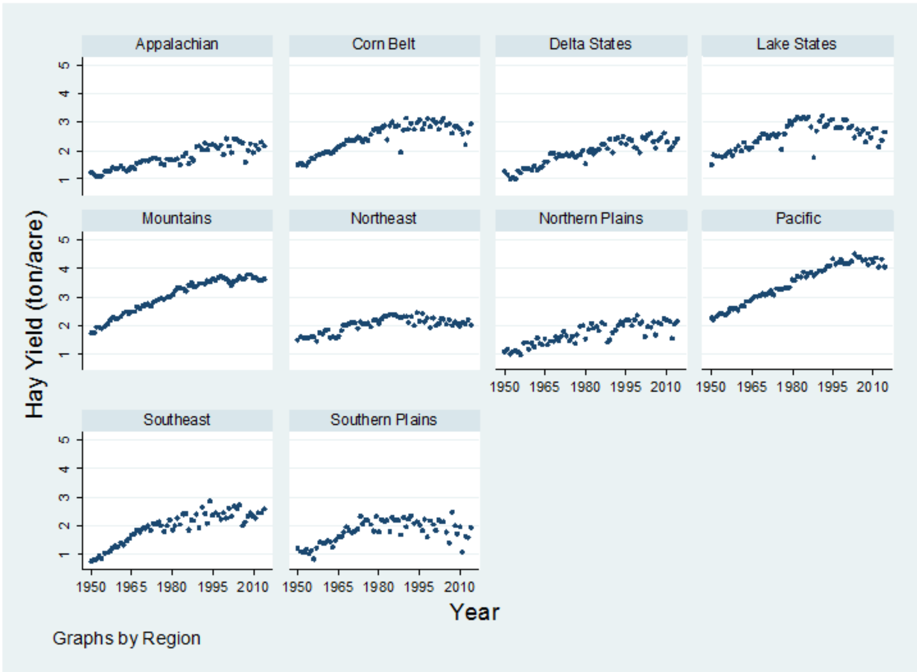

Figure 5. US historical hay yield from 1950 to 2014 at the regional level

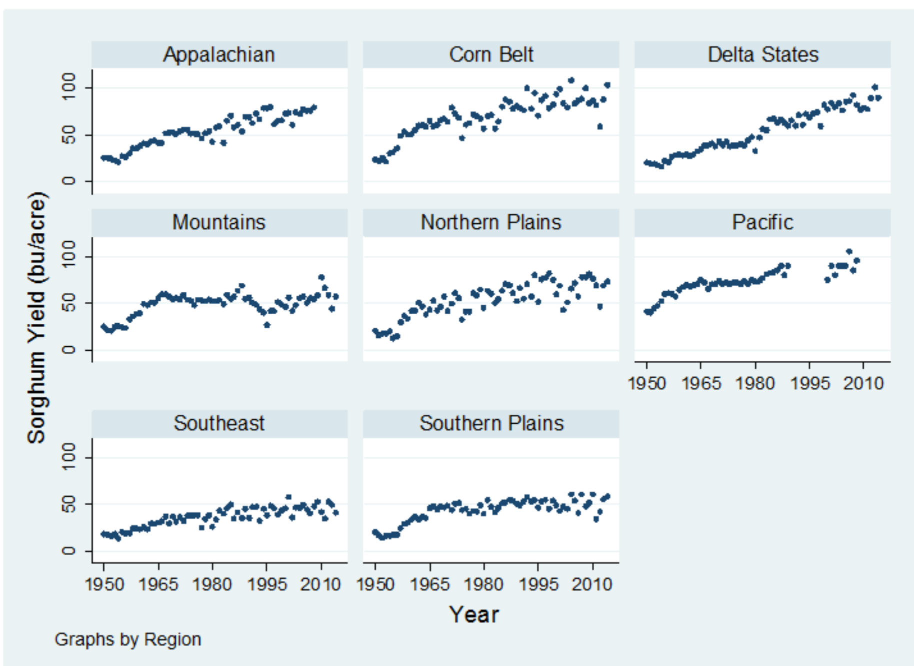

Figure 6. US historical sorghum yield from 1950 to 2014 at the regional level

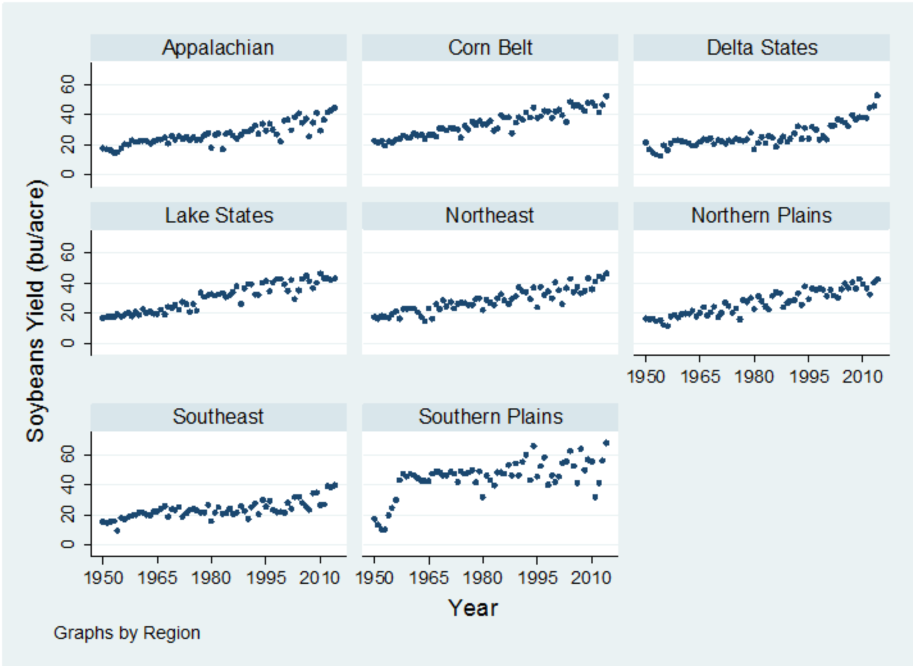

Figure 7. US historical soybean yield from 1950 to 2014 at the regional level

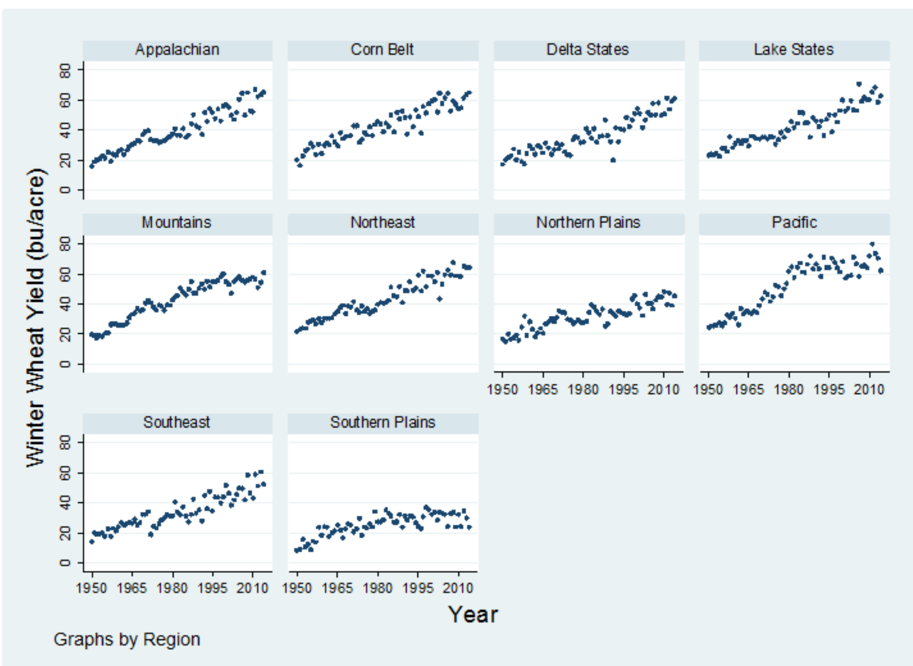

Figure 8. US historical winter wheat yield from 1950 to 2014 at the regional level

Methodology

We estimated crop growth rates using a time series technique approach over historical crop yield data. In general, the estimation proceeds in the following general steps:

1. Select the best fitting model for each region for each crop by fitting the data with a time trend while considering a possible break point where there is a shift in the trend.
2. Examine the residuals from the best fitting model and manage the autocorrelation (serial correlation) of the residuals if it is present.

We estimated the yield growth rate allowing possible changes in yield growth rates over time. In selecting time trend functions, after summarizing and displaying the data, the potential functional forms considered are linear and exponential functions as follows:

(1) Linear: $y_t = a + b * t + \varepsilon_t,$

(2) Exponential: $y_t = e^{a_1 + b_1 * t} + \varepsilon_t$,

where y_t denotes yield at time *t*; *t* is a time variable; ε_t is the error term; and a, b, a_1, and b_1 are estimated parameters. In estimating crop yield growth using these two forms, we assumed the growth was constant in physical unit (in the linear form) or constant in percentage unit (in the exponential form). The growth rates are presented as follows:

(3) Linear: $GrowthRate_t = \frac{a+b*t}{a+b*(t-1)} - 1 = \frac{b}{a+b*(t-1)},$

(4) Exponential: $GrowthRate_t = \frac{e^{a_1+b_1*t}}{e^{a_1+b_1*(t-1)}} - 1 = e^{b_1} - 1,$

where $GrowthRate_t$ is the yield growth rate at time *t* or the yield growth rate from period *t-1* to period *t*.

Additionally, it is possible that the yield growth rate differs across time. Hence, a structural break point was allowed within the model. With the possible break year (*i*), two parameters, an intercept and a slope, are allowed to change at the break point. This implies one possible shift in the growth trend at the year *i*. Hence, for each crop in each region, the four models are fitted where the two models have the specific break points determined for each type of the functional form used. The four models are Linear (L), Exponential (E), Linear-Linear with a break year (L-L), and Exponential- Exponential with a break year (E-E) listed in table 2.

Table 2. Model Choices in Estimating Crop Yield Growth Rates

Model	Form	Estimated Growth rate (%)	
		Beginning of the Period	End of the Period
1. Linear (No break year)	$y = a + b * t$, $t = 1950, \dots, 2014$	$\frac{b*100}{a+b*(t-1)}$, $t = 1951$	$\frac{b*100}{a+b*(t-1)}$, $t = 2014$
2. Exponential (No break year)	$y = e^{a_1+b_1*t}$, $t = 1950, \dots, 2014$	$e^{b_1} - 1$	$e^{b_1} - 1$
3. Linear-Linear (i = break year)	$y = a_{21} + b_{21} * t_1$, $t_1 = 1950, \dots, i-1$	$\frac{b_{21}*100}{a_{21}+b_{21}*(t_1-1)}$, $t_1 = 1951$	$\frac{b_{21}*100}{a_{21}+b_{21}*(t_1-1)}$, $t_1 = i$
	$y = a_{22} + b_{22} * t_2$, $t_2 = 0, \dots, 2014 - i$	$\frac{b_{22}*100}{a_{22}+b_{22}*(t_2-1)}$, $t_2 = 1$	$\frac{b_{22}*100}{a_{22}+b_{22}*(t_2-1)}$, $t_2 = 2014 - i$
4. Exponential-Exponential (i = break year)	$y = e^{a_{31}+b_{31}*t_1}$, $t_1 = 1950, \dots, i-1$	$(e^{b_{31}} - 1) * 100$	$(e^{b_{31}} - 1) * 100$
	$y = e^{a_{32}+b_{32}*t_2}$, $t_2 = 0, \dots, 2014 - i$	$(e^{b_{32}} - 1) * 100$	$(e^{b_{31}} - 1) * 100$

Note: For the regression of the second part after the break year i, , $t_2 = 0, 1, 2, \dots, 2014- i$ represent the break year (i), year i+1, year i+2, …, and year 2014, respectively.

The structural break test is employed to identify whether there is a structural break point or not. Since it is not obvious to observe the change in technological progress, the break point is assumed to be unknown. Thus, a structural break test is performed with the unknown break date detected by significant abrupt changes at a point in time. The test uses the supremum Wald test comparing between the maximum sample test and the expectation from the null hypothesis of no structural break point (Quandt 1960; Kim and Siegmund 1989; Andrews 1993; and StataCorp 2005). If the null hypothesis is rejected, there is sufficient evidence to support that the break occurs at year i.

For each crop in each region, the best fitting model was selected from the four model choices using the simple criterion of minimizing the residual root mean squared error (Root MSE). The lower the Root MSE is, the better the model fits the actual yield data. The other measure of the model's fit considered is the coefficient of determination or R^2. It indicates the percentage of entire variation explained by the model. The larger the R^2 is, the better the model fits. Additionally, we also precluded the model with the break year that caused a small number of observations (less than 20 percent of the entire observations) in each regression section to avoid a possible error in the estimation. Finally, since the best fitting model provides a long-term prediction, it is used in the simulation in Chapter IV. We checked forecasted yield values from the best fitting model to estimate if the increase in value was too large and explosive. Hence, a reasonable limit of crop yield ratio was applied to rule out any problematic models.

After the best fitting model was selected, the correlation of the residuals would be tested to see whether there was additional uncaptured information in the data. Hence, the autocorrelation of the residuals was tested whether it was different from zero. The interpretation of zero autocorrelation of the residuals is that it is probably that the deterministic part of the data has been completely captured (Feng 2012). On the other hand when non-zero autocorrelation of the residuals is found, then further modeling is required.

In this study, the residuals from the model were tested for autocorrelation using the Portmanteau (or Q) test developed by Box and Pierce (1970) and extended by Ljung and Box (1978). The test examines whether the residuals exhibit general randomness on a number of lags and is preferable to tests that use a specific lag such as the Durbin-Watson test. The test's null hypothesis is that the data is random or there is no autocorrelation. Failing to reject the null hypothesis suggests that the deterministic part of the data has been entirely captured (Feng 2012). In contrast, rejecting the null hypothesis indicates the presence of autocorrelation is suspected. With the autocorrelation problem, the model was mainly corrected using Prais-Winsten (PW) estimation. PW estimation which is one approach of the feasible Generalized Least Squared (FGLS) estimation is considered a common treatment for the autocorrelation issue (Wooldridge 2009). The estimates of crop yields from the best fitting models after correcting for autocorrelation are used to form technological progress scenarios in the next chapter.

Analysis and Results

For each crop in each region, the four models: Linear (L), Exponential (E), Linear-Linear with a break year (L-L), and Exponential- Exponential with a break year (E-E) were estimated to determine the crop yield growth rates. These crop yield growth rates imply our interested U.S. agricultural technological progress.

Structural Break Test Results

The results for four regression models for corn, cotton, hay, sorghum, soybeans, and winter wheat are illustrated in table 3 to table 8, respectively. The tables include the estimated coefficients and the growth rates; the results of structural break and serial correlation tests; and two measures of goodness of fit for the model i.e. Root MSE and R^2.

Table 3. Estimation of Model Choices for Corn Yield Data in Ten Regions

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation		Estimated Growth Rate (%)		Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
				Constant	Year	Beginning of the Period	End of the Period				
Northeast	1. Linear : No break point			-2716.55***	1.4165***	3.11	1.05	Fail to reject	0.8272	12.338	65
	2. Exponential: No break point			-27.8751***	0.0163 ***	1.64	1.64	Fail to reject	0.8371	12.602	
	3. Linear-Linear	1963*	Fail to reject	-3891.305***	2.0171***	4.80	3.14	Fail to reject	0.8284	12.495	
				64.2583***	1.4070***	2.19	1.05	Fail to reject			
	4. Exponential-Exponential	1963	Reject	-67.3651***	0.0365***	3.71	3.71	Fail to reject	0.8620	12.122	
				4.2174***	0.0140***	1.41	1.41	Fail to reject			
Lake States	1. Linear : No break point			-3364.38***	1.7477***	4.00	1.14	Fail to reject	0.9181	9.9487	65
	2. Exponential: No break point			-32.3361***	0.0186***	1.88	1.88	Fail to reject	0.9073	10.596	
	3. Linear-Linear	1973*	Fail to reject	-3740.55 ***	1.9405***	4.46	2.30	Fail to reject	0.9238	9.7539	
				78.6157 ***	1.9525***	2.48	1.25	Fail to reject			
	4. Exponential-Exponential	1973	Reject	-54.9221***	0.0301***	3.06	3.06	Fail to reject	0.9241	9.7966	
				4.3965***	0.0172***	1.73	1.73	Fail to reject			
Corn Belt	1. Linear : No break point			-3416.40***	1.7771***	3.62	1.10	Fail to reject	0.8641	13.431	65
	2. Exponential: No break point			-31.1460***	0.0180***	1.82	1.82	Fail to reject	0.8592	14.746	
	3. Linear-Linear	1970	Reject	-4650.766 ***	2.4073***	5.54	2.77	Fail to reject	0.8674	13.485	
				84.8121***	1.7576***	2.07	1.10	Fail to reject			
	4. Exponential-Exponential	1970	Reject	-67.4934***	0.0366***	3.72	3.72	Fail to reject	0.8984	13.308	
				4.4715***	0.0145***	1.46	1.46	Fail to reject			
Northern Plains	1. Linear : No break point			-3723.72***	1.9220***	7.97	1.32	Fail to reject	0.9351	9.653	65
	2. Exponential: No break point			-48.4673***	0.0266***	2.70	2.70	Reject	0.8826	15.975	
	3. Linear-Linear	1960	Reject	-1793.282 **	0.9326**	3.69	2.85	Fail to reject	0.9382	9.569	
				45.9024 ***	1.8497***	4.03	1.29	Fail to reject			
	4. Exponential-Exponential	1977	Reject	-84.6249***	0.0450***	4.61	4.61	Fail to reject	0.9530	9.395	
				4.4444***	0.0143***	1.44	1.44	Fail to reject			
Appalachian	1. Linear : No break point			-2953.20***	1.5314***	4.63	1.18	Fail to reject	0.8430	12.592	65
	2. Exponential: No break point			-36.4067 ***	0.0206***	2.08	2.08	Reject	0.8451	13.985	
	3. Linear-Linear	1977*	Fail to reject	-3847.006***	1.9873***	7.04	2.55	Fail to reject	0.8495	12.532	
				72.6494***	1.5825***	2.18	1.22	Fail to reject			
	4. Exponential-Exponential	1977	Reject	-70.3725***	0.0379***	3.86	3.86	Fail to reject	0.8973	12.337	
				4.3061***	0.0158***	1.59	1.59	Fail to reject			
Southeast	1. Linear : No break point			-3255.57***	1.6754***	14.61	1.43	Fail to reject	0.8914	11.145	65
	2. Exponential: No break point			-54.2868 ***	0.0294***	2.99	2.99	Fail to reject	0.8785	11.322	
	3. Linear-Linear	2005	Reject	-2958.204***	1.5245***	10.50	1.60	Fail to reject	0.9135	10.11	
				94.3046***	4.9879***	5.29	3.72	Fail to reject			
	4. Exponential-Exponential	1968	Reject	-131.4627***	0.0688***	7.12	7.12	Fail to reject	0.9201	9.993	
				3.7216***	0.0251***	2.54	2.54	Fail to reject			

Note: 1) *** is significant at the 1 percent level.
2) [a] denotes the portmanteau (or Q) test for white noise.
3) N denotes the number of observations.

Table 3. Continued

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation		Estimated Growth Rate (%)		Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
				Constant	Year	Beginning of the Period	End of the Period				
Delta States	1. Linear : No break point			-4685.52***	2.4036***	150.36	1.57	Reject	0.9260	12.952	65
	2. Exponential: No break point			-65.1478 ***	0.0350***	3.56	3.56	Fail to reject	0.9433	12.917	
	3. Linear-Linear	1976	Reject	-2069.98***	1.0714***	5.57	2.38	Fail to reject	0.9555	10.21	
				52.7205***	2.9675***	5.63	1.83	Fail to reject			
	4. Exponential-Exponential	1982	Reject	-61.4506***	0.0331***	3.36	3.36	Fail to reject	0.9632	9.019	
				4.3970***	0.0224***	2.26	2.26	Fail to reject			
Southern Plains	1. Linear : No break point			-3965.85***	2.0442***	10.06	1.37	Reject	0.8432	16.802	65
	2. Exponential: No break point			-60.7452***	0.0328***	3.33	3.33	Reject	0.7794	29.475	
	3. Linear-Linear	1968	Reject	-2150.135***	1.1109***	6.86	3.27	Fail to reject	0.9232	11.95	
				79.2793***	1.2811***	1.62	0.94	Fail to reject			
	4. Exponential-Exponential	1971	Reject	-110.9312***	0.0583***	6.00	6.00	Fail to reject	0.9605	10.907	
				4.5006***	0.0096***	0.96	0.96	Fail to reject			
Mountains	1. Linear : No break point			-4618.71***	2.3828***	8.57	1.34	Reject	0.9625	8.960	65
	2. Exponential: No break point			-49.8063***	0.0274***	2.78	2.78	Reject	0.9086	19.912	
	3. Linear-Linear	1981	Reject	-4527.79***	2.3349***	9.25	2.51	Fail to reject	0.9902	4.655	
				120.6924***	1.4105***	1.17	0.85	Fail to reject			
	4. Exponential-Exponential	1981	Reject	-77.4450***	0.0415***	4.23	4.23	Reject	0.9884	5.040	
				4.7991***	0.0100***	1.00	1.00	Fail to reject			
Pacific	1. Linear : No break point			-4909.29***	2.5432***	5.09	1.21	Reject	0.9625	9.568	65
	2. Exponential: No break point			-37.6301***	0.0214***	2.16	2.16	Reject	0.9409	15.742	
	3. Linear-Linear	1982	Reject	-4134.203***	6.4408***	4.10	1.84	Fail to reject	0.9887	5.347	
				150.1812***	1.5935***	1.06	0.80	Reject			
	4. Exponential-Exponential	1982	Reject	-46.0636***	0.0257***	2.60	2.60	Reject	0.9895	5.134	
				5.0191***	0.0091***	0.91	0.91	Reject			

Note: 1) *** is significant at the 1 percent level.
2) [a] denotes the portmanteau (or Q) test for white noise.
3) N denotes the number of observations.

Table 4. Estimation of Model Choices for Cotton Yield Data in Ten Regions

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation		Estimated Growth Rate (%)		Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
				Constant	Year	Beginning of the Period	End of the Period				
Northeast	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Lake States	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Corn Belt	1. Linear : No break point			-21426.03***	11.1109***	4.63	1.18	Reject	0.7416	124.99	65
	2. Exponential: No break point			-30.8757***	0.0188***	1.89	1.89	Fail to reject	0.7259	112.37	
	3. Linear-Linear	1966	Reject	-34312.18***	17.7360***	6.49	3.40	Fail to reject	0.8280	103.65	
				291.2469***	15.2648***	5.24	1.51	Fail to reject			
	4. Exponential-Exponential	1966	Reject	-87.4084***	0.0477***	4.89	4.89	Fail to reject	0.8013	97.8429	
				5.8436***	0.0239***	2.42	2.42	Fail to reject			
Northern Plains	1. Linear : No break point			-31779.94***	16.1267***	-4.84	2.36	Fail to reject	0.6734	110.33	33
	2. Exponential: No break point			-72.0799***	0.0391***	3.98	3.98	Fail to reject	0.5770	105.22	
	3. Linear-Linear	1988	Reject	-119906.7***	60.5714***	-3.38	15.60	Fail to reject	0.7606	97.67	
				211.5794***	20.1178***	9.51	2.82	Fail to reject			
	4. Exponential-Exponential	1988	Reject	-450.6073***	0.2299***	25.85	25.85	Fail to reject	0.6930	93.90	
				5.4582***	0.0467***	4.78	4.78	Fail to reject			
Appalachian	1. Linear : No break point			-16550.42 ***	8.6290***	3.12	1.05	Reject	0.6899	110.24	65
	2. Exponential: No break point			-23.9829***	0.0153***	1.54	1.54	Reject	0.6800	101.92	
	3. Linear-Linear	1966	Reject	-24775***	12.8702***	4.00	2.56	Fail to reject	0.8065	88.504	
				293.7831***	12.5951***	4.29	1.42	Fail to reject			
	4. Exponential-Exponential	1966	Reject	-61.9130***	0.0347***	3.53	3.53	Fail to reject	0.7958	85.212	
				5.8129***	0.0217***	2.19	2.19	Fail to reject			
Southeast	1. Linear : No break point			-15810.14***	8.2467***	3.04	1.04	Fail to reject	0.7579	88.83	65
	2. Exponential: No break point			-25.7468***	0.0161***	1.63	1.63	Fail to reject	0.7823	90.01	
	3. Linear-Linear	1998	Reject	-16773.49***	8.7382***	3.29	1.31	Fail to reject	0.8013	81.779	
				536.9706***	22.1673***	4.13	2.55	Fail to reject			
	4. Exponential-Exponential	1966	Reject	-67.1765***	0.0373***	3.80	3.80	Fail to reject	0.8041	88.041	
				5.9966***	0.0150***	1.51	1.51	Fail to reject			

Note: 1) *** is significant at the 1 percent level.
2) [a] denotes the portmanteau (or Q) test for white noise.
3) N denotes the number of observations.

Table 4. Continued

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation: Constant	Estimation: Year	Estimated Growth Rate (%): Beginning of the Period	Estimated Growth Rate (%): End of the Period	Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
Delta States	1. Linear : No break point			-17930.98***	9.3769***	2.65	0.99	Fail to reject	0.7583	100.88	65
	2. Exponential: No break point			-22.1345***	0.0144***	1.45	1.45	Reject	0.7674	95.39	
	3. Linear-Linear	1966	Reject	-35552.17***	18.4***	5.61	3.14	Reject	0.7958	94.243	
				445.0419***	11.2681***	2.53	1.16	Fail to reject			
	4. Exponential-Exponential	1966	Reject	-72.7163***	0.0403***	4.11	4.11	Reject	0.8115	89.120	
				6.1645***	0.0156***	1.57	1.57	Fail to reject			
Southern Plains	1. Linear : No break point			-14060.03***	7.2917***	4.59	1.18	Reject	0.7192	86.821	65
	2. Exponential: No break point			-30.7511 ***	0.0185***	1.87	1.87	Reject	0.7370	79.42	
	3. Linear-Linear	2004	Reject	-9562.789***	5.0071***	2.49	1.09	Fail to reject	0.8485	64.814	
				741.3864***	-12.5046***	-1.69	-1.99	Fail to reject			
	4. Exponential-Exponential	2004	Reject	-24.6316***	0.0154***	1.55	1.55	Fail to reject	0.7828	62.607	
				6.6071***	-0.0185***	-1.83	-1.83	Fail to reject			
Mountains	1. Linear : No break point			-15035.05***	8.0401***	1.25	0.70	Reject	0.6357	115.99	65
	2. Exponential: No break point			-10.6932***	0.0088***	0.89	0.89	Reject	0.6119	111.42	
	3. Linear-Linear	1969	Reject	-39644.07***	20.6418***	3.40	2.15	Fail to reject	0.8328	79.846	
				650.3932***	13.0777***	2.01	1.07	Reject			
	4. Exponential-Exponential	1969	Reject	-47.4934***	0.0276***	2.80	2.80	Fail to reject	0.8154	76.389	
				6.5190***	0.0138***	1.39	1.39	Reject			
Pacific	1. Linear : No break point			-20256.82***	10.7810***	1.41	0.75	Fail to reject	0.6652	150.94	55
	2. Exponential: No break point			-12.4912***	0.0098***	0.99	0.99	Fail to reject	0.6440	146.45	
	3. Linear-Linear	Gaps not allowed									
	4. Exponential-Exponential	Gaps not allowed									

Note: 1) *** is significant at the 1 percent level.
2) [a] denotes the portmanteau (or Q) test for white noise.
3) N denotes the number of observations.

Table 5. Estimation of Model Choices for Hay Yield Data in Ten Regions

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation: Constant	Estimation: Year	Estimated Growth Rate (%): Beginning of the Period	Estimated Growth Rate (%): End of the Period	Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
Northeast	1. Linear : No break point			-17.0623***	0.0096***	0.56	0.42	Reject	0.4631	0.1976	65
	2. Exponential: No break point			-9.4701***	0.0051***	0.51	0.51	Reject	0.4823	0.2047	
	3. Linear-Linear	1982	Reject	-44.5053***	0.0236***	1.60	1.08	Fail to reject	0.8245	0.1148	
				2.3456***	-0.0096***	-0.41	-0.47	Reject			
	4. Exponential-Exponential	1987	Reject	-25.2280***	0.0131***	1.32	1.32	Reject	0.8312	0.1124	
				0.8213***	-0.0038***	-0.38	-0.38	Reject			
Lake States	1. Linear : No break point			-26.2598***	0.0145***	0.70	0.49	Reject	0.3718	0.3598	65
	2. Exponential: No break point			-11.5469***	0.0063***	0.63	0.63	Reject	0.3968	0.3732	
	3. Linear-Linear	1987	Reject	-80.7973***	0.0423***	2.61	1.36	Fail to reject	0.7484	0.2313	
				2.8975***	-0.0129	-0.45	-0.50	Fail to reject			
	4. Exponential-Exponential	1987	Reject	-34.3199***	0.0179***	1.80	1.80	Fail to reject	0.7580	0.2264	
				1.0526***	-0.0043	-0.43	-0.43	Fail to reject			
Corn Belt	1. Linear : No break point			-38.7398***	0.0208***	1.15	0.67	Reject	0.6724	0.2766	65
	2. Exponential: No break point			-17.2571***	0.0092***	0.92	0.92	Reject	0.6705	0.3043	
	3. Linear-Linear	1973	Reject	-87.0227***	0.0454***	3.12	1.88	Reject	0.8197	0.2085	
				2.6344***	0.0063*	0.24	0.22	Fail to reject			
	4. Exponential-Exponential	1973	Reject	-45.3692***	0.0235***	2.37	2.37	Reject	0.8589	0.2059	
				0.9633***	0.0024*	0.24	0.24	Fail to reject			
Northern Plains	1. Linear : No break point			-30.9176***	0.0165***	1.39	0.74	Fail to reject	0.6924	0.2091	65
	2. Exponential: No break point			-19.8687***	0.0103***	1.03	1.03	Reject	0.6924	0.2241	
	3. Linear-Linear	1988	Reject	-50.1619***	0.0263***	2.56	1.33	Fail to reject	0.7579	0.1885	
				1.8609***	0.0094	0.50	0.45	Fail to reject			
	4. Exponential-Exponential	1988	Reject	-34.3064***	0.0176***	1.78	1.78	Fail to reject	0.7862	0.1859	
				0.6092***	0.0051	0.52	0.52	Fail to reject			
Appalachian	1. Linear : No break point			-33.5349***	0.0178***	1.50	0.77	Reject	0.7949	0.1724	65
	2. Exponential: No break point			-20.3253 ***	0.0105***	1.06	1.06	Reject	0.8055	0.1839	
	3. Linear-Linear	1989	Reject	-30.8525***	0.0164***	1.39	0.92	Fail to reject	0.8559	0.1468	
				2.1446***	-0.0003	-0.01	-0.01	Fail to reject			
	4. Exponential-Exponential	1989	Reject	-22.0555***	0.0114***	1.15	1.15	Reject	0.8642	0.1474	
				0.7616***	-0.0003	-0.03	-0.03	Fail to reject			
Southeast	1. Linear : No break point			-47.4343***	0.0249***	2.15	0.91	Reject	0.7644	1.2637	65
	2. Exponential: No break point			-29.0453***	0.0150***	1.51	1.51	Reject	0.7183	0.3254	
	3. Linear-Linear	1972	Reject	-118.9991***	0.0614***	8.72	3.18	Reject	0.8957	0.1783	
				2.0149***	0.0121***	0.60	0.48	Fail to reject			
	4. Exponential-Exponential	1968	Reject	-99.9657***	0.0511***	5.25	5.25	Fail to reject	0.9436	0.1781	
				0.6621***	0.0059***	0.59	0.59	Fail to reject			

Note: 1) *** is significant at the 1 percent level.
2) [a] denotes the portmanteau (or Q) test for white noise.
3) N denotes the number of observations.

Table 5. Continued

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation		Estimated Growth Rate (%)		Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
				Constant	Year	Beginning of the Period	End of the Period				
Delta States	1. Linear : No break point			-39.0958***	0.0206***	1.65	0.81	Reject	0.7965	0.1993	65
	2. Exponential: No break point			-22.6506***	0.0117***	1.18	1.18	Reject	0.7779	0.2280	
	3. Linear-Linear	1965	Reject	-48.3772***	0.0254***	2.32	1.78	Fail to reject	0.8554	0.1708	
				1.7537***	0.0145***	0.83	0.59	Fail to reject			
	4. Exponential-Exponential	1967	Reject	-44.8024***	0.0230***	2.33	2.33	Fail to reject	0.8877	0.1682	
				0.5955***	0.0065***	0.65	0.65	Fail to reject			
Southern Plains	1. Linear : No break point			-20.5491***	0.0113***	0.79	0.53	Reject	0.2796	0.3448	65
	2. Exponential: No break point			-13.7177***	0.0072***	0.72	0.72	Reject	0.2938	0.3587	
	3. Linear-Linear	1977	Reject	-90.5434***	0.0469***	5.06	2.23	Fail to reject	0.6925	0.2290	
				2.1707***	-0.0103**	-0.47	-0.57	Fail to reject			
	4. Exponential-Exponential	1977	Reject	-60.1367***	0.0308***	3.13	3.13	Fail to reject	0.7214	0.2244	
				0.7808***	-0.0059**	-0.59	-0.59	Fail to reject			
Mountains	1. Linear : No break point			-58.8095***	0.0312***	1.54	0.78	Reject	0.9203	0.1750	65
	2. Exponential: No break point			-20.8604***	0.0111***	1.11	1.11	Reject	0.8851	0.2323	
	3. Linear-Linear	1993	Reject	-79.4578***	0.0417***	2.27	1.17	Fail to reject	0.9843	0.0789	
				3.6011***	0.0033	0.09	0.09	Reject			
	4. Exponential-Exponential	1993	Reject	-30.4142***	0.0159***	1.61	1.61	Reject	0.9742	0.1006	
				1.2810***	0.0009	0.09	0.09	Reject			
Pacific	1. Linear : No break point			-67.0647***	0.0356***	1.51	0.77	Reject	0.9391	0.1728	65
	2. Exponential: No break point			-19.9541***	0.0107***	1.07	1.07	Reject	0.9220	0.2260	
	3. Linear-Linear	1999	Reject	-81.5743***	0.0430***	1.93	1.01	Reject	0.9836	0.0912	
				4.3059***	-0.0055	-0.13	-0.13	Fail to reject			
	4. Exponential-Exponential	1995	Reject	-25.9373***	0.0137***	1.38	1.38	Reject	0.9824	0.1001	
				1.4552***	-0.0006	-0.06	-0.06	Fail to reject			

Note: 1) *** is significant at the 1 percent level.
2) [a] denotes the portmanteau (or Q) test for white noise.
3) N denotes the number of observations.

Table 6. Estimation of Model Choices for Sorghum Yield Data in Ten Regions

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation		Estimated Growth Rate (%)		Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
				Constant	Year	Beginning of the Period	End of the Period				
Northeast	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Lake States	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	11
Corn Belt	1. Linear : No break point			-1744.11***	0.9150***	2.28	0.94	Reject	0.7107	11.125	65
	2. Exponential: No break point			-27.0092***	0.0157***	1.59	1.59	Reject	0.6385	13.016	
	3. Linear-Linear	1966	Reject	-6157.425***	3.1678***	16.06	4.94	Reject	0.8103	9.1553	
				62.3422***	0.6490***	1.04	0.70	Reject			
	4. Exponential-Exponential	1964	Reject	-170.5645***	0.0890***	9.31	9.31	Reject	0.8818	9.1639	
				4.1205***	0.0085***	0.85	0.85	Fail to reject			
Northern Plains	1. Linear : No break point			-1483.99***	0.7755***	2.75	1.01	Fail to reject	0.6484	10.883	65
	2. Exponential: No break point			-32.3746***	0.0183***	1.85	1.85	Reject	0.5928	12.800	
	3. Linear-Linear	1960	Reject	-3713.5***	1.9111***	14.51	6.72	Fail to reject	0.7451	9.4169	
				44.1687***	0.5367***	1.22	0.74	Fail to reject			
	4. Exponential-Exponential	1960	Reject	-144.0484***	0.0752***	7.81	7.81	Fail to reject	0.8211	9.3997	
				3.7934***	0.0094***	0.94	0.94	Fail to reject			
Appalachian	1. Linear : No break point			-1718.64***	0.8958***	3.18	1.06	Reject	0.8589	6.2895	59
	2. Exponential: No break point			-32.6580***	0.0185***	1.87	1.87	Reject	0.8131	7.5837	
	3. Linear-Linear	1974	Reject	-3036.308***	1.5680***	7.38	2.81	Fail to reject	0.8938	5.5558	
				49.9385***	0.8442***	1.69	1.02	Fail to reject			
	4. Exponential-Exponential	1974	Reject	-78.5616***	0.0419***	4.28	4.28	Reject	0.9131	5.6536	
				3.9153***	0.0137***	1.38	1.38	Reject			
Southeast	1. Linear : No break point			-880.4564***	0.4625***	2.15	0.91	Reject	0.7030	5.7289	65
	2. Exponential: No break point			-25.0192***	0.0144***	1.45	1.45	Reject	0.6886	6.4410	
	3. Linear-Linear	1977	Reject	-1840.588***	0.9518***	6.19	2.43	Fail to reject	0.7719	5.1021	
				36.4089***	0.3255***	0.89	0.68	Fail to reject			
	4. Exponential-Exponential	1977	Reject	-67.6954***	0.0362***	3.68	3.68	Fail to reject t	0.8257	5.1324	
				3.5782***	0.0083***	0.84	0.84	Fail to reject			

Note: 1) *** is significant at the 1 percent level.

2) [a] denotes the portmanteau (or Q) test for white noise.

3) N denotes the number of observations.

Table 6. Continued

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation: Constant	Estimation: Year	Estimated Growth Rate (%): Beginning of the Period	Estimated Growth Rate (%): End of the Period	Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
Delta States	1. Linear : No break point			-2301.597***	1.1885***	7.47	1.31	Fail to reject	0.9393	5.7558	65
	2. Exponential: No break point			-45.0718***	0.0247***	2.50	2.50	Reject	0.9175	7.7032	
	3. Linear-Linear	1982	Reject	-1700.022***	0.8817***	4.56	1.93	Reject	0.9528	5.1576	
				58.1040***	1.0080***	1.73	1.13	Fail to reject			
	4. Exponential-Exponential	1982	Reject	-54.0416***	0.0293***	2.97	2.97	Reject	0.9469	5.3541	
				4.0777***	0.0136***	1.37	1.37	Fail to reject			
Southern Plains	1. Linear : No break point			-876.7651***	0.4645***	1.60	0.80	Reject	0.5394	8.1806	65
	2. Exponential: No break point			-22.6470***	0.0133***	1.34	1.34	Reject	0.5073	9.2720	
	3. Linear-Linear	1974	Reject	-3385.001***	1.7430***	12.51	3.33	Fail to reject	0.8043	5.4187	
				46.5078***	0.1578 *	0.34	0.30	Fail to reject			
	4. Exponential-Exponential	1965	Reject	-131.8906***	0.0690***	7.15	7.15	Reject	0.8760	5.2202	
				3.8353***	0.0023*	0.23	0.23	Fail to reject			
Mountains	1. Linear : No break point			-612.9424***	0.3338***	0.88	0.57	Reject	0.2793	10.22	65
	2. Exponential: No break point			-12.9879***	0.0085***	0.85	0.85	Reject	0.2954	10.617	
	3. Linear-Linear	1969	Reject	-4727.415***	2.4330***	14.30	4.17	Reject	0.6530	7.207	
				52.2313***	0.0240	0.05	0.05	Reject			
	4. Exponential-Exponential	1961	Reject	-117.0991***	0.0616***	6.35	6.35	Fail to reject	0.7485	7.1537	
				3.9633***	-0.0002	-0.02	-0.02	Reject			
Pacific	1. Linear : No break point			-1330.614***	0.7102***	1.31	0.72	Reject	0.7949	6.2565	49
	2. Exponential: No break point			-15.9597***	0.0102***	1.03	1.03	Reject	0.1069	6.9074	
	3. Linear-Linear	Gaps not allowed									
	4. Exponential-Exponential	Gaps not allowed									

Note: 1) *** is significant at the 1 percent level.
2) [a] denotes the portmanteau (or Q) test for white noise.
3) N denotes the number of observations.

Table 7. Estimation of Model Choices for Soybean Yield Data in Ten Regions

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation		Estimated Growth Rate (%)		Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
				Constant	Year	Beginning of the Period	End of the Period				
Northeast	1. Linear : No break point			-711.2061***	0.3732***	2.25	0.93	Fail to reject	0.7995	3.5618	65
	2. Exponential: No break point			-23.3138***	0.0134***	1.35	1.35	Fail to reject	0.7937	3.5469	
	3. Linear-Linear	2005	Reject	-677.1399***	0.3560***	2.10	0.99	Fail to reject	0.8205	3.4247	
				33.2782***	1.3382***	4.02	3.04	Reject			
	4. Exponential-Exponential	2005	Reject	-23.8860***	0.0137***	1.38	1.38	Fail to reject	0.8013	3.4116	
				3.5116***	0.0339***	3.45	3.45	Reject			
Lake States	1. Linear : No break point			-855.6425***	0.4470***	2.78	1.01	Fail to reject	0.8661	3.3504	65
	2. Exponential: No break point			-27.3379***	0.0155***	1.56	1.56	Reject	0.8709	3.7063	
	3. Linear-Linear	1977	Reject	-552.0534***	0.2919***	1.70	1.19	Reject	0.8941	3.0275	
				31.1053***	0.3243***	1.04	0.76	Reject			
	4. Exponential-Exponential	1977	Reject	-24.0104***	0.0138***	1.39	1.39	Reject	0.9154	2.9871	
				3.4424***	0.0087***	0.88	0.88	Fail to reject			
Corn Belt	1. Linear : No break point			-790.3271***	0.4160***	1.99	0.88	Fail to reject	0.8854	2.8524	65
	2. Exponential: No break point			-21.2267***	0.0125***	1.26	1.26	Fail to reject	0.8867	2.9344	
	3. Linear-Linear	2004*	Fail to reject	-744.4195***	0.3927***	1.84	0.94	Fail to reject	0.8919	2.816	
				45.8591***	0.1173	0.26	0.25	Fail to reject			
	4. Exponential-Exponential	1983*	Fail to reject	-27.7580***	0.0158***	1.59	1.59	Fail to reject	0.8962	2.8296	
				3.5179***	0.0119***	1.19	1.19	Fail to reject			
Northern Plains	1. Linear : No break point			-777.5979***	0.4059***	2.91	1.03	Fail to reject	0.8399	3.3779	65
	2. Exponential: No break point			-28.3053***	0.0159***	1.60	1.60	Fail to reject	0.8203	3.5286	
	3. Linear-Linear	2005*	Fail to reject	-753.055***	0.3935***	2.77	1.12	Fail to reject	0.8439	3.3896	
				38.5796***	0.0379	0.10	0.10	Fail to reject			
	4. Exponential-Exponential	1977*	Fail to reject	-29.8928***	0.0167***	1.69	1.69	Fail to reject	0.8354	3.3244	
				3.2580***	0.0116***	1.17	1.17	Fail to reject			
Appalachian	1. Linear : No break point			-614.2565***	0.3236***	1.93	0.87	Fail to reject	0.7372	3.6817	65
	2. Exponential: No break point			-20.2502***	0.0119***	1.19	1.19	Reject	0.7444	3.5765	
	3. Linear-Linear	1963	Reject	-1256.243***	0.6522***	4.20	2.87	Reject	0.7480	3.6643	
				20.2004***	0.3459***	1.71	0.92	Fail to reject			
	4. Exponential-Exponential	1968	Reject	-45.777***	0.0249***	2.52	2.52	Reject	0.7653	3.4939	
				3.0854***	0.0122***	1.23	1.23	Fail to reject			
Southeast	1. Linear : No break point			-427.7283 ***	0.2276***	1.41	0.75	Reject	0.5575	3.865	65
	2. Exponential: No break point			-16.1446***	0.0097***	0.98	0.98	Fail to reject	0.5472	3.8136	
	3. Linear-Linear	1968	Reject	-1229.94***	0.6376***	4.74	2.69	Fail to reject	0.6076	3.6985	
				19.1868***	0.2596***	1.35	0.84	Fail to reject			
	4. Exponential-Exponential	1968	Reject	-65.9412***	0.0352***	3.58	3.58	Fail to reject	0.6288	3.5839	
				2.9841***	0.0096***	0.96	0.96	Fail to reject			

Note: 1) *** is significant at the 1 percent level.
2) [a] denotes the portmanteau (or Q) test for white noise.
3) N denotes the number of observations.

Table 7. Continued

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation		Estimated Growth Rate (%)		Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
				Constant	Year	Beginning of the Period	End of the Period				
Delta States	1. Linear : No break point			-668.1833***	0.3503***	2.35	0.95	Reject	0.6905	4.4699	65
	2. Exponential: No break point			-22.1861***	0.0128***	1.29	1.29	Reject	0.7170	4.1325	
	3. Linear-Linear	1998	Reject	-389.0693 ***	0.2086***	1.18	0.76	Fail to reject	0.8558	3.101	
				25.1438***	1.3742***	5.47	3.00	Fail to reject			
	4. Exponential-Exponential	1998	Reject	-15.5907***	0.0095***	0.95	0.95	Fail to reject	0.7962	3.0499	
				3.2527***	0.0391***	3.99	3.99	Fail to reject			
Southern Plains	1. Linear : No break point			-715.168***	0.3835***	1.17	0.67	Reject	0.3737	9.462	65
	2. Exponential: No break point			-19.2118***	0.0116***	1.17	1.17	Reject	0.3278	10.233	
	3. Linear-Linear	1963	Reject	-6965.962***	3.5769***	39.57	7.39	Reject	0.6733	6.945	
				44.1266***	0.1730**	0.39	0.33	Reject			
	4. Exponential-Exponential	1963	Reject	-263.909***	0.1366***	14.64	14.64	Reject	0.7773	7.182	
				3.7911***	0.0031**	0.31	0.31	Reject			
Mountains	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Pacific	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0

Note: 1) *** is significant at the 1 percent level.
2) [a] denotes the portmanteau (or Q) test for white noise.
3) N denotes the number of observations.

Table 8. Estimation of Model Choices for Winter Wheat Yield Data in Ten Regions

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation		Estimated Growth Rate (%)		Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
				Constant	Year	Beginning of the Period	End of the Period				
Northeast	1. Linear : No break point			-1215.312 ***	0.6351***	2.75	1.01	Fail to reject	0.9056	3.9085	65
	2. Exponential: No break point			-26.4158***	0.0152***	1.53	1.53	Reject	0.9098	4.0626	
	3. Linear-Linear	1972	Reject	-1598.127 ***	0.8309***	3.74	2.14	Fail to reject	0.9198	3.6598	
				34.3775***	0.7350***	2.14	1.14	Fail to reject			
	4. Exponential-Exponential	1972	Reject	-49.9556***	0.0272***	2.76	2.76	Fail to reject	0.9331	3.7784	
				3.5671***	0.0152***	1.54	1.54	Fail to reject			
Lake States	1. Linear : No break point			-1177.367 ***	0.6154***	2.72	1.00	Reject	0.8700	4.5343	65
	2. Exponential: No break point			-25.7144***	0.0148***	1.50	1.50	Reject	0.8869	4.3515	
	3. Linear-Linear	1965	Reject	-1575.763***	0.8196***	3.64	2.47	Reject	0.8777	4.4681	
				30.1326***	0.6712***	2.23	1.08	Fail to reject			
	4. Exponential-Exponential	1965	Reject	-54.1127***	0.0294***	2.98	2.98	Reject	0.8976	4.2733	
				3.4611***	0.0144***	1.45	1.45	Reject			
Corn Belt	1. Linear : No break point			-1175.739 ***	0.6149***	2.63	0.99	Fail to reject	0.8693	4.5437	65
	2. Exponential: No break point			-26.4550***	0.0152***	1.53	1.53	Fail to reject	0.8418	4.9040	
	3. Linear-Linear	1973*	Fail to reject	-1685.867***	0.8754***	4.14	2.21	Reject	0.8787	4.4481	
				36.3378***	0.6533***	1.80	1.05	Fail to reject			
	4. Exponential-Exponential	1973	Reject	-55.0779***	0.0298***	3.03	3.03	Fail to reject	0.8791	4.4625	
				3.6113***	0.0135***	1.36	1.36	Fail to reject			
Northern Plains	1. Linear : No break point			-761.1904 ***	0. 4000***	2.12	0.91	Fail to reject	0.7639	4.2383	65
	2. Exponential: No break point			-23.5346***	0.0136***	1.37	1.37	Reject	0.7435	4.4241	
	3. Linear-Linear	1974	Reject	-1450.767***	0.7519***	4.86	2.35	Fail to reject	0.7980	3.9842	
				27.5797***	0.4228***	1.53	0.96	Fail to reject			
	4. Exponential-Exponential	1974	Reject	-58.7571***	0.0316***	3.21	3.21	Fail to reject	0.8132	3.8813	
				3.3330***	0.0118***	1.19	1.19	Fail to reject			
Appalachian	1. Linear : No break point			-1313.168 ***	0.68278***	3.74	1.11	Fail to reject	0.9056	4.2002	65
	2. Exponential: No break point			-32.1289***	0.0180***	1.82	1.82	Reject	0.9056	4.4006	
	3. Linear-Linear	1972	Reject	-1873.34***	0.9692***	5.86	2.70	Fail to reject	0.9219	3.8843	
				30.5730***	0.7817***	2.56	1.25	Fail to reject			
	4. Exponential-Exponential	1972	Reject	-67.8061***	0.0362***	3.69	3.69	Fail to reject	0.9429	3.8251	
				3.4683***	0.0169***	1.71	1.71	Fail to reject			
Southeast	1. Linear : No break point			-1045.532 ***	0.5447***	3.27	1.07	Fail to reject	0.8321	4.6621	65
	2. Exponential: No break point			-29.1883***	0.0165***	1.66	1.66	Fail to reject	0.8434	4.4995	
	3. Linear-Linear	1972	Reject	-1409.412***	0.7312***	4.47	2.36	Fail to reject	0.8665	4.2255	
				24.5307***	0.6990***	2.85	1.31	Fail to reject			
	4. Exponential-Exponential	1972	Reject	-57.6689***	0.0310***	3.15	3.15	Fail to reject	0.8791	4.2145	
				3.2451***	0.0186***	1.88	1.88	Fail to reject			

Note: 1) *** is significant at the 1 percent level.
2) [a] denotes the portmanteau (or Q) test for white noise.
3) N denotes the number of observations.

Table 8. Continued

Region	Model	Break Year	Ho: No Structural Break (5% Confidence)	Estimation		Estimated Growth Rate (%)		Ho: No Serial Correlation[a] (5% Confidence)	R^2	Root MSE	N
				Constant	Year	Beginning of the Period	End of the Period				
Delta States	1. Linear : No break point			-1123.622 ***	0.5852***	3.36	1.08	Fail to reject	0.8238	5.1574	65
	2. Exponential: No break point			-28.8109***	0.0163***	1.65	1.65	Fail to reject	0.8124	4.7834	
	3. Linear-Linear	1968	Reject	-1093.619***	0.5709***	2.92	1.99	Fail to reject	0.8485	4.8605	
				24.3741***	0.7145***	2.93	1.26	Fail to reject			
	4. Exponential-Exponential	1968	Fail to reject	-43.6806***	0.0239***	2.42	2.42	Fail to reject	0.8212	4.6842	
				3.2611***	0.0178***	1.80	1.80	Reject			
Southern Plains	1. Linear : No break point			-529.3813 ***	0.2798***	1.72	0.83	Reject	0.5563	4.7619	65
	2. Exponential: No break point			-23.3786***	0.0134***	1.35	1.35	Reject	0.5350	5.3047	
	3. Linear-Linear	1962	Reject	-2688.988***	1.3829***	18.19	6.45	Fail to reject	0.6755	4.1391	
				22.6635***	0.1855***	0.82	0.58	Fail to reject			
	4. Exponential-Exponential	1962	Reject	-174.6858***	0.0907***	9.49	9.49	Reject	0.7635	4.1203	
				3.1088***	0.0072***	0.72	0.72	Fail to reject			
Mountains	1. Linear : No break point			-1236.333 ***	0.645 ***	2.95	1.03	Reject	0.9000	4.099	65
	2. Exponential: No break point			-30.5192***	0.0173***	1.74	1.74	Reject	0.8475	5.8440	
	3. Linear-Linear	2000	Reject	-1576.135***	0.8178***	4.38	1.41	Reject	0.9553	2.7861	
				53.2833***	0.2678	0.50	0.47	Fail to reject			
	4. Exponential-Exponential	1973	Reject	75.6567***	0.0403***	4.11	4.11	Reject	0.9556	3.3564	
				3.6985***	0.0102***	1.02	1.02	Reject			
Pacific	1. Linear : No break point			-1492.03***	0.7790***	2.88	1.02	Reject	0.8339	6.6257	65
	2. Exponential: No break point			-29.6494***	0.0169***	1.71	1.71	Reject	0.8236	8.3942	
	3. Linear-Linear	1980	Reject	-1883.22***	0.9772***	4.38	1.97	Fail to reject	0.9341	4.2421	
				62.5762***	0.1543*	0.25	0.23	Fail to reject			
	4. Exponential-Exponential	1980	Reject	-49.0922***	0.0268***	2.72	2.72	Fail to reject	0.9546	4.0982	
				4.1363***	0.0022*	0.22	0.22	Fail to reject			

Note: 1) *** is significant at the 1 percent level.

2) [a] denotes the portmanteau (or Q) test for white noise.

3) N denotes the number of observations.

We begin with a discussion of the results for the corn (see table 3) which is the largest agricultural crop in terms of U.S. acreage. To determine the best fitting model for each region, first, the structural break test is used to eliminate unpromising models. Failing to reject the null hypothesis of no structural break in the Linear-Linear model of Northeast, Lake States and Appalachian regions at the 5 percent level implies that in these areas the Linear-Linear model is not viewed as a proper model for examining corn yield growth rate. This suggests not enough evidence to support the existence of the structural break during the analyzed period. Thus, the Linear-Linear models of Northeast, Lake States and Appalachian regions are not considered when making a decision for the best fitting model for these two regions.

For cotton, hay, and sorghum (see table 4 to table 6), a break year is exhibited in yield growth in all regions, whether the functional form is linear or exponential, except only for the Pacific for cotton and sorghum. This exception results from the lack of cotton and sorghum yield data from 1964 to 1973 and 1990 to 1999, respectively. Nevertheless for soybeans (see table 7), the results of the structural break tests for Corn Belt and Northern Plains apparently suggest no structural break for both Linear-Linear and Exponential- Exponential models. However, in other regions, soybeans show a sufficient evidence for a presence of structural break.

For winter wheat, the results from table 8 support the presence of a structural break for most of the regions excluding the Linear-Linear model of Corn Belt region and the Exponential- Exponential model of Delta States region. Hence, the models of soybeans with a structural break for Corn Belt and Northern Plains regions, and the

Linear-Linear model of Corn Belt region and the Exponential- Exponential model of Delta States region for winter wheat are ruled out. Overall, there exists the evidence of the structural break year for all six crops in most of the regions, and also most of the break years are the same or close to each other. Hence, it is necessary to take account of a change in the technological progress of these six crops via a structural break. After using the structural break test to eliminate some of the unpromising model choices, the simple criterion of minimizing Root MSE comes to play a major role in selecting the best fitting model.

The Best Fitting Model and Estimated Growth Rates

To find the best fitting model, the main items considered are the structural break test, the simple criterion of minimizing Root MSE, and autocorrelation. For all six crops in each region, the estimated results from the best fitting models after correcting for autocorrelation if it is detected are presented in table 9 to table 14. Furthermore, to get the clear picture of the trends from the best fitting models, we also display the predicted crop yield value line from the best fitting model for each crop in each region along with its historical yield data in figure 9 to figure 14.

Table 9. The Best Fitting Models for Estimated Corn Yield Growth Rate in Ten Regions

Region	Model	Break Year	Estimation		Estimated Growth Rate (%)		R^2	Root MSE	N
			Constant	Year	Beginning of the Period	End of the Period			
Northeast	4. E-E	1963	-67.3651***	0.0365***	3.71	3.71	0.8620	12.122	65
			4.2174***	0.0140***	1.41	1.41			
Lake States	4. E-E	1973	-54.9221***	0.0301***	3.06	3.06	0.9241	9.797	65
			4.3965***	0.0172***	1.73	1.73			
Corn Belt	4. E-E	1970	-67.4934***	0.0366***	3.72	3.72	0.8984	13.308	65
			4.4715***	0.0145***	1.46	1.46			
Northern Plains	4. E-E	1977	-84.6249***	0.0450***	4.61	4.61	0.9530	9.395	65
			4.4444***	0.0143***	1.44	1.44			
Appalachian	4. E-E	1977	-70.3725***	0.0379***	3.86	3.86	0.8973	12.337	65
			4.3061***	0.0158***	1.59	1.59			
Southeast	4. E-E	1968	-131.4627***	0.0688***	7.12	7.12	0.9201	9.993	65
			3.7216***	0.0251***	2.54	2.54			
Delta States	4. E-E	1982	-61.4506***	0.0331***	3.36	3.36	0.9632	9.019	65
			4.3970***	0.0224***	2.26	2.26			
Southern Plains	4. E-E	1971	-110.9312***	0.0583***	6.00	6.00	0.9605	10.907	65
			4.5006***	0.0096***	0.96	0.96			
Mountains	3. L-L	1981	-4527.79***	2.3349***	9.25	2.51	0.9902	4.655	65
			120.6924***	1.4105***	1.17	0.85			
Pacific	4. E-E[a]	1982	-50.4422***	0.0279***	2.83	2.83	0.9723	5.501	65
			5.0037***	0.0095***	0.95	0.95			

Note: 1) *** is significant at the 1 percent level.

2) [a] denotes the model after being corrected for autocorrelation and the model can pass the Durbin-Watson test.

3) N denotes the number of observations.

Table 10. The Best Fitting Models for Estimated Cotton Yield Growth Rate in Ten Regions

Region	Model	Break Year	Estimation		Estimated Growth rate (%)		R^2	Root MSE	N
			Constant	Year	Beginning of the Period	End of the Period			
Northeast	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Lake States	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Corn Belt	4. E-E	1966	-87.4084***	0.0477***	4.89	4.89	0.8013	97.843	65
			5.8436***	0.0239***	2.42	2.42			
Northern Plains	3. L-L	1988	-119906.7***	60.5714***	-3.38	15.60	0.7606	97.67	33
			211.5794***	20.1178***	9.51	2.82			
Appalachian	4. E-E	1966	-61.9130***	0.0347***	3.53	3.53	0.7958	85.212	65
			5.8129***	0.0217***	2.19	2.19			
Southeast	3. L-L	1998	-16773.49***	8.7382***	3.29	1.31	0.8013	81.779	65
			536.9706***	22.1673***	4.13	2.55			
Delta States	4. E-E[a]	1966	-72.0088***	0.0399***	4.07	4.07	0.7443	89.090	65
			6.1662***	0.0156***	1.57	1.57			
Southern Plains	1. L[a]	No	-14019.05***	7.2712***	4.55	1.18	0.4498	74.789	65
Mountains	4. E-E[a]	1969	-44.8836***	0.0263***	2.67	2.67	0.8417	76.434	65
			6.5254***	0.0136***	1.37	1.37			
Pacific	2. E	Gaps not allowed	-12.4912***	0.0098***	0.99	0.99	0.6440	146.45	55

Note: 1) *** is significant at the 1 percent level.

2) [a] denotes the model after being corrected for autocorrelation and the model can pass the Durbin-Watson test.

3) N denotes the number of observations.

Table 11. The Best Fitting Models for Estimated Hay Yield Growth Rate in Ten Regions

Region	Model	Break Year	Estimation		Estimated Growth Rate (%)		R^2	Root MSE	N.
			Constant	Year	Beginning of the Period	End of the Period			
Northeast	4. E-E[a]	1987	-25.2264***	0.0131***	1.32	1.32	0.8288	0.112	65
			0.8214***	-0.0038***	-0.38	-0.38			
Lake States	4. E-E	1987	-34.3199***	0.0179***	1.80	1.80	0.7580	0.226	65
			1.0526***	-0.0043	-0.43	-0.43			
Corn Belt	4. E-E[a]	1973	-45.8352***	0.0237***	2.40	2.40	0.7651	0.206	65
			0.9603***	0.0025*	0.25	0.25			
Northern Plains	4. E-E	1988	-34.3064***	0.0176***	1.78	1.78	0.7862	0.186	65
			0.6092***	0.0051	0.52	0.52			
Appalachian	3. L-L	1989	-30.8525***	0.0164***	1.39	0.92	0.8559	0.147	65
			2.1446***	-0.0003	-0.01	-0.01			
Southeast	4. E-E	1968	-99.9657***	0.0511***	5.25	5.25	0.9436	0.178	65
			0.6621***	0.0059***	0.59	0.59			
Delta States	4. E-E	1967	-44.8024***	0.0230***	2.33	2.33	0.8877	0.168	65
			0.5955***	0.0065***	0.65	0.65			
Southern Plains	4. E-E	1977	-60.1367***	0.0308***	3.13	3.13	0.7214	0.224	65
			0.7808***	-0.0059**	-0.59	-0.59			
Mountains	3. L-L[a]	1993	-79.1063***	0.0415***	2.26	1.17	0.9491	0.069	65
			3.6286***	0.0012	0.03	0.03			
Pacific	3. L-L[a]	1999	-81.6571***	0.0430***	1.93	1.01	0.9777	0.090	65
			4.3036***	-0.0056	-0.13	-0.13			

Note: 1) ***, **, and * are significant at the 1, 5, and 10 percent level, respectively.

2) [a] denotes the model after being corrected for autocorrelation and the model can pass the Durbin-Watson test.

3) N denotes the number of observations.

Table 12. The Best Fitting Models for Estimated Sorghum Yield Growth Rate in Ten Regions

Region	Model	Break Year	Estimation		Estimated Growth rate (%)		R^2	Root MSE	N
			Constant	Year	Beginning of the Period	End of the Period			
Northeast	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Lake States	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	11
Corn Belt	3. L-L[a]	1966	-6124.998***	3.1512***	15.83	4.92	0.7534	9.048	65
			62.2565***	0.6540***	1.05	0.70			
Northern Plains	1. L	No	-1483.99***	0.7755***	2.75	1.01	0.6484	10.883	65
Appalachian	3. L-L	1974	-3036.308***	1.5680***	7.38	2.81	0.8938	5.556	59
			49.9385***	0.8442***	1.69	1.02			
Southeast	3. L-L	1977	-1840.588***	0.9518***	6.19	2.43	0.7719	5.102	65
			36.4089***	0.3255***	0.89	0.68			
Delta States	3. L-L[a]	1982	-1700.683***	0.8821***	4.56	1.93	0.9425	5.130	65
			58.0801***	1.0090***	1.74	1.13			
Southern Plains	4. E-E[a]	1965	-127.6605***	0.0669***	6.92	6.92	0.8283	5.220	65
			3.8360***	0.0023	0.23	0.23			
Mountains	3. L-L[a]	1969	-4196.87***	2.1622***	11.12	3.85	0.2893	5.957	65
			52.6238***	0.0187	0.04	0.03			
Pacific	1. L[a]	Gaps not allowed	-1345.611***	0.7176***	1.34	0.73	0.6303	5.530	49

Note: 1) *** is significant at the 1 percent level.

2) [a] denotes the model after being corrected for autocorrelation and the model can pass the Durbin-Watson test.

3) N denotes the number of observations.

Table 13. The Best Fitting Models for Estimated Soybean Yield Growth Rate in Ten Regions

Region	Model	Break Year	Estimation		Estimated Growth Rate (%)		R^2	Root MSE	N
			Constant	Year	Beginning of the Period	End of the Period			
Northeast	3. E	No	-23.3138***	0.0134***	1.35	1.35	0.7937	3.547	65
Lake States	4. E-E[a]	1977	-24.3307***	0.0139***	1.40	1.40	0.9382	2.988	65
			3.4400***	0.0088***	0.89	0.89			
Corn Belt	1. L		-790.3271***	0.4160***	1.99	0.88	0.8854	2.852	65
Northern Plains	1. L		-777.5979***	0.4059***	2.91	1.03	0.8399	3.378	65
Appalachian	4. E-E[a]	1968	-45.7951***	0.0249***	2.52	2.52	0.7697	3.494	65
			3.0854***	0.0122***	1.23	1.23			
Southeast	4. E-E	1968	-65.9412***	0.0352***	3.58	3.58	0.6288	3.584	65
			2.9841***	0.0096***	0.96	0.96			
Delta States	3. L-L	1998	-389.0693 ***	0.2086***	1.18	0.76	0.8558	3.101	65
			25.1438***	1.3742***	5.47	3.00			
Southern Plains	3. L-L[a]	1963	-6888.015***	3.5371***	38.10	7.34	0.6394	6.931	65
			44.1214***	0.1743**	0.40	0.33			
Mountains	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Pacific	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

Note: 1) *** and ** are significant at the 1 and 5 percent level, respectively.

2) [a] denotes the model after being corrected for autocorrelation and the model can pass the Durbin-Watson test

3) N denotes the number of observations.

Table 14. The Best Fitting Models for Estimated Winter Wheat Yield Growth Rate in Ten Regions

Region	Model	Break Year	Estimation		Estimated Growth Rate (%)		R^2	Root MSE	N
			Constant	Year	Beginning of the Period	End of the Period			
Northeast	3. L-L	1972	-1598.127 ***	0.8309***	3.74	2.14	0.9198	3.660	65
			34.3775***	0.7350***	2.14	1.14			
Lake States	4. E-E[a]	1965	-54.1693***	0.0294***	2.98	2.98	0.8825	4.273	65
			3.4609***	0.0144***	1.45	1.45			
Corn Belt	4. E-E	1973	-55.0779***	0.0298***	3.03	3.03	0.8791	4.463	65
			3.6113***	0.0135***	1.36	1.36			
Northern Plains	4. E-E	1974	-58.7571***	0.0316***	3.21	3.21	0.8132	3.881	65
			3.3330***	0.0118***	1.19	1.19			
Appalachian	4. E-E	1972	-67.8061***	0.0362***	3.69	3.69	0.9429	3.825	65
			3.4683***	0.0169***	1.71	1.71			
Southeast	4. E-E	1972	-57.6689***	0.0310***	3.15	3.15	0.8791	4.215	65
			3.2451***	0.0186***	1.88	1.88			
Delta States	2. E		-28.8109***	0.0163***	1.65	1.65	0.8124	4.783	65
Southern Plains	4. E-E[a]	1962	-176.1104***	0.0914***	9.57	9.57	0.7275	4.120	65
			3.1083***	0.0072***	0.72	0.72			
Mountains	3. L-L[a]	2000	-1571.189***	0.8153***	4.35	1.41	0.8947	2.551	65
			53.1595***	0.3117	0.59	0.54			
Pacific	4. E-E	1980	-49.0922***	0.0268***	2.72	2.72	0.9546	4.098	65
			4.1363***	0.0022*	0.22	0.22			

Note: 1) ***and * are significant at the 1 and 10 percent level, respectively.

2) [a] denotes the model after being corrected for autocorrelation and the model can pass the Durbin-Watson test.

3) N denotes the number of observations.

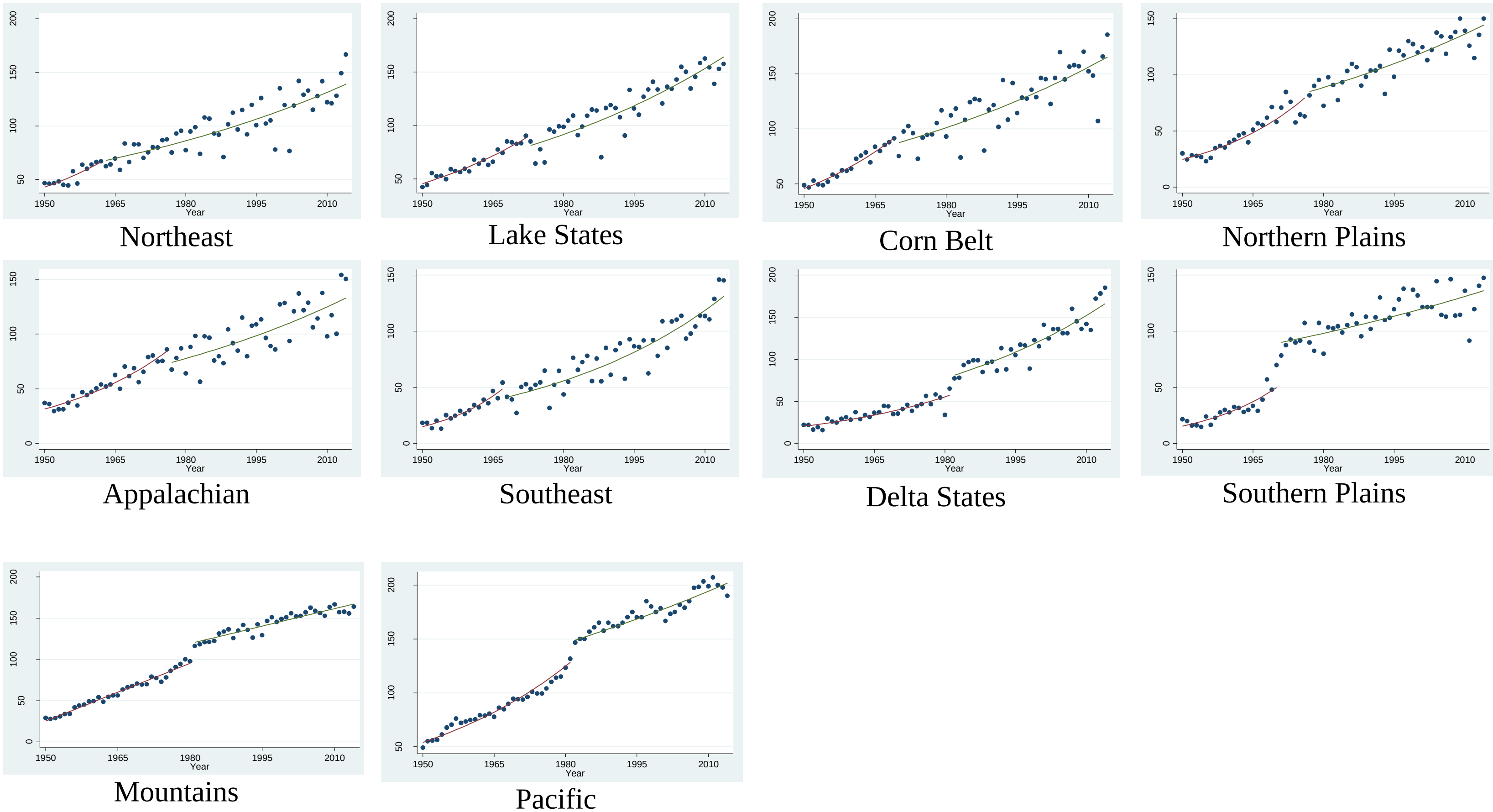

Figure 9. U.S. historical corn yield with the best fitting models in ten regions from 1950 to 2014

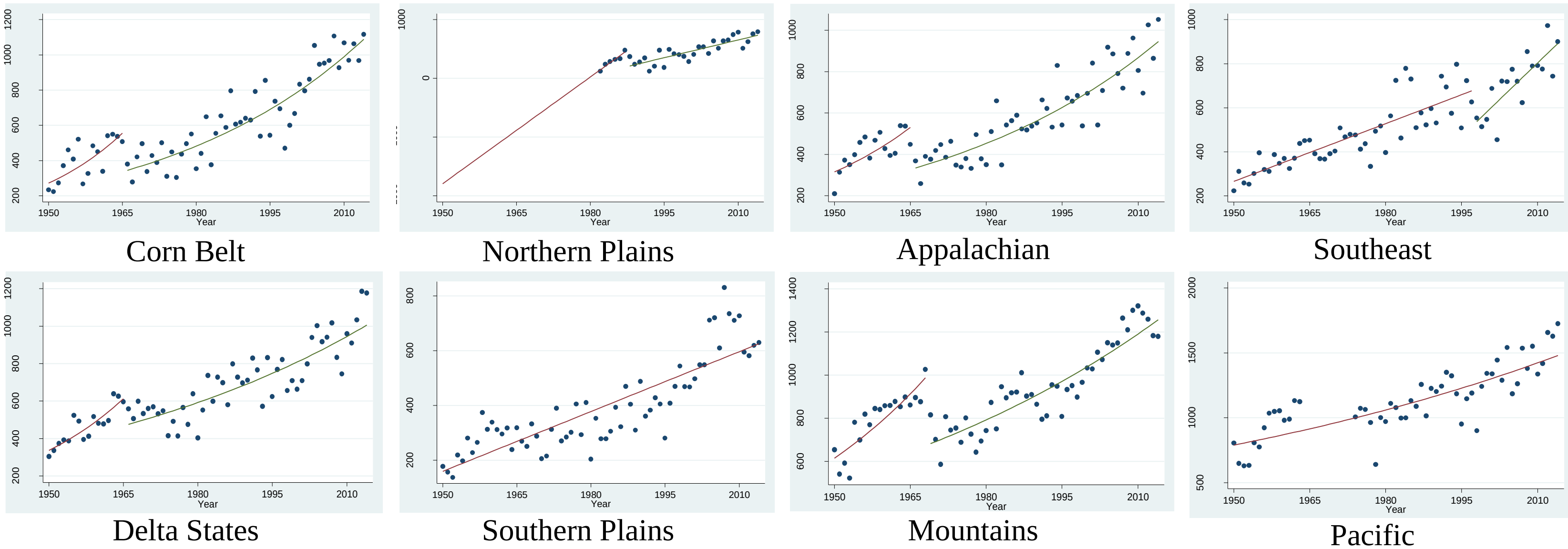

Figure 10. U.S. historical cotton yield with the best fitting models in eight regions from 1950 to 2014

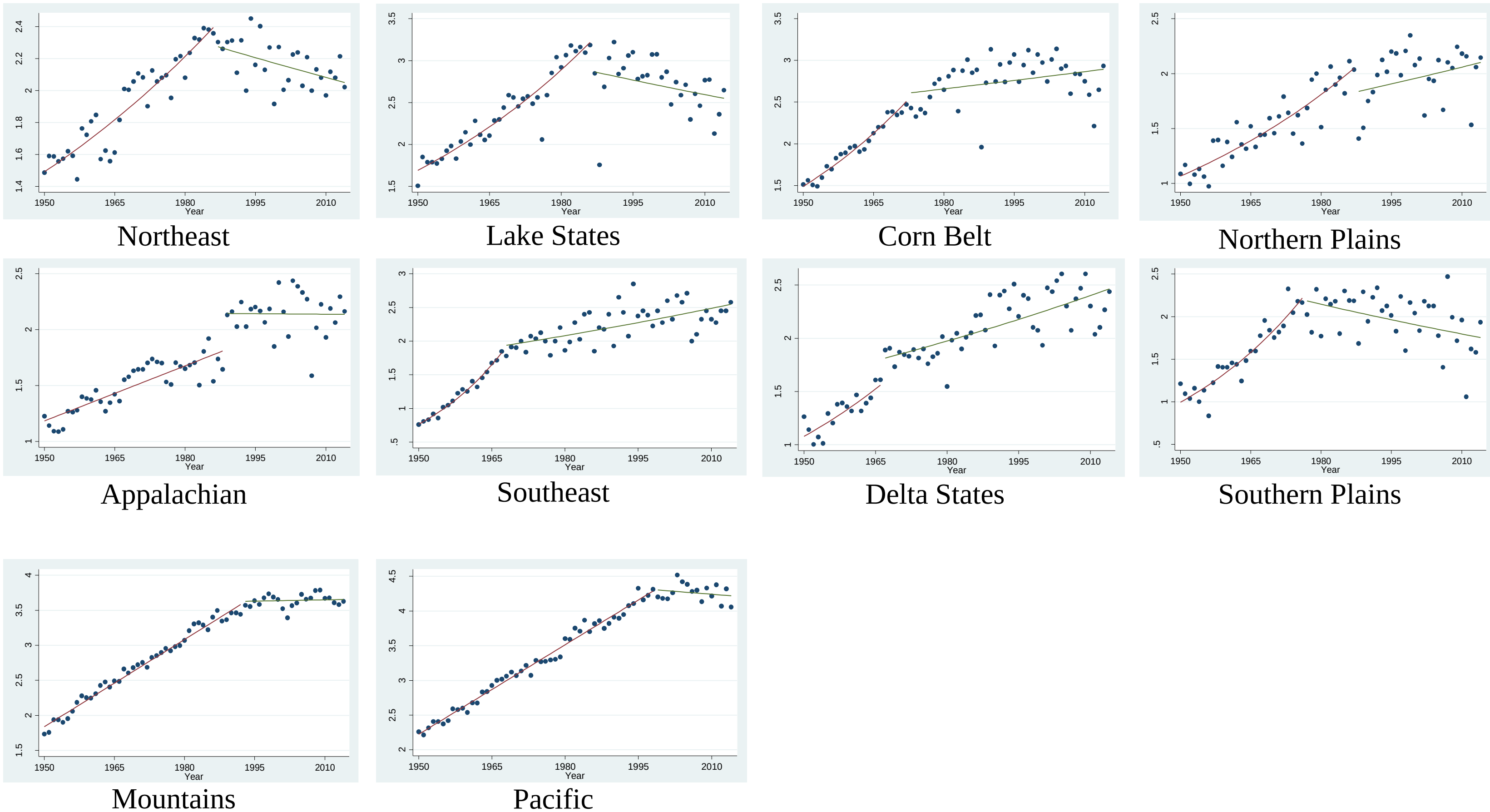

Figure 11. U.S. historical hay yield with the best fitting models in ten regions from 1950 to 2014

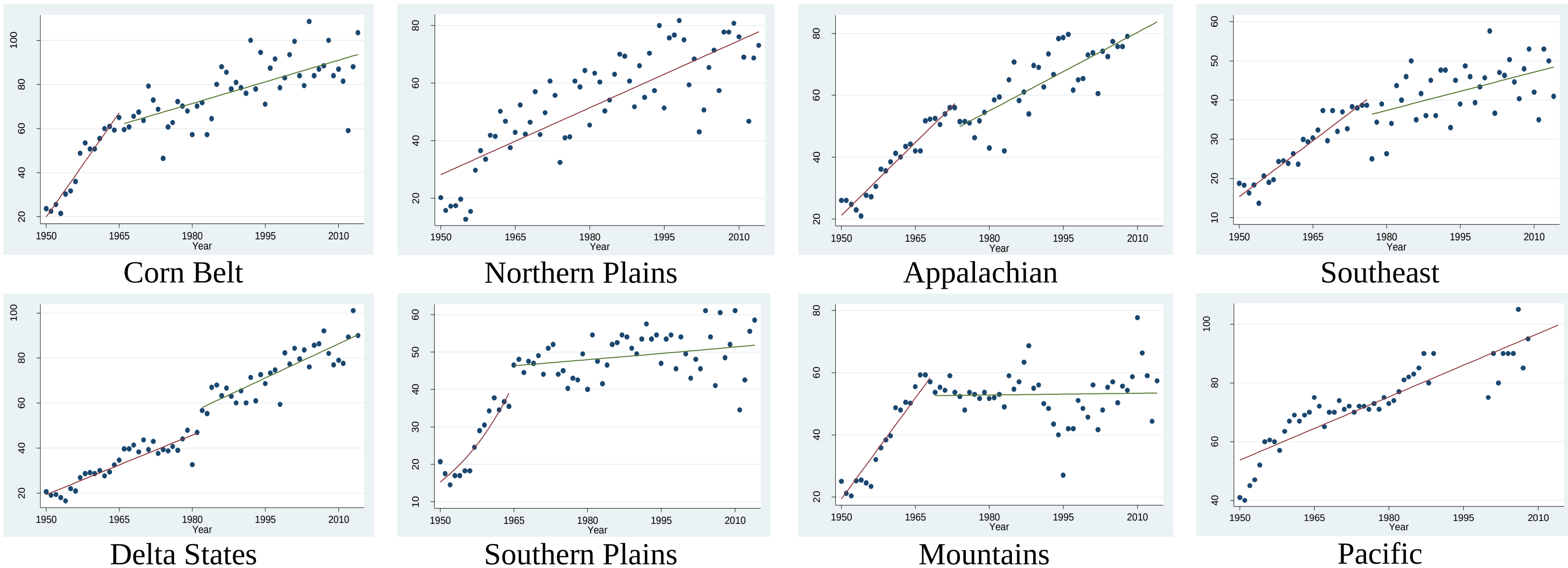

Figure 12. U.S. historical sorghum yield with the best fitting models in eight regions from 1950 to 2014

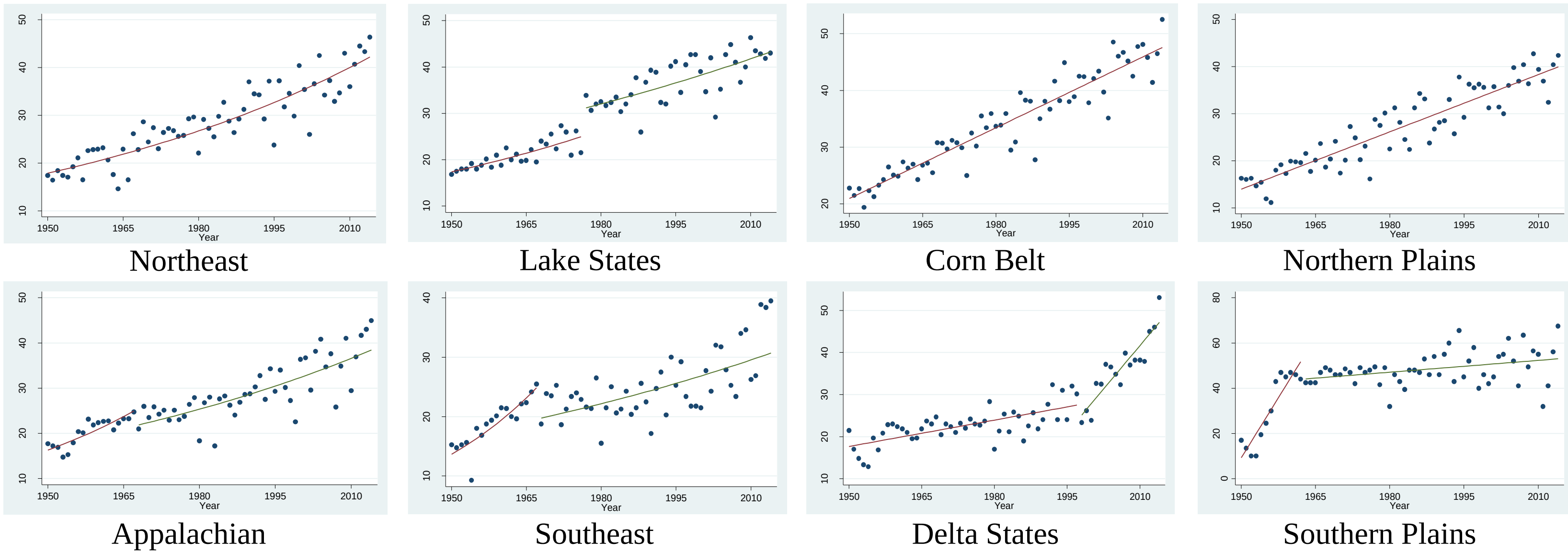

Figure 13. U.S. historical soybean yield with the best fitting models in eight regions from 1950 to 2014

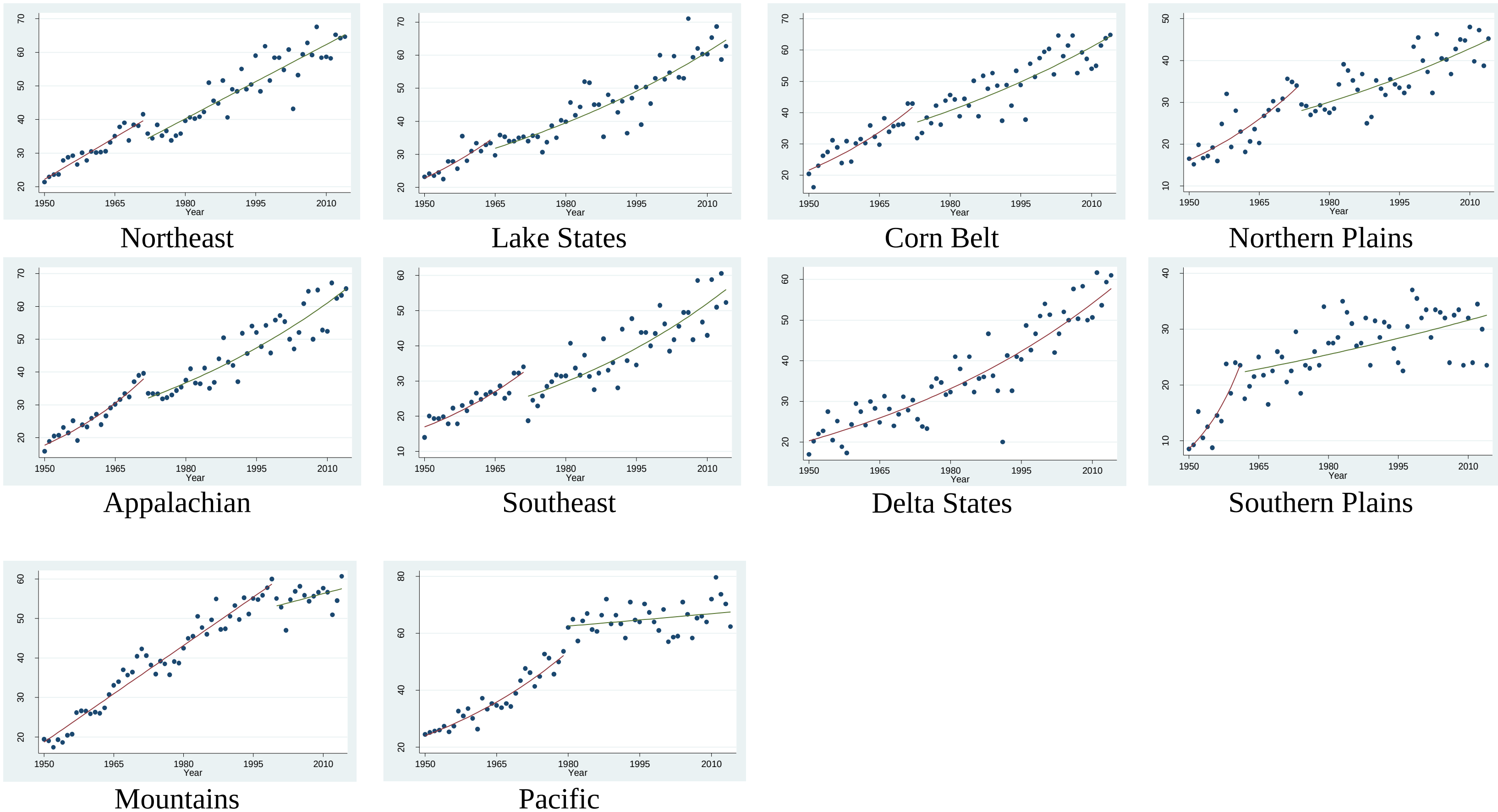

Figure 14. U.S. historical winter wheat yield with the best fitting models in ten regions from 1950 to 2014

In general for the corn yield results (table 9), the best fitting model is the Exponential-Exponential model except only for the Mountains region of which the best fitting model is the Linear-Linear model. These results are also consistent with the best fitting model in terms of R^2. Hence, we can conclude that a break point is exhibited in corn yield growth. The estimated break years are during the 1960s to the beginning of the 1980s differing by region. Half of the estimated break years exist in the 1970s. We notice that for all of the regions, the corn yield growth rate after the break year is less than the rate before the break mostly by 60 percent or more. Thus, generally, corn yield growth continues but at a slower rate after the break year (see figure 9). Surprisingly, the corn yield growth rate in the Corn Belt region is not the highest rate of all regions, even though we expect to see the faster increases of technological progress in this region since it is the predominant corn production area in the U.S.

The best fitting models for other crops i.e. cotton, hay, sorghum, soybeans, and winter wheat are presented in table 10 to table 14, respectively. A presence of a structural break point is clearly exhibited in cotton and winter wheat yield growths except only for the Delta States region of winter wheat. While the two regions of cotton and sorghum data, and the three regions of soybean data do not have the break point in the best fitting models. Nevertheless, the Pacific region of cotton and sorghum are not mentioned about the break point since the break is not allowed in the model for this region.

For soybean best fitting models (table 13), it is concluded that most of the models have the structural break point. However, there is not enough evidence to support the existence of a structural break year in the Corn Belt and the Northern Plains regions of soybean growth rate estimation. Most of the estimated break years from the best fitting models for cotton, sorghum, and soybeans are defined during the 1960s, while for hay and winter wheat they exist near the end of the 1980s and the early 1970s, respectively.

For the best fitting model choice, the Exponential-Exponential model is the best model for estimating yield growth rate for cotton, hay, soybeans, and winter wheat. However, the Linear-Linear model is the dominant model for estimating the sorghum yield growth rate. Concerning the best fitting models with the presence of structural break for hay, sorghum, and winter wheat, all of these crop yield growth rates after the break year are lower than the rates before the break. Generally, the rates after the break reduced by about 50 percent or more relative to the rates before the break.

Especially, all of the growth rates of hay after the break are less than 1 percent with the reductions of 70 percent or more relative to the growth rates before the break. Furthermore, for hay in some regions i.e. Northeast, Lake States, Appalachian, Southern Plains, and Pacific, it shows a decreasing yield growth (negative growth rate) after its break year (see table 11) and this is illustrated by the downward-sloping graphs shown in figure 11. Whereas for other regions of hay and all regions of sorghum and winter wheat with the break point model, the estimate results imply that their crop yield growths are increasing but grow at a decreasing rate after the break year.

Nevertheless, the growth rate results of cotton and soybeans differ from the others. Most of the growth rates after the break year are less than the rates before the break year, but for a few regions, the rates are found to be larger (table 10 and table 13).

In the Northern Plains region of cotton, it indicates a decreasing rate at the beginning of the period before the break year, but after the break year, the growth rate becomes an increasing rate with its value tripled the former. In addition, after the break year it shows almost 30 percent increase in the cotton growth rate in the Southeast region at the beginning of the period and the rate at the end of the period is nearly double the one before the break year. Likewise, the soybean growth rate in the Delta States region increases after the break year, but the increase is much greater as noticed by the sharp increase after the break point in these two regions (see figure 10 and figure 13). Hence for the results of cotton and soybean growth rates, it is uncertain to conclude the uniform tendency of their growth rates after the break because in most of the regions the growth rates are found to be larger than the growth rates before the break, while they are smaller in a few regions.

Within the same crop, the magnitude of yield growth rate varies across regions, especially before the break year. Nevertheless, corn and winter wheat growth rates are mostly around 3 to 4 percent, while hay growth rate is approximately 1 to 2 percent for most of the regions. After the break year, the growth rate value is more similar across regions in each crop, mostly 1 to 2 percent growth rate for corn, sorghum, and winter wheat; 1 to 3 percent for cotton, -0.6 to 0.7 percent for hay; and 0.3 to 1.2 percent for soybeans. Among all six crops, the estimated growth rates for corn and hay seem to be most alike.

Furthermore, we notice that the corn growth rates in the Northeast and the Corn Belt regions are very close to each other i.e. 3.71 and 3.72 percent before the break year;

and 1.41 and 1.46 percent after the break year. We also see this similarity in the Appalachian region where the corn growth rates before and after the break year are 3.86 and 1.59 percent, respectively. This result points out the relationship of corn yield growth rate that appears to exist in some regions.

There are three anomalous results in the linear growth rates. The two growth rate values at the beginning of the period before the break year in the Corn Belt region of sorghum and the Southern Plains region of soybeans are very large being 15.83 and 38.10 percent, respectively. The other result is the large linear growth rate of cotton at the end of the period before the break year in the Northern Plains region, which equals to 15.6 percent. These growth rates are much larger compared to other linear growth rates which are generally less than 10 percent and their linear graphs are very steep as shown in figure 10, figure 12 and figure 13. For cotton in the Northern Plains region, this may be caused by the small number of yield data observed in this region and its relatively minor acreages. We do not have the cotton yield data in the Northern Plains region during the year 1950 to 1981 which should be the data used to estimate the growth rate before its break year (see figure 10). This issue of having a smaller number of observations possibly accounts for the error in estimating the growth rate before the break year in the Northern Plains region. As for sorghum in the Corn Belt region and soybeans in the Southern Plains region, the possible error may result from the lack of yield data in some states during the few years at the beginning of the analysis, i.e. the soybean yield data in Texas, the sorghum yield data in Illinois and Iowa.

Regarding statistical significance of the estimated coefficients from the best fitting models, most of the estimated coefficients from all the best fitting models are statistically significant at the 1 percent level. Nevertheless, some statistically insignificant estimated coefficients are found in hay models, where the coefficients are from the after break section. With the autocorrelation issue, the problem are mostly found in sorghum and hay best fitting models. However, after we correct this problem and obtain the growth rates, we notice that the estimates are similar to the ones obtained from the models before correcting for the autocorrelation.

Long Term Correlation

To analyze technological progress across regions in the U.S., it is also important to consider what happens across regions in particular to what extent do the yields vary together – i.e. their historical correlation. Estimates of the historical correlation help improve the formulation of scenarios that are used in the simulation which is performed later in this study. Hence, the correlation of historical crop yield across regions was analyzed.

Since we focus on the technological progress, the long-term correlation is for the ratios of average yield growth between different time periods. We first examined the ten-year average yield growth. To do this for each crop, we computed the average yield in a period of ten years then form the ratio. The average data contain ten-year average yield values in 1950 to 1959, 1951 to 1960, 1952 to 1961,…, and 2005 to 2014. Let Ave1950s, Ave1951s,…, and Ave2005s denote ten- year average yield value in 1950 to

1959, ten-year average yield value in 1951 – 1960, …, and ten-year average yield value in 2005 – 2014, respectively. Then the ratios between the current ten-year average yield and the corresponding one 10 years earlier were calculated. For example, the first ratio is the average yield value in 1960-1969 (Ave 1960s) dividing by the average yield value in 1950-1959 (Ave 1950s), and the last ratio is the average yield value in 2005-2014 (Ave 2005s) dividing by the average yield value in 1995-2004 (Ave 1995s). Using the ratios of average yield, we calculated the correlation coefficients among all available regions and used a Student-t test to test for their significance at 5 percent level for corn, cotton, hay, sorghum, soybean, and winter wheat as shown in table 15 to table 20.

Then the historical data were reanalyzed via the same approach but the average period was changed to five and three years. The purpose of this reanalysis with the shorter periods is to have more average yield observations in the study compared to the ten-year average yield data. Hence, it reduces the information loss from the historical data. Furthermore, the shorter period analysis offers an alternative insight into the correlation of long-term technological progress across regions in the U.S. The results of the shorter time analysis containing the correlation coefficients of ratios across all available regions for the main six crops are provided in table 55 to table 66 in Appendix A.

Table 15. Correlation Matrix of Ratios of Ten-Year Average Corn Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP	MT	PA
NE	1	0.63*	0.82*	0.81*	0.85*	0.82*	-0.04	0.64*	0.55*	0.14
LS		1	0.86*	0.81*	0.65*	0.75*	0.15	0.43*	0.55*	0.17
CB			1	0.89*	0.88*	0.88*	-0.03	0.55*	0.52*	0.04
NP				1	0.90*	0.84*	0.12	0.80*	0.76*	0.32
AC					1	0.79*	-0.22	0.78*	0.49*	-0.02
SE						1	0.22	0.43*	0.64*	0.26
DS							1	-0.14	0.64*	0.89*
SP								1	0.58*	0.21
MT									1	0.84*
PA										1
No. of Obs.	46									

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 16. Correlation Matrix of Ratios of Ten-Year Average Cotton Yield across Regions

Ratio	CB	NP	AC	SE	DS	SP	MT	PA
CB	1	0.88*	0.75*	0.83*	0.94*	0.84*	0.94*	0.96*
NP		1	0.52	0.62*	0.86*	0.87*	0.94*	0.78*
AC			1	0.86*	0.71*	0.47	0.62*	0.78*
SE				1	0.89*	0.49	0.68*	0.84*
DS					1	0.79*	0.90*	0.89*
SP						1	0.95*	0.79*
MT							1	0.90*
PA								1
No. of Obs.	14							

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 17. Correlation Matrix of Ratios of Ten-Year Average Hay Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP	MT	PA
NE	1	0.88*	0.83*	0.66*	0.26	0.69*	0.70*	0.87*	0.88*	0.79*
LS		1	0.94*	0.92*	0.24	0.70*	0.59*	0.81*	0.93*	0.89*
CB			1	0.90*	0.44*	0.86*	0.75*	0.91*	0.91*	0.91*
NP				1	0.32	0.67*	0.49*	0.70*	0.82*	0.83*
AC					1	0.56*	0.70*	0.46*	0.41*	0.50*
SE						1	0.92*	0.92*	0.81*	0.79*
DS							1	0.84*	0.77*	0.78*
SP								1	0.84*	0.78*
MT									1	0.94*
PA										1
No. of Obs.	46									

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 18. Correlation Matrix of Ratios of Ten-Year Average Sorghum Yield across Regions

Ratio	CB	NP	AC	SE	DS	SP	MT	PA
CB	1	0.97*	0.94*	0.91*	0.85*	0.97*	0.99*	0.92*
NP		1	0.86*	0.83*	0.83*	0.92*	0.96*	0.96*
AC			1	0.99*	0.81*	0.99*	0.97*	0.77*
SE				1	0.82*	0.97*	0.95*	0.73*
DS					1	0.84*	0.86*	0.87*
SP						1	0.99*	0.84*
MT							1	0.89*
PA								1
No. of Obs.	21							

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 19. Correlation Matrix of Ratios of Ten-Year Average Soybean Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP
NE	1	0.23	0.33*	-0.16	-0.02	-0.04	-0.21	0.09
LS		1	0.44*	0.49*	-0.72*	-0.67*	-0.84*	-0.20
CB			1	0.65*	0.05	0.18	-0.22	0.40*
NP				1	-0.13	0.07	-0.34*	0.37*
AC					1	0.80*	0.67*	0.66*
SE						1	0.73*	0.71*
DS							1	0.18
SP								1
No. of Obs.	46							

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 20. Correlation Matrix of Ratios of Ten-Year Average Winter Wheat Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP	MT	PA
NE	1	-0.13	0.30	0.18	0.83*	0.50*	-0.28	0.20	0.65*	-0.07
LS		1	0.53*	0.09	-0.24	0.37*	0.70*	0.45*	-0.09	-0.04
CB			1	0.66*	0.49*	0.48*	0.40*	0.70*	0.57*	0.13
NP				1	0.54*	0.04	-0.02	0.33*	0.54*	0.08
AC					1	0.49*	-0.26	0.28	0.79*	-0.02
SE						1	0.56*	0.47*	0.31	-0.20
DS							1	0.32	-0.29	-0.25
SP								1	0.66*	0.56*
MT									1	0.55*
PA										1
No. of Obs.	46									

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

With reference to Peck and Devore (2011), the correlation (ρ) is classified as follows:

1. $-1 \leq \rho \leq -0.8$ denotes a strong negative correlation,
2. $-0.8 \leq \rho \leq -0.5$ denotes a moderate negative correlation,
3. $-0.5 \leq \rho \leq 0$ denotes a weak negative correlation,
4. $0 \leq \rho \leq 0.5$ denotes a weak positive correlation,

5. $0.5 \leq \rho \leq 0.8$ denotes a moderate positive correlation,
6. $0.8 \leq \rho \leq 1$ denotes a strong positive correlation.

Based on this classification, we provide table 21 containing the numbers and proportions of significant strong (S), moderate (M), and weak (W) correlations between each region yield ratios for all interested six crops in three different average times; ten-year, five-year, and three-year periods.

According to table 21, first, we discuss the correlations of ten-year average yield ratios. For corn, cotton, hay and sorghum, more than a half of all correlations exhibit strong and moderate positive correlations. Strong positive correlations are mostly founded in cotton, hay, and sorghum, especially sorghum which its strong positive correlation accounts for 93 percent. Furthermore, all of the correlations of sorghum yield across regions are statistically significant at the 5 percent level. As for corn data, most of the correlations are strong and moderate positive correlations accounting for the same proportion (31 percent). Regarding winter wheat, positive moderate and strong correlations comprise about one-third of all correlations, which mostly are the moderate ones. While, for soybeans, the numbers of moderate and weak positive correlations are the same (18 percent) and they represent most of all correlations. Interestingly, we notice the strong and moderate negative correlations only from soybean data. All these negative correlations are associated with the Lake States region. Although we take much interest in the strong and moderate correlation, we have to keep in mind that even the weak correlation can imply meaningfulness in a relationship (Peck and Devore 2011).

Table 21. Proportions of Significant Strong, Moderate, and Weak Correlations between Average Yield Ratios in Different Time Periods

	Number of Significant[1] Correlations								Total[3]
Average Period	Strong (S)	S Neg.	Moderate (M)	M Neg.	Weak (W)	W Neg.	All S&M[2]	All	
Ten-year									
Corn	14 (31%)	0 (0%)	14 (31%)	0 (0%)	3 (7%)	0 (0%)	28 (62%)	31 (69%)	45
Cotton	16 (57%)	0 (0%)	9 (32%)	0 (0%)	0 (0%)	0 (0%)	25 (89%)	25 (89%)	28
Hay	22 (49%)	0 (0%)	16 (36%)	0 (0%)	4 (9%)	0 (0%)	38 (84%)	42 (93%)	45
Sorghum	26 (93%)	0 (0%)	2 (7%)	0 (0%)	0 (0%)	0 (0%)	28 (100%)	28 (100%)	28
Soybeans	1 (4%)	1 (4%)	5 (18%)	2 (7%)	5 (18%)	1 (4%)	9 (32%)	15 (54%)	28
Winter Wheat	1 (2%)	0 (0%)	14 (31%)	0 (0%)	0 (0%)	8 (18%)	15 (33%)	23 (51%)	45
Five-year									
Corn	0 (0%)	0 (0%)	16 (36%)	0 (0%)	12 (27%)	0 (0%)	16 (36%)	28 (62%)	45
Cotton	1 (4%)	0 (0%)	11 (39%)	0 (0%)	1 (4%)	0 (0%)	12 (43%)	13 (46%)	28
Hay	1 (2%)	0 (0%)	31 (69%)	0 (0%)	7 (16%)	0 (0%)	32 (71%)	39 (87%)	45
Sorghum	11 (39%)	0 (0%)	15 (54%)	0 (0%)	2 (7%)	0 (0%)	26 (93%)	28 (100%)	28
Soybeans	2 (7%)	0 (0%)	5 (18%)	0 (0%)	10 (36%)	3 (11%)	7 (25%)	20 (71%)	28
Winter Wheat	0 (0%)	0 (0%)	9 (20%)	0 (0%)	14 (31%)	0 (0%)	9 (20%)	23 (51%)	45
Three-year									
Corn	0 (0%)	0 (0%)	7	0 (0%)	12	0 (0%)	7 (16%)	19 (42%)	45
Cotton	0 (0%)	0 (0%)	2	0 (0%)	2	0 (0%)	2 (7%)	4 (14%)	28
Hay	0 (0%)	0 (0%)	9	0 (0%)	18	0 (0%)	9 (20%)	27 (60%)	45
Sorghum	1	0 (0%)	12	0 (0%)	7	0 (0%)	13 (46%)	20 (71%)	28
Soybeans	0 (0%)	0 (0%)	8	0 (0%)	5	1	8 (29%)	14 (50%)	28
Winter Wheat	0 (0%)	0 (0%)	7	0 (0%)	9	0 (0%)	7 (16%)	16 (36%)	45

Note: 1) [1] means significant at the 5 percent level.

2) [2] include all strong and moderate correlations both in negative and positive form.

3) [3] is the total number of correlations as shown in the reduce form of the correlation matrix excluding correlations of a variable with itself and duplicate values.

For the five-year average time, most of the correlations between each region yield ratios are moderate positive correlations for corn, cotton, hay, and sorghum; and weak positive correlations for soybeans and winter wheat. Like in the case of the correlation in ten-year average time, all correlations are significant for sorghum, but the different is the proportion of strong positive correlations decreases by more than 50 percent. For the three-year average time, weak positive correlation represents most of all correlations for corn, hay, and winter wheat; while moderate positive correlation is mostly found in sorghum and soybean data. As for cotton data, most of the correlations are moderate and weak positive correlations accounting for the same proportion about 7 percent. The strong correlation is only observed in sorghum, but it accounts for only a small portion (4 percent). The weak negative correlation is only noticed in the Lake States region of soybean data for both five-year and three-year average periods.

In addition, we notice that the relationship between the long-term technical correlations and the estimated crop growth rates. Some strong positive correlations are found in the same regions where their estimated growth rate levels are very similar such as the case of corn in the Northeast and the Corn Belt, and the Appalachian regions (see table 9 and table 15). Oppositely, we also notice a strong negative correlation between two regions corresponding to the difference direction of growth rates exhibited in the same regions. In the case of soybeans in the Lake States and the Delta States, after the break Lake States growth rate decreases, an increase is found in the Delta States (see table 13 and table 19).

In general, mostly positive correlations are found for all six crops for all different time durations. This implies that when the crop yield in one region increases, so generally will the crop yields in the other regions, and vice versa. This association of crop yields in different regions which move in the same direction is apparently shown in sorghum and hay yields. However, for soybean yield, the negative correlations are presented and associated with the Lake States region and some regions i.e. Appalachian, Southeast and Delta States. This indicates that as the level of soybean yield in Lake States region increases, the levels of soybean yield in the three regions mentioned above decrease. Nevertheless, these negative correlations are weak when using five-year and three-year average periods. In conclusion, for most crops, more than 50 percent of all crop yield correlations among regions are statistically significant, so these correlations should not be ignored in our study of technological progress.

Comparing between the correlations from ten-year, five-year, and three- year average periods, we notice that in general, the number of significant correlations and the degree or strength of the relationship between yields of different regions is lower as the average time is getting shorter. The possible explanation is that longer average time makes the data smoother by reducing the effect of extreme events such as droughts, floods, and hurricanes and also the measurement error in the data, so the degree of the relationship becomes stronger. It also better addresses long-term trends. An example of an extreme event with severely affected U.S. agricultural crops is the 2012 U.S. Corn Belt drought which damaged U.S. primary field crops in the Midwest Region, especially corn and soybeans (ERS 2015). This had an impact on crop yield production and a particularly severe impact in some regions, which may result in distortion of the exact technological progress. Hence, in order to project technological progress in long-term period, the appropriate average time should be considered to reduce the effect of extreme events and measurement errors, and to achieve valid results.

Conclusion

This study investigates how crop yields have progressed over time using historical crop yield data based on the regional level. The first major finding is that there has been non-uniform technical progress across available regions for each crop especially cotton and soybeans. The possible explanation is that regions have different degrees of suitability for the crops exhibiting varying altitudes, soil types, and weather. Nevertheless, in some regions, the growth rates are very similar, and this possibly links to the long-term strong positive correlation among those regions.

The second finding is that technical progress is slowing down in many cases with the estimations showing a break year, especially for corn, cotton, and winter wheat. The break year mostly occurs in the 1960s or 1970s. For most of the regions, initially, the technical progress rate is 3 to 4 percent for corn and winter wheat and 1 to 2 percent for hay. After the break, most of the technical progress rates are less than 2 percent and some cases exhibiting a decreasing rate. This slowing technical progress raises concerns about the extent to which U.S. agriculture can participate in biofuel production while meeting growing food demands.

The third finding is that positive long-term technical progress correlations are mostly found in the historical data for all crops. Hence, most of the regions advance together in terms of technical progress. These correlations are related to the estimated technical progress rates. For example, the strong positive long-term correlation among Northeast and Corn Belt regions of corn corresponds with the similarity of the estimated corn growth rates in these areas. Nevertheless, there exist some of the negative long-term technical progress correlations.

CHAPTER III

FORMING FUTURE SCENARIOS ON TECHNOLOGICAL PROGRESS, AGRICULTURAL DEMAND, AND ENERGY POLICY

Introduction

This essay will form scenarios based on the forecast technological progress in the prior chapter under scenarios of demand growth and biofuel policy.

Data

The technological progress data used to form scenarios in this chapter are scenarios based on the historical crop yield analysis in Chapter II. Agricultural demand data were obtained from other sources as follows:

1. Commodity import, export, domestic consumption, price, and production data from NASS Database (2016)
2. Crop price projections from USDA (2015) long-term projections
3. Real historical gross domestic product (GDP), growth rates of GDP, and historical GDP deflators in 1969 to 2014; projected GDP, growth rates of GDP, projected GDP deflators, projected U.S. population, and growth rates in 2010 to 2030 from the Economic Research Service (ERS) Database (2016).
4. Historical GDP, GDP deflators, and U.S. population in 1950 to 2009 from Economic Research Division Federal Reserve Bank of St. Louis Database (2016).

Methodology

To carry out this analysis, the agricultural technological progress, demand growth, and biofuel policy scenarios were formed separately. Then we incorporated them together. Finally, we carried out a dynamic simulation under those integrated scenarios in the next chapter.

Setting up Scenarios

Technological Progress Scenarios

The technological progress scenarios were formed from the years 2015 to 2100 based on the error distributions around the best fitting models from Chapter II coupled with the long-term correlations developed there.

Steps to Randomly Draw Technical Progress Scenarios

A number of steps were followed in forming the scenarios. First, we used the best fitting models to forecast crop yields for the years 2015 to 2100 for the old USDA Farm Production Regions for each crop. The forecast yield for year *k* and region *j* is represented by $\hat{Y}_{kj}$, where *j* = 1, 2, 3,…, n and *k* = 2015, 2016, 2017,…, 2100. This is the deterministic component of the scenarios.

The second step is to form the error distributions around those forecasts based on the historical residuals ($\hat{e}_{ij}$) obtained from

$$\hat{e}_{ij} = Y_{ij} - \hat{Y}_{ij} \; . \tag{5}$$

$\hat{Y}_{ij}$ is the predicted crop yield, and Y_{ij} is the observed yield for historical year *i* and region *j* where *i* = 1950, 1951, 1952, …., 2014 and *j* = 1, 2, 3,…, *n*. The residuals, $\hat{e}_{ij}$, give the distributions used to form the stochastic component.

Third, we simulated alternative yields in the years 2015 to 2100 under stochastic yield variables ($\tilde{Y}_{kj}$) based on a multivariate (MV) probability distribution, and randomly drew 50 technological progress scenarios. The stochastic yield variables were also correlated based on the ten-year results from Chapter II.

To randomly draw the regionally correlated technical progress scenarios, we followed the approach in Richardson (2010). The three core components needed to be estimated for each stochastic yield variable are:

1. Deterministic component is the forecast yield ($\hat{Y}_{kj}$) from the best fitting models.
2. Stochastic component denotes $S_{\hat{e}ij}$ which is the measure of the deviation from the deterministic component. The $S_{\widehat{e\imath}j}$ are sorted fractional deviations from the predicted yields in a historical period calculated for each yield random variable Y_j (each region). The $S_{\widehat{e\imath}j}$ can be expressed as

   (6) $$S_{\hat{e}ij} = Sorted\left(F_{\hat{e}ij}\right), where\ F_{\hat{e}ij} = \hat{e}_{ij}/\hat{Y}_{ij}.$$

   We computed the fractional residuals ($F_{\hat{e}ij}$) for each region and then these values were sorted for each region to obtain $S_{\hat{e}ij}$. Then we used $S_{\hat{e}ij}$ to calculate the pseudo minimums and maximums. After that, we assigned probabilities to each $S_{\hat{e}ij}$ based on an empirical distribution with probability zero and one to the pseudo minimum and maximum, respectively. Finally, for each region, we obtained the vector of sorted fractional residuals (S_j) with the vector of cumulative distribution probabilities, $P(S_j)$, which was required in simulating a multivariate empirical (MVE) distribution.

3. Multivariate component is represented by the correlation matrix of all the yield random variables. The correlation matrix was calculated using the long-term correlations of technological progress which is 10-year ratios of historical crop yield data. This long-term technological correlation matrix was used to simulate an nx1 vector of correlated uniform standard deviates (CUSDs), which was the other component used to simulate the MVE distribution.

Each yield random variable was simulated as

$$\widetilde{Y_{kj}} = \hat{Y}_{kj} + \hat{Y}_{kj} * EMP_j. \tag{7}$$

EMP_j represents the j^{th} empirical distribution. Both stochastic and multivariate components are embedded in the empirical distribution. Hence the EMP_j can also be written as $EMP_j(\, S_j, P(S_j), CUSD_j)$.

We chose a two-step procedure in order to simulate an MVE distribution because we would like to have more control on using the long-term correlations of technological progress incorporating the three main components of the MVE distribution. Then each yield random variable was simulated for 50 iterations under the MVE distribution.

Lastly, we tested whether the resultant random data exhibited the appropriate correlation coefficients. The test uses all the simulated random variables in the specific forecast year *k* with the setting number of iterations. The simple way to explain the null hypothesis is that Simulated Correlation$_{ij}$= Input Correlation$_{ij}$. In this study, the input correlations are the long-term correlations of technological progress between regions. The expected result is failing to reject the null hypothesis; in other words, the test statistic being less than the critical value. Failing to reject the null hypothesis implies that the correlation matrix used as the input is reproduced in the simulation. With the passing result of the correlation coefficients test, the set of 50 technological progress scenarios from the random draw of crop yield simulation under the MVE distribution are appropriate and ready to use.

Demand Growth Scenarios

Analysis of demand for crops and other related commodities focuses on the demand in the U.S. To set up the demand scenarios, first, we drew data on the commodities barley, corn, cotton, oats, rice, sorghum, soybeans, wheat, beef, broiler, and pork. The commodities were selected due to their value, incidence in U.S. crop acreage and availability of demand data. Furthermore, much of the demand for corn, barley, oats, sorghum, and soybeans are for livestock feed, so beef, broiler, and pork were included.

In the demand analysis, the main variables examined are consumption per capita or per capita demand of each commodity (D), real GDP per capita (GDPP), and real commodity price (P). The dependent variable is per capita demand, which is computed as the aggregate quantities of commodity consumption in the U.S. divided by U.S. population. The explanatory variables include GDPP and P. GDPP is the gross domestic product in the U.S. divided by U.S. population and adjusted for inflation, using 2010 as a base year. P denotes commodity price adjusted for inflation, using the same base year.

The price variable is USDA reported annual average price of the commodity and also can include prices of related commodities, such as substitutes and complements. In this study, we provided basic demand analysis model. Hence, separate regression models were used. For the eight field crops (i.e. barley, corn, cotton, oats, rice, sorghum, soybeans, and wheat), only the own price of the commodity was used in each commodity model. For example, the linear demand model for corn is represented as

(8) $$D_{Corn} = \alpha_{Corn0} + \alpha_{Corn1} GDPP + \beta_{Corn} P_{Corn} + \varepsilon_{Corn},$$

where αs and β_{Corn} are estimated parameters, and ε_{Corn} is the error term. For meat and poultry products, both own price and substitute commodity prices were used. For example, the linear demand model for beef can be written as

(9) $$D_{beef} = \alpha_{Beef0} + \alpha_{Beef1} GDPP + \beta_{BeefBeef} P_{Beef} + \beta_{BeefBroiler} P_{Broiler} + \beta_{BeefPork} P_{Pork} + \varepsilon_{Beef},$$

where αs and βs are parameter estimates, and ε_{Beef} is the error term. The most commonly used functional forms selected to use in this demand analysis are:

1. Linear, where dependent and explanatory variables are on the same level.
2. Log-Lin, where only values of dependent variable are converted into logarithmic form.
3. Lin-Log, where only values of explanatory variables are converted into logarithmic form.
4. Double-log, where the logarithmic form is applied for both dependent and explanatory variables.

For each functional form, we estimated four models. The first model contains D as a dependent variable and GDPP and P as explanatory variables. In this model, quantity demanded in a year (t) is defined by the explanatory variables within that period only ($GDPP_t$ and P_t). The other models are based on that specification but included more explanatory variables. The second model (the Time Demand model) includes a time trend variable (T_t). The third model (the Lag Demand model) includes quantity demanded in the previous period (D_{t-1}) as an extra explanatory variable. The last model (the Time and Lag Demand model) contains both the time trend variable (Tt) and the lagged quantity demanded variable (D_{t-1}) as additional explanatory variables. The specifications of all demand models used in this demand analysis are presented in table 22.

Table 22. Demand Model Specifications

Model Type and Functional Form	Model Specification	Model Number
1. Main Demand		
Linear	$D_{it} = \alpha_{i0} + \alpha_{i1} GDPP_t + \sum_{j=1}^{n} \beta_{ij} P_{jt} + \varepsilon_{it}$	1.1
Log-Lin	$\ln D_{it} = \alpha_{i0} + \alpha_{i1} GDPP_t + \sum_{j=1}^{n} \beta_{ij} P_{jt} + \varepsilon_{it}$	1.2
Lin-Log	$D_{it} = \alpha_{i0} + \alpha_{i1} \ln GDPP_t + \sum_{j=1}^{n} \beta_{ij} \ln P_{jt} + \varepsilon_{it}$	1.3
Double -Log	$\ln D_{it} = \alpha_{i0} + \alpha_{i1} \ln GDPP_t + \sum_{j=1}^{n} \beta_{ij} \ln P_{jt} + \varepsilon_{it}$	1.4
2. Time Demand		
Linear	$D_{it} = \alpha_{i0} + \alpha_{i1} GDPP_t + \alpha_{i2} T_t + \sum_{j=1}^{n} \beta_{ij} P_{jt} + \varepsilon_{it}$	2.1
Log-Lin	$\ln D_{it} = \alpha_{i0} + \alpha_{i1} GDPP_t + \alpha_{i2} T_t + \sum_{j=1}^{n} \beta_{ij} P_{jt} + \varepsilon_{it}$	2.2
Lin-Log	$D_{it} = \alpha_{i0} + \alpha_{i1} \ln GDPP_t + \alpha_{i2} T_t + \sum_{j=1}^{n} \beta_{ij} \ln P_{jt} + \varepsilon_{it}$	2.3
Double -Log	$\ln D_{it} = \alpha_{i0} + \alpha_{i1} \ln GDPP_t + \alpha_{i2} T_t + \sum_{j=1}^{n} \beta_{ij} \ln P_{jt} + \varepsilon_{it}$	2.4

Note: Variables are defined as follows:

D_{it} = quantity demanded or consumption per capita of a commodity *i* in period *t*
D_{it-1} = lagged quantity demanded or consumption per capita of a commodity *i* in period *t-1*
$GDPP_t$ = real GDP per capita in period *t*
P_{jt} = real price of commodity *j* in period *t*
T_t = time variable in period *t*
ε_{it} = error or disturbance term in period *t*
i = index for commodities
j = index for commodities. If the commodity *i* is barley, corn, cotton, oats, rice, sorghum, soybeans, or wheat, *j* equals *i* i.e. *j* includes one member. Otherwise if the commodity *i* is beef, broiler, or pork, *j* consists of three members i.e. beef, broiler, and pork
αs and βs = estimated parameters.

Table 22. Continued

Model Type and Functional Form	Model Specification	Model Number
3. Lag Demand		
Linear	$D_{it} = \alpha_{i0} + \alpha_{i1} GDPP_t + \alpha_{i2} D_{it-1} + \sum_{j=1}^{n} \beta_{ij} P_{jt} + \varepsilon_{it}$	3.1
Log-Lin	$\ln D_{it} = \alpha_{i0} + \alpha_{i1} GDPP_t + \alpha_{i2} \ln D_{it-1} + \sum_{j=1}^{n} \beta_{ij} P_{jt} + \varepsilon_{it}$	3.2
Lin-Log	$D_{it} = \alpha_{i0} + \alpha_{i1} \ln GDPP_t + \alpha_{i2} D_{it-1} + \sum_{j=1}^{n} \beta_{ij} \ln P_{jt} + \varepsilon_{it}$	3.3
Double -Log	$\ln D_{it} = \alpha_{i0} + \alpha_{i1} \ln GDPP_t + \alpha_{i2}\alpha_{i2} \ln D_{it-1} + \sum_{j=1}^{n} \beta_{ij} \ln P_{jt} + \varepsilon_{it}$	3.4
4. Time and Lag Demand		
Linear	$D_{it} = \alpha_{i0} + \alpha_{i1} GDPP_t + \alpha_{i2} T_t + \alpha_{i3} D_{it-1} + \sum_{j=1}^{n} \beta_{ij} P_{jt} + \varepsilon_{it}$	4.1
Log-Lin	$\ln D_{it} = \alpha_{i0} + \alpha_{i1} GDPP_t + \alpha_{i2} T_t + \alpha_{i3} \ln D_{it-1} + \sum_{j=1}^{n} \beta_{ij} P_{jt} + \varepsilon_{it}$	4.2
Lin-Log	$D_{it} = \alpha_{i0} + \alpha_{i1} \ln GDPP_t + \alpha_{i2} T_t + \alpha_{i3} D_{it-1} + \sum_{j=1}^{n} \beta_{ij} \ln P_{jt} + \varepsilon_{it}$	4.3
Double -Log	$\ln D_{it} = \alpha_{i0} + \alpha_{i1} \ln GDPP_t + \alpha_{i2} T_t + \alpha_{i3} \ln D_{it-1} + \sum_{j=1}^{n} \beta_{ij} \ln P_{jt} + \varepsilon_{it}$	4.4

Note: Variables are defined as follows:

D_{it} = quantity demanded or consumption per capita of a commodity *i* in period *t*

D_{it-1} = lagged quantity demanded or consumption per capita of a commodity *i* in period *t-1*

$GDPP_t$ = real GDP per capita in period *t*

P_{jt} = real price of commodity *j* in period *t*

T_t = time variable in period *t*

ε_{it} = error or disturbance term in period *t*

i = index for commodities

j = index for commodities. If the commodity *i* is barley, corn, cotton, oats, rice, sorghum, soybeans, or wheat, *j* equals *i* i.e. *j* includes one member. Otherwise if the commodity *i* is beef, broiler, or pork, *j* consists of three members i.e. beef, broiler, and pork

αs and βs = estimated parameters.

In summary, 16 different models were estimated for each commodity using OLS. To choose the best model for estimating quantity demanded for each commodity, first, we used the simple criterion of minimizing the residual root mean squared error (Root MSE) to get the best model in fitting the actual demand data. Then the residual from the model with the lowest Root MSE was tested and corrected for autocorrelation (serial correlation). The Durbin-Watson statistic was used to test for autocorrelation in most of the models, except for the models with lagged quantity demanded variable included in the explanatory variables. When lagged dependent variables were included as the explanatory variables, we used an alternative test for autocorrelation suggested by Durbin (1970). Hence, for Lag Demand model and Time and Lag Demand model, the Durbin's alternative test was used to test for autocorrelation instead of typical Durbin-Watson statistic. If the autocorrelation problem is presented at lag 1, the model is corrected by using the AR (1) model, as we explained in the technological progress section.

Table 67 and table 68 in Appendix A show the best fitting demand models for all commodities and the results derived from the model regressions containing the estimated coefficients, the measures of goodness of fit for the model i.e. R-squared (R^2), Adjusted R^2, and Root MSE, and the test results for autocorrelation. These best fitting demand models were used to forecast quantity demanded for all commodities during 2000 to 2100. Then three demand scenarios were set up based on estimated demand forecast. The three demand settings are:

1. Base Demand scenario uses the mean of the estimates of quantity demanded ($\bar{x}$),

2. Fast Demand scenario uses the upper boundary of a 66.67 percent confidence interval estimate ($\bar{x} + z_{0.833} * SD$),
3. Slow Demand scenario uses the lower boundary of a 66.67 percent confidence interval estimate($\bar{x} - z_{0.833} * SD$),

where $z_{0.833}$ is the value from the standard normal distribution for the 66.67 percent confidence level and SD is the standard deviation value. For each demand scenario, we calculated the ratios of demand values, using 2015 as a reference year and these ratios were put in the dynamic simulation discussed in the next chapter

Biofuel Policy Scenarios

Lastly, the biofuel policy was combined into the scenarios. We provide three biofuel policy scenarios which differ in feedstock and volume mandates. The scenarios are a control scenario that implements the volumes foreseen in the Energy Independence and Security Act (EISA) for the RFS and then ones that alter the production of ethanol from corn and corn residue as shown in table 23. In short, the control scenario has all the RFS requirements using corn, switchgrass, corn residue, and other ethanol, while the other scenarios decrease the ethanol volume of corn or corn residue so we can observe the marginal effects of requiring ethanol from those feedstocks. For the Corn scenario, only the volume mandate for corn ethanol produced is reduced from 15.0 to 12.4 billion gallons. And for the CornRes scenario, the volume mandate for ethanol from corn residue is reduced from four billion gallons to zero.

Table 23. Biofuel Policy Scenario Specifications for Production in the Years 2020 to 2030 with Feedstock and Volume Mandates in Billion Gallons

Ethanol produced from the Feedstock	Biofuel Policy Scenario		
	Control	Corn	CornRes
Corn	15.0	12.4	15.0
Switchgrass	8.8	8.8	8.8
Corn Residue	4.0	4.0	0
Other Ethanol	0.2	0.2	0.2
Total	28	25.4	24

Note: Other ethanol denotes that from wheat residue, sweet sorghum pulp, and sweet sorghum.

Main Integrated Scenarios

Finally, we set up nine main integrated scenarios by combining the three demand growth scenarios, and the three biofuel policy scenarios together that were run under all of the 50 technical progress scenarios. The nine scenarios are Base Control, Base Corn, Base CornRes, Fast Control, Fast Corn Fast CornRes, Slow Control, Slow Corn, and Slow CornRes, described in table 24. These scenarios were used in a dynamic simulation discussed in the next chapter.

Table 24. Main Integrated Scenario Specifications

Main Integrated Scenario	Scenario		
	Technical Progress	Demand	Biofuel Policy
1.Base Control	All (50 scenarios)	Base	Control
2.Base Corn	All (50 scenarios)	Base	Corn
3.Base CornRes	All (50 scenarios)	Base	CornRes
4.Fast Control	All (50 scenarios)	Fast	Control
5.Fast Corn	All (50 scenarios)	Fast	Corn
6.Fast CornRes	All (50 scenarios)	Fast	CornRes
7.Slow Control	All (50 scenarios)	Slow	Control
8.Slow Corn	All (50 scenarios)	Slow	Corn
9.Slow CornRes	All (50 scenarios)	Slow	CornRes

CHAPTER IV

DYNAMIC SIMULATION ANALYSIS OF EFFECTS OF TECHNOLOGICAL PROGRESS, DEMAND GROWTH AND BIOFUEL POLICY ON PRODUCT MARKETS, RESOURCE USAGE AND GREENHOUSE GASSES

Introduction

Technological progress inevitably connects prospects for production in support of meeting food and bioenergy demands from a growing population. It also influences land use and environmental emissions including net GHG emissions (McCarl 2008). Hence, the relationship between crop yield growth rate, biofuel production, conventional production and environmental quality is worth exploring.

Feng (2012) estimated the crop yield growth rate of eight main U.S. crops and investigates the relationship between RFS policy and the crop yield. She found recent reductions in the growth rates for most of the crops and found this influences the effects of RFS implementation in terms of crop production, usage, prices, total domestic welfare, and GHG emissions. The interesting finding by Feng (2012) is that in the short-run and under the current crop yield growth rate, the RFS policy had a strong effect on crop production. Feng also found at the end of her simulations that the impacts of RFS implementation were considerably smaller than the effects of technical progress. Another important finding related to climate change is that under the higher crop yield growth rates, GHG emissions associated with land use change were found to be smaller than those under other scenarios (Feng 2012). These findings lay emphasis on the significance of the technological progress or crop growth rates as it influences the effects of bioenergy policy.

In addition, a promising climate change policy involves GHG reductions through carbon trading and price policy (IPCC 2014). This policy is possibly implemented in the U.S. and is in place in current regional policies i.e. Regional Greenhouse Gas Initiative (RGGI). However, the impacts of carbon price regulations on the agricultural sector, environmental consequence, and bioenergy markets are uncertain. Baker et al. (2013) found that agricultural productivity improvements coupled with CO_2 price incentives significantly enhanced net GHG mitigation potential. Nevertheless, their study did not examine the effects of agricultural demand growth combined with agricultural productivity growth and energy policy. Considering only the crop supply side may not provide enough perspective in studying technological progress. Hence, apart from the crop supply side represented by the technological improvement, crop demand forces are also important and cannot be overlooked. This encourages us to investigate the effect of technological progress, agricultural demand, and energy policy on crops, livestock, and bioenergy markets plus resource usage. Investigation of this subject may also provide information regarding the consequences of energy policy. Also, agricultural technological progress will be explored in a broader scope considering the demand for both food and energy, and climate mitigation.

Literature Review

Technological Progress

Technological progress for the agricultural sector can be investigated by looking at observed crop yield growth or productivity growth. Alston et al. (2009) examined agricultural productivity growth and found a slowdown in the productivity growth during 1990 to 2007. Feng (2012) found in more recent times, crops growth rates dropped by 50 percent or more relative to earlier growth rates. Such a slowdown is in line with findings in Villavicencio et al. (2013). Villavicencio et al. (2013) investigated the effects of climate change on agricultural productivity and U.S. returns to agricultural research investment concluding that projected climate change differentially affected agricultural factor productivity growth rates on a regional basis. For example, they found the negative effect in the Southern Plains but the positive effect in the Pacific region. Furthermore, at the national level, they found the overall negative effect and computed that approximately an 18 percent increase in annual investment was needed to maintain pre-climate-change of agricultural productivity growth rates. Oppositely, Arizen et al. (2008) investigated crop yield growth and found no evidence of a slowdown in crop yield growth.

Recent literature has examined the relationship between agricultural productivity growth, land use and management, and GHG mitigation potential. Baker et al. (2013) estimated both crop and livestock yields as a function of time and used the yield estimates in the Forest and Agricultural Sector Optimization Model with Greenhouse

Gases (FASOMGHG; Beach et al. 2010). They found that increased agricultural productivity with carbon price incentives significantly improved net GHG mitigation potential, even though the magnitude of the improvement was small. The noticeable conclusion from their finding is that agricultural productivity improvements played a crucial role in GHG mitigation and could enhance the effectiveness of incentives to reduce GHGs directly nationwide and indirectly worldwide. Nevertheless, the study did not pay much attention to bioenergy production and markets; and bioenergy investment, which are yet to be uncovered.

Objective

This study will investigate the ways that alternative levels of agricultural technological progress, biofuel policy, and demand growth influence crops, livestock, and bioenergy markets plus resource usage and GHG emissions. This is done by using dynamic simulation under alternative technological progress, demand growth and biofuel policy scenarios. Furthermore, the investigation of technological effect expands using the output from the dynamic simulation.

Methodology

The dynamic simulation model used will be FASOMGHG (Beach et al. 2010) that simulates markets and biofuel investment over time. It was run under the integrated scenarios of technical progress, demand growth, and biofuel policy, which were formed in the previous chapter.

The FASOMGHG model solves a dynamic optimization problem by maximizing the inter-temporal economic welfare, in other words, the net present value of the sum of producers' and consumers' surplus across the U.S. forest and agricultural sectors over time (Baker et al. 2013; Beach et al. 2010). This simulates perfectly competitive equilibria in the factor and product markets in each time period simulated. The model structure of FASOMGHG is described in figure 15.

In FASOMGHG, the main endogenous variables are commodity and factor prices; production, consumption, and export and import quantities; land use allocation between sectors; crop mix, livestock mix, agricultural processing, management strategy adoption; resource use; economic welfare measures; producer and consumer surplus; net welfare effects; and environmental impact indicators, such as net GHG emissions (Beach et al. 2010).

We simulated nine main integrated scenarios for technical progress, demand growth, and biofuel mandate changes. Then the results of the simulation under alternative scenarios were compared and discussed regarding land use, price, and GHG emissions to examine the effects of agricultural technological progress, demand growth, and biofuel mandates.

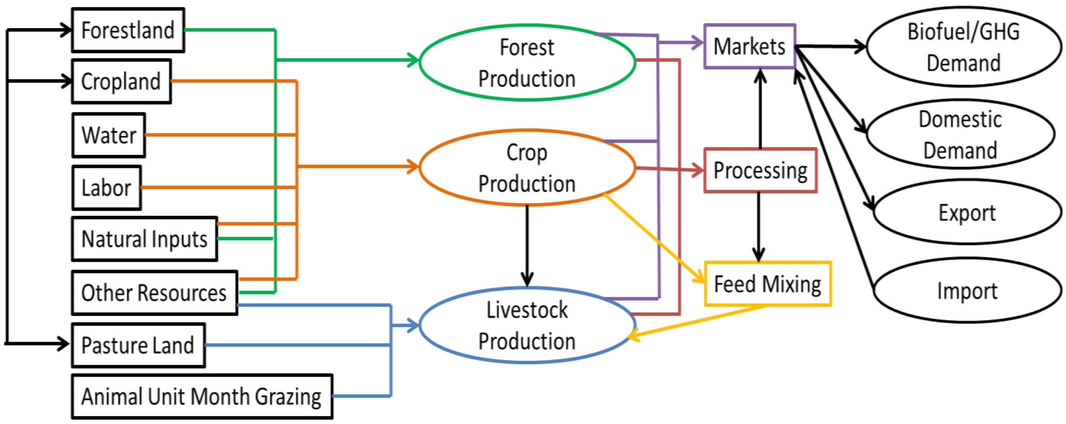

Figure 15. FASOMGHG model structure
Source: Adapted from McCarl and Sands (2007)

Furthermore, we used the FASOMGHG output from the simulations for several select years to estimate a regression equation that gave the effect of technological improvement on land use, price, or environmental concerns including GHG emissions. After the function was derived, we could examine the marginal effect of alternative levels of technological improvement.

Analysis and Results

The content for the rest of this chapter is separated into two parts. The first part provides the average results from the dynamic simulation analysis, the effect on the mean. The second part presents the results of the regression analysis using the output from the simulations. The discussion and the possible reasons for the results are also provided on both parts.

Effect on the Mean

Cropland Mean Results

In this section, the primary focus is on cropland use for biofuel production, crop production, and livestock. In addition, we will discuss the average land use trend, comparative percentage changes, and the impacts of technological progress, biofuel policy and demand growth on land use.

Cropland for Biofuel Production

The trend for average cropland devoted to dedicated energy crops for biofuel production is presented in figure 16, where the area increases rapidly in 2020 by more than 150 percent then trends downward as conversion efficiency and crop yields increase. Regarding figure 16, two lines are clearly separated, so we have two groups of scenarios. The first line shows the Control and the Corn scenarios with various demand growth scenarios. The second line which is apparently below the first line represents the CornRes scenarios for the three demand growth scenarios. This generally shows that at the beginning of the projection, the results under the Control and the Corn scenarios have more land devoted to biofuel production than does the CornRes scenarios. The simple explanation is the lower total biofuel requirement level in the CornRes scenario as compared to the others.

Table 25 presents results of the changes in cropland devoted to biofuel production by year. First, we examine the influence of biofuel policy setting across cases with the same demand growth setting. The biofuel production land use under the CornRes scenarios are 34 to 35 percent and 48 to 49 percent less than those under the Control and the Corn scenarios in the near future (2020 to 2025 and 2030, respectively). As for the demand growth effect on land use for biofuel production, the effect is trivial like because we are running under the mandate which requires a given amount of production. Most of the comparative percentages among the different demand growth settings are less than 1 percent when having the same biofuel mandate.

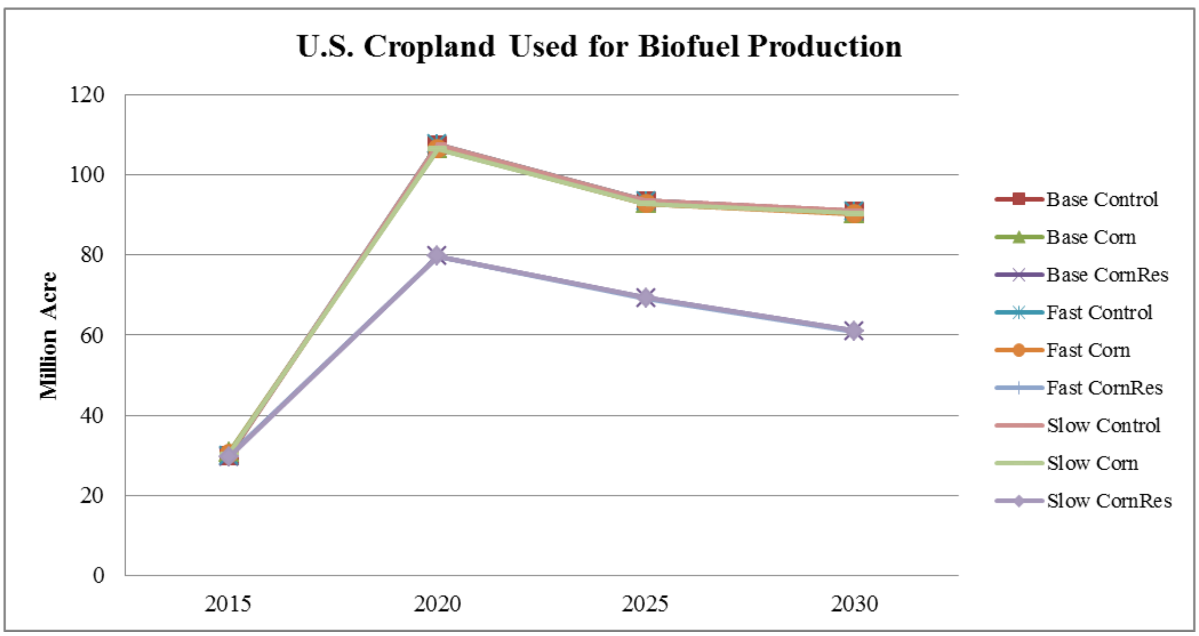

Figure 16. Average U.S. cropland for biofuel production projection during 2015 to 2030

Table 25. Average U.S. Cropland Used for Biofuel Production (in Million Acres) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand growth			Slow Demand growth		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	29.7955	30.7074	29.6502	30.0013	30.3687	29.7244	30.0777	30.2764	29.5085
2020	107.3980	106.4997	79.7382	107.5344	106.5631	79.6386	107.4642	106.4995	79.7383
2025	93.4803	92.7890	69.3569	93.4620	92.7293	69.1631	93.5155	92.7890	69.3570
2030	90.9285	90.3842	61.0928	90.8190	90.2940	60.9650	90.9240	90.3847	61.0928

Cropland for Crop Production

In general, there is a downward trend in the average U.S. land use for crop production during 2015 to 2030 (figure 17). The average land use for crop production increases in 2020 and then is systematically reduced until the end of the projection. Considering different demand growth and biofuel policy scenarios, figure 17 shows that the Base demand growth with Control scenario (a red line) has the largest average land use for crop production, while the Fast demand growth with Corn scenario (an orange line) provides the smallest land use area.

When comparing among the biofuel policy scenarios, the Corn scenario has the lowest land use for crop production in all demand growth cases as it does stimulate a reduction in corn acres, but the percentage changes among different policy scenarios are very small (not greater than 1 percent see table 26). Regarding the demand growth scenarios, the lowest land use is presented in the Fast demand growth scenario while the biofuel policy setting is held constant. This anomalous result may be caused by a competition between land use for crops and livestock, which we will discuss in the next section. Additionally, the possible explanation may be related to technological progress hidden by the averages. However, their percentage changes of the average areas are very small, less than 1 percent (table 26). Thus, it indicates trivial influences of biofuel policy and demand growth on land use for crop production in the U.S.

In conclusion, the average U.S. land use for crop production from the projection during 2015 to 2030 exhibits a downward sloping curve for all various biofuel policy and demand growth scenarios. In addition, the impacts of biofuel policy and demand growth on U.S. area for crop production are insignificant in terms of percentage changes.

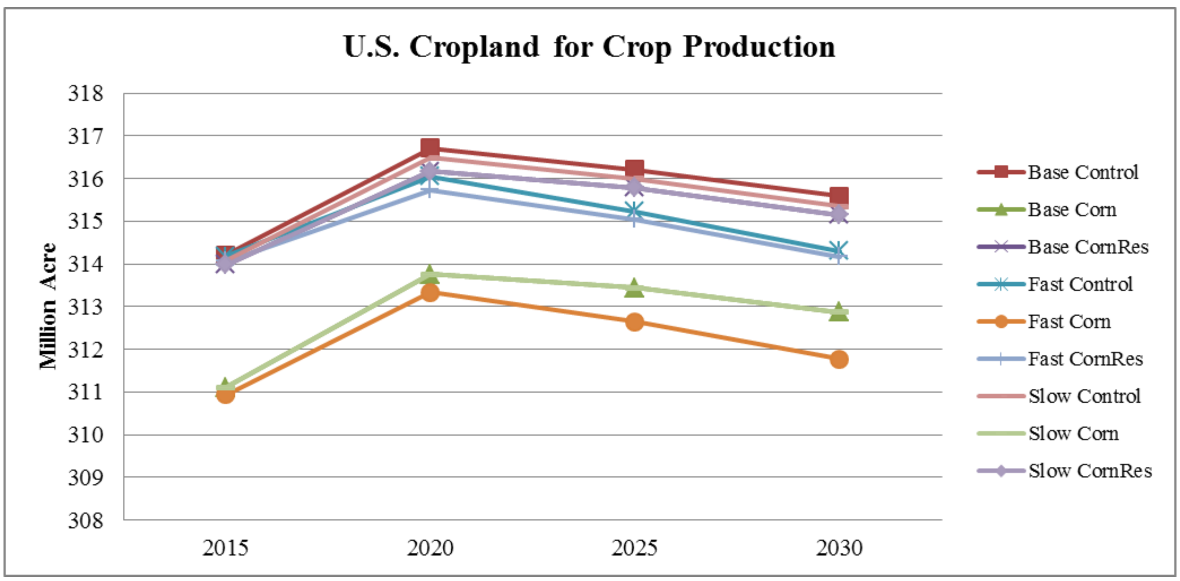

Figure 17. Average U.S. cropland for crop production projection during 2015 to 2030

Table 26. Average U.S. Cropland used for Crop Production (in Million Acres) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	314.2105	311.1096	313.9768	314.1849	310.9381	314.0603	314.0796	311.1095	313.9768
2020	316.7147	313.7538	316.1717	316.0569	313.3317	315.7287	316.4902	313.7537	316.1717
2025	316.2071	313.4354	315.7800	315.2331	312.6385	315.0376	315.9942	313.4353	315.7800
2030	315.5829	312.8743	315.1541	314.3068	311.7743	314.1695	315.3453	312.8743	315.1541

Cropland Pasture Used for Livestock

The average cropland pasture used for livestock from the projection from 2015 to 2030 shows a decreasing trend of cropland pasture use for livestock (see figure 18). Among the biofuel policy and demand growth scenarios, the Corn policy with Fast demand growth scenario (the orange line in figure 18) have the largest cropland pasture land use for livestock through the projection period, while the smallest one occurs under the Control policy with Base demand growth scenario (a red line in figure 18). This is oppositely different from the cropland for crop production discussed in the previous section. The result suggests a tendency of competition between land use for crops and livestock, where meat demand may have more effect on land use as compared with other non-feed crop demands.

When the demand growth setting is held constant, the Corn policy scenario provides the largest percentage change in cropland pasture use for livestock with the Control scenario being the smallest. The percentage changes are around 4 to 5 percent during 2015 to 2030, and 2 percent in 2035 (see table 27). Among the demand growth scenarios, the Fast demand growth scenario mostly has the largest cropland pasture use for livestock, while the smallest one differs depending on the biofuel policy setting. However, the percentage changes as compared to the smallest one are small (no larger than 2 percent).

In conclusion, the projection of the average U.S. cropland pasture use for livestock during 2015 to 2030 shows an obvious decreasing trend largely due to land moving into developed uses. Using percentage changes as a criterion for significance, the influence of biofuel policy seems to have a minor significance, where the Corn policy scenario provides the largest area of cropland pasture use for livestock. Another explanation is that under the Corn scenario which reduces the requirement of ethanol from corn, lands shift from corn production as a biofuel feedstock to livestock. However, the influence of demand growth is insignificant.

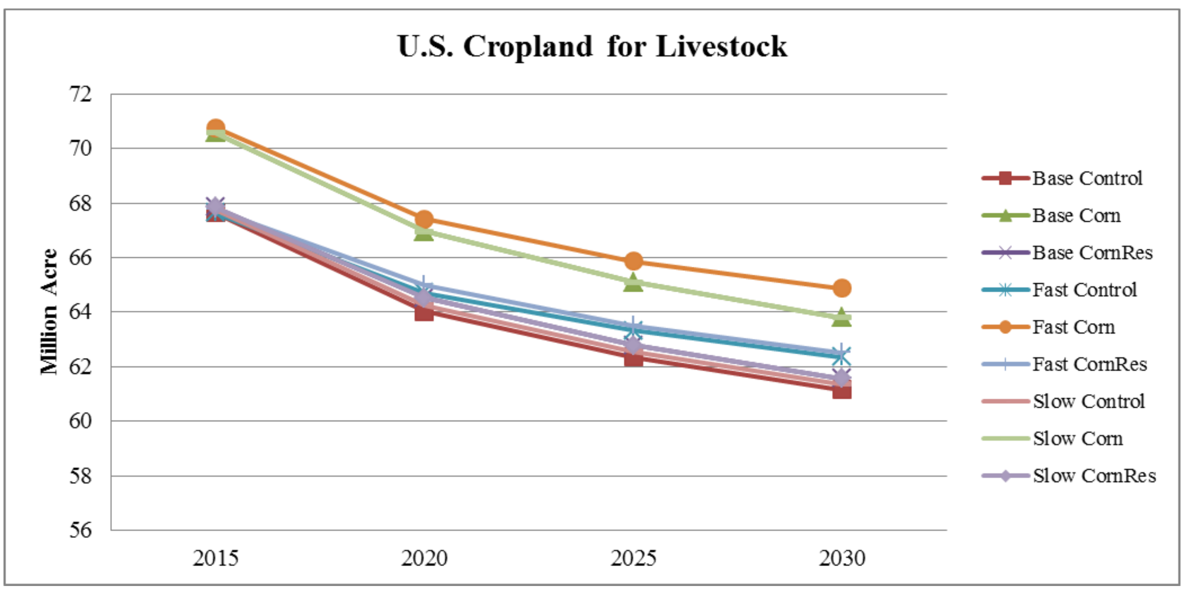

Figure 18. Average U.S. cropland pasture used for livestock projection during 2015 to 2030

Table 27. Average U.S. Cropland Pasture Used for Livestock (Million Acre) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	67.6372	70.5818	67.8560	67.6458	70.7557	67.7705	67.7518	70.5818	67.8560
2020	64.0337	66.9649	64.5315	64.7096	67.4059	64.9990	64.2534	66.9650	64.5315
2025	62.3539	65.1120	62.7884	63.3197	65.8588	63.5159	62.5696	65.1121	62.7884
2030	61.1546	63.8126	61.5778	62.3544	64.8863	62.5216	61.3730	63.8127	61.5778

Additional Result: Variability of U.S. Cropland

To see more reflection of the stochastic results, we discuss the variability of the stochastic results for all U.S. cropland used for biofuel, crop production and cropland pasture used for livestock. Table 28 presents the summary statistics including average, minimum (Min), maximum (Max), standard deviation (SD), and the interquartile range (IQR) of the result distribution. SD and IQR are both statistics measure the amount of variation or dispersion in data. The larger the statistics become, the more variability the data has. To show how the relative variability of stochastic results changes as time progresses, we provide fan graphs for all scenarios in figure 19 to figure 21 displaying the average and multiple percentile lines about the mean of the stochastic results for U.S. cropland used for biofuel, crop production and cropland pasture used for livestock, respectively.

Table 28. Variability Summary Statistics of U.S. Cropland (in Million Acres) Stochastic Draw during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Scenario	Summary Statistic	Cropland Use											
		Biofuel Production				Crop Production				Livestock			
		2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
Base Control	Average	29.796	107.398	93.480	90.929	314.211	316.715	316.207	315.583	67.637	64.034	62.354	61.155
	Min	25.086	88.026	78.119	78.316	307.867	293.390	292.986	291.369	62.525	49.066	48.343	48.996
	Max	33.195	127.961	115.669	111.556	319.264	331.731	330.364	327.762	74.292	87.225	85.721	85.390
	SD	2.029	10.993	10.253	10.296	2.770	6.922	7.076	7.445	2.895	6.825	6.968	7.433
	IQR	5.766	24.742	19.609	20.004	8.268	18.018	16.021	17.414	5.395	13.250	13.754	15.480
Base Corn	Average	30.707	106.500	92.789	90.384	311.110	313.754	313.435	312.874	70.582	66.965	65.112	63.813
	Min	25.047	87.885	77.936	78.101	303.172	291.063	291.411	289.794	63.543	52.328	50.186	50.605
	Max	36.743	125.730	114.804	109.543	318.076	328.470	328.521	326.154	79.028	89.436	87.296	86.965
	SD	2.463	10.583	9.995	10.092	4.061	7.081	6.986	7.548	4.198	6.926	6.852	7.478
	IQR	5.623	25.158	19.236	20.233	11.221	19.409	14.562	16.410	9.329	12.862	14.529	16.877
Base CornRes	Average	29.650	79.738	69.357	61.093	313.977	316.172	315.780	315.154	67.856	64.531	62.788	61.578
	Min	26.075	41.771	43.626	40.776	307.705	290.169	291.627	290.010	62.569	49.511	48.637	49.500
	Max	34.905	122.408	111.234	109.736	319.177	331.286	330.070	327.258	74.347	88.530	87.080	86.748
	SD	2.126	24.491	17.665	19.341	2.802	7.277	7.223	7.646	2.936	7.034	7.134	7.631
	IQR	4.816	56.092	38.122	32.012	8.292	18.713	15.794	18.143	5.737	13.822	14.062	15.614

Table 28. Continued

Scenario	Summary Statistic	Land Use											
		Biofuel Production				Crop Production				Livestock			
		2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
Fast Control	Average	30.078	107.464	93.515	90.924	314.185	316.057	315.233	314.307	67.646	64.710	63.320	62.354
	Min	25.713	87.996	78.315	78.486	307.837	292.675	291.003	289.248	62.293	49.205	48.461	48.353
	Max	32.917	127.737	115.709	111.523	319.399	331.592	330.246	328.405	74.226	88.073	87.704	87.511
	SD	1.925	11.010	10.244	10.298	2.877	7.214	7.412	7.825	2.998	7.159	7.299	7.719
	IQR	5.575	24.718	19.689	20.070	8.100	19.601	16.831	17.898	5.791	13.487	13.967	15.926
Fast Corn	Average	30.276	106.499	92.789	90.385	310.938	313.332	312.639	311.774	70.756	67.406	65.859	64.886
	Min	25.022	87.875	77.932	78.101	302.819	290.665	289.366	287.421	63.371	53.244	51.777	51.668
	Max	35.297	125.730	114.804	109.543	318.248	327.553	326.930	325.090	79.429	89.711	89.341	89.337
	SD	2.500	10.583	9.995	10.093	4.107	7.212	7.263	7.678	4.255	7.092	7.089	7.554
	IQR	5.714	25.158	19.236	20.233	10.581	20.158	15.746	16.848	9.732	13.519	14.848	16.782
Fast CornRes	Average	29.509	79.738	69.357	61.093	314.060	315.729	315.038	314.170	67.771	64.999	63.516	62.522
	Min	25.490	41.771	43.626	40.776	307.922	289.839	290.060	288.443	62.465	49.599	48.855	48.747
	Max	33.694	122.408	111.234	109.736	319.281	331.198	329.852	328.011	74.070	89.017	88.647	88.315
	SD	1.971	24.491	17.665	19.341	2.873	7.426	7.471	7.864	2.994	7.239	7.368	7.802
	IQR	4.785	56.092	38.122	32.012	8.080	19.538	17.141	19.099	5.818	13.868	14.631	16.177

Table 28. Continued

Scenario	Summary Statistic	Land Use											
		Biofuel Production				Crop Production				Livestock			
		2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
Slow Control	Average	30.001	107.534	93.462	90.819	314.080	316.490	315.994	315.345	67.752	64.253	62.570	61.373
	Min	25.770	88.238	78.499	78.153	307.486	293.026	292.558	290.941	62.409	49.109	48.327	49.131
	Max	36.794	128.031	115.617	112.046	319.338	331.688	330.380	327.628	74.577	87.609	86.149	85.817
	SD	2.396	11.017	10.199	10.239	2.816	7.046	7.133	7.558	2.949	6.941	7.031	7.527
	IQR	5.543	25.130	20.200	20.222	8.301	18.616	15.746	18.329	5.531	13.505	13.657	15.370
Slow Corn	Average	30.369	106.563	92.729	90.294	311.110	313.754	313.435	312.874	70.582	66.965	65.112	63.813
	Min	26.140	88.127	78.230	77.253	303.172	291.063	291.411	289.794	63.543	52.328	50.186	50.605
	Max	35.462	125.551	114.313	109.804	318.076	328.470	328.521	326.154	79.028	89.436	87.296	86.965
	SD	2.604	10.486	9.939	10.084	4.061	7.081	6.986	7.548	4.198	6.926	6.852	7.478
	IQR	5.935	24.716	19.775	20.021	11.221	19.409	14.562	16.410	9.329	12.862	14.529	16.877
Slow CornRes	Average	29.724	79.639	69.163	60.965	313.977	316.172	315.780	315.154	67.856	64.531	62.788	61.578
	Min	25.557	41.711	43.661	40.810	307.705	290.169	291.627	290.010	62.569	49.511	48.637	49.500
	Max	35.683	123.289	111.397	109.503	319.177	331.286	330.070	327.258	74.347	88.530	87.080	86.748
	SD	2.140	24.532	17.552	19.310	2.802	7.277	7.223	7.646	2.936	7.034	7.134	7.631
	IQR	5.188	55.934	37.840	32.114	8.292	18.713	15.794	18.143	5.737	13.822	14.062	15.614

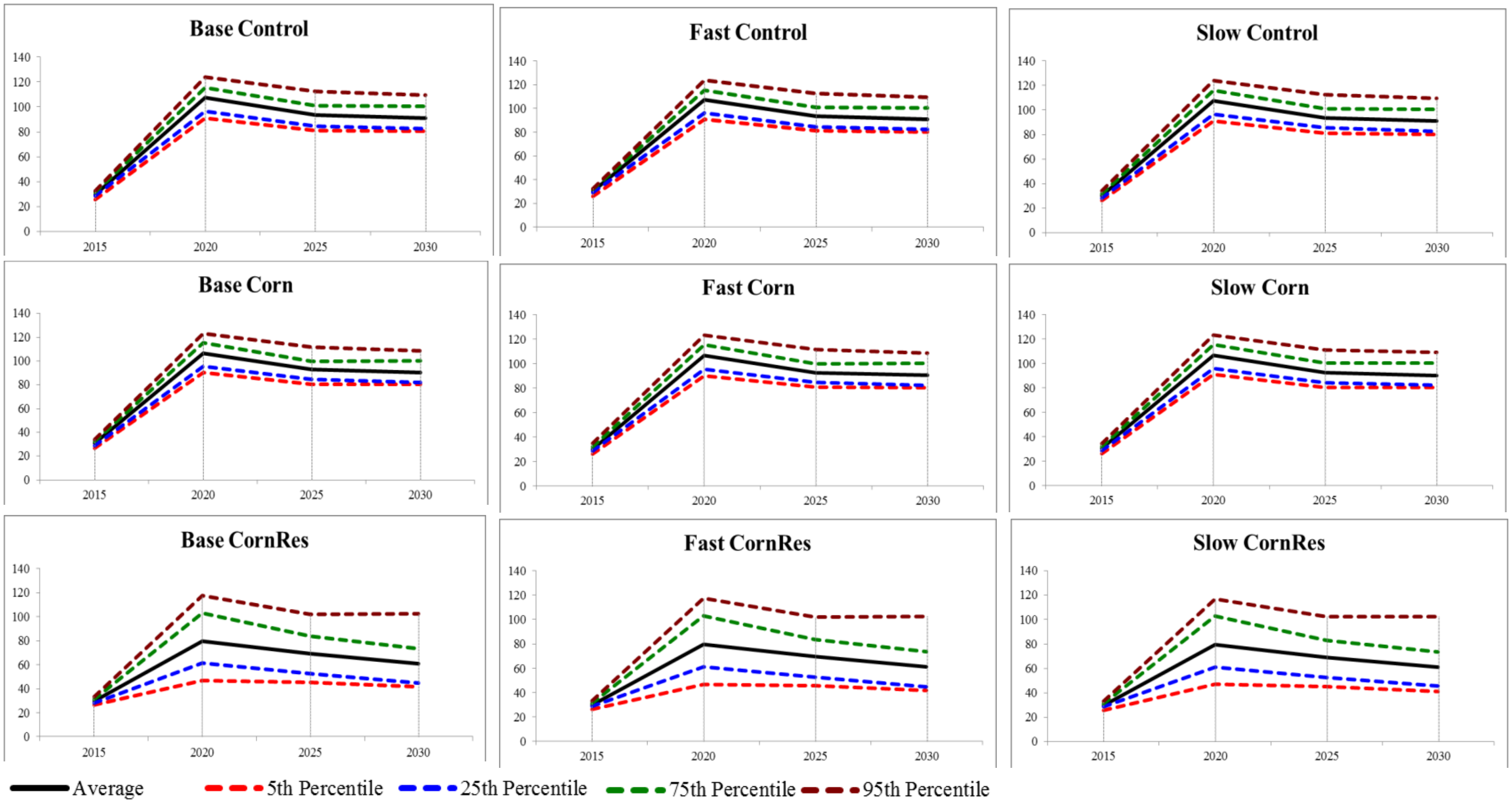

Figure 19. Variability of U.S. cropland used for biofuel production (in million acres) stochastic draw during 2015 to 2030 under various biofuel policy and demand growth scenarios

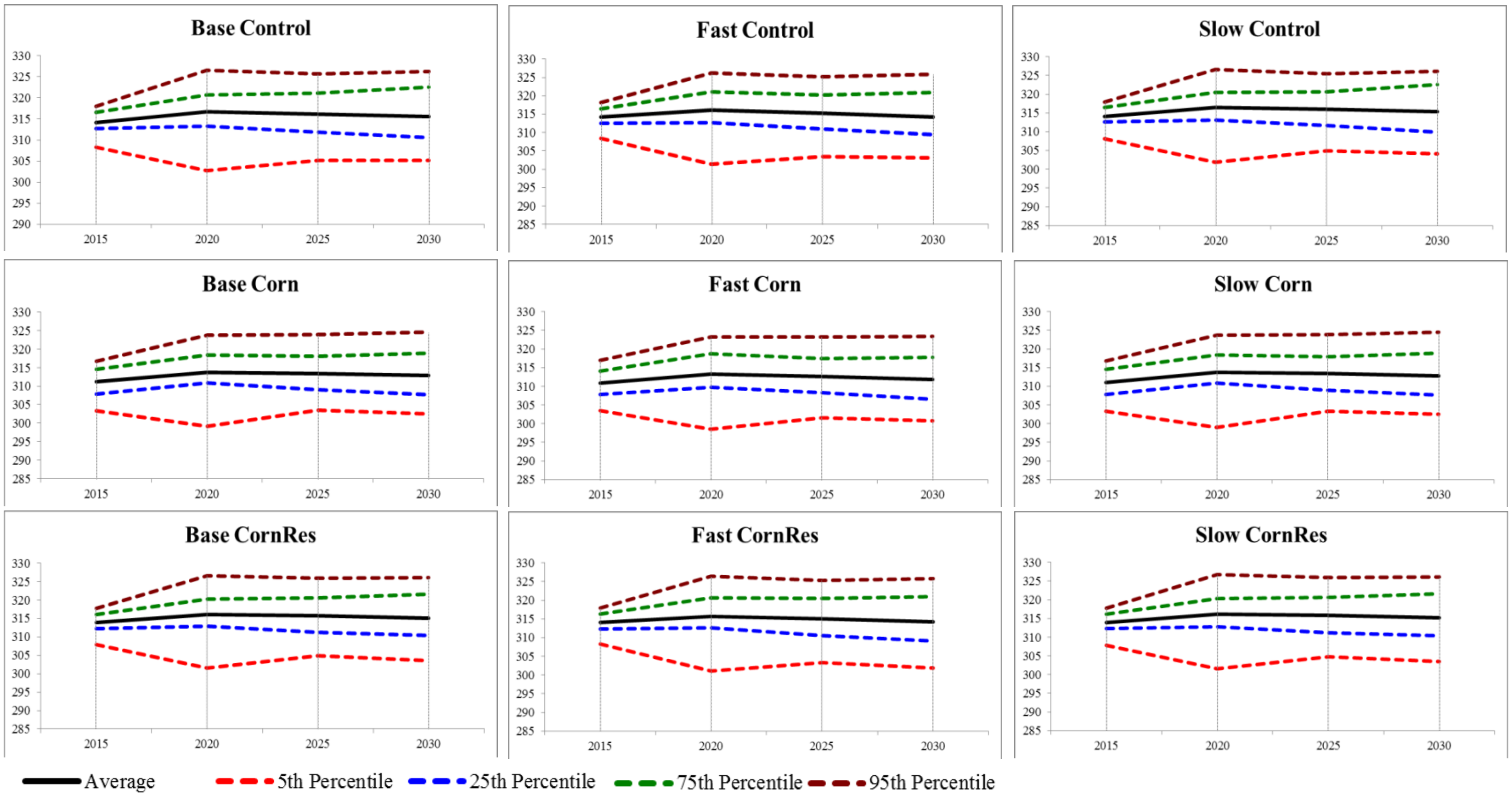

Figure 20. Variability of U.S. cropland used for crop production (in million acres) stochastic draw during 2015 to 2030 under various biofuel policy and demand growth scenarios

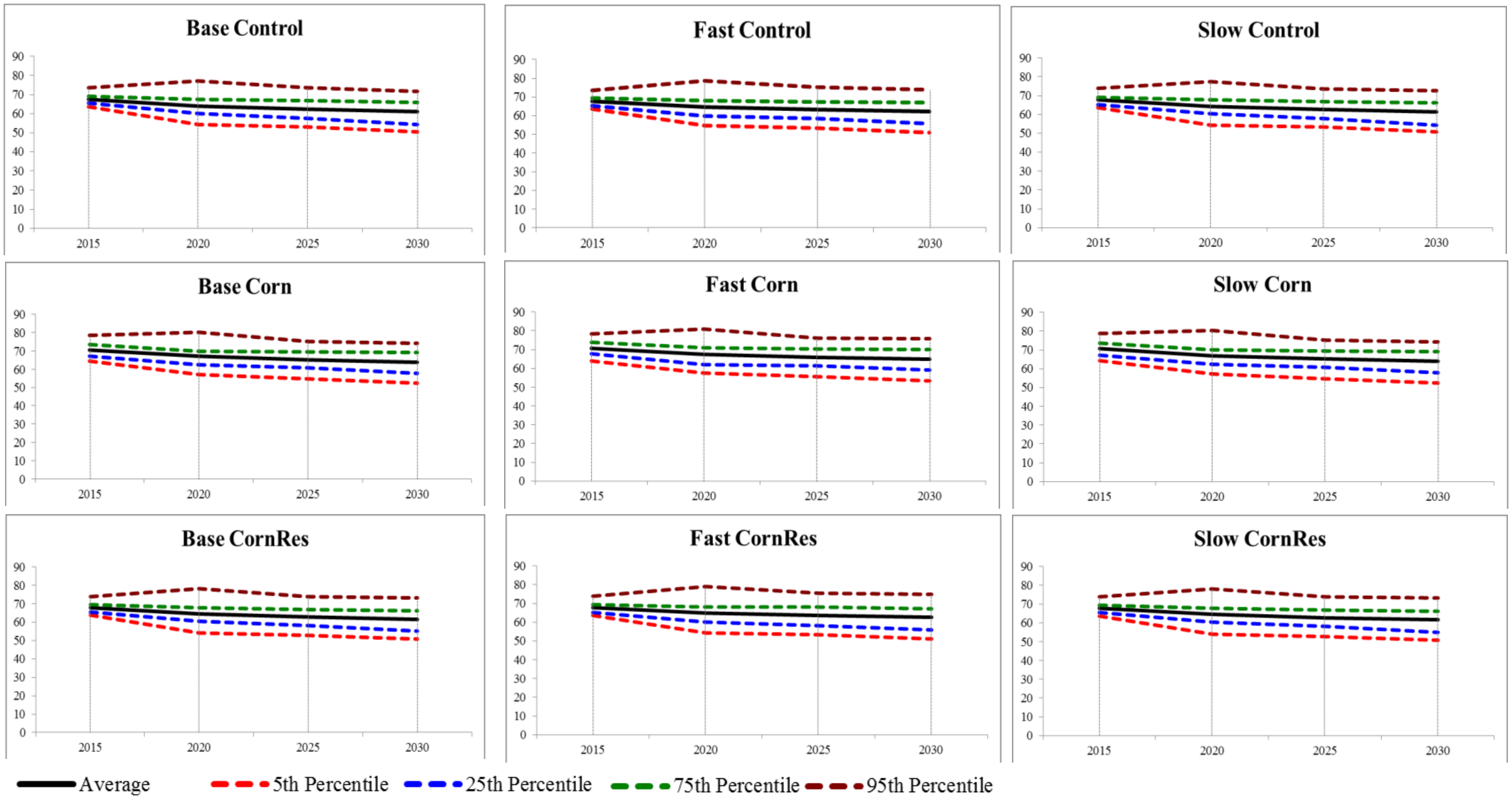

Figure 21. Variability of U.S. cropland pasture used for livestock (in million acres) stochastic draw during 2015 to 2030 under various biofuel policy and demand growth scenarios

Regarding the stochastic result of cropland used for biofuel production, it apparently notices more variability of cropland for biofuel under the CornRes scenarios during 2020 to 2030, where the values of SD and IQR mostly doubled those under other biofuel policy scenarios (see table 28 and figure 19). Additionally, the amount of variability is less under the Corn policy scenario. Hence, the CornRes scenario evidently influences greater dispersion in the cropland for biofuel production. As for the demand effect, the influence is not evident. Nevertheless, the lowest amount of variability is shown under the Slow demand cases during 2020 to 2030.

The variability results of cropland for crop production and cropland pasture for livestock exhibit in the similar direction. For the effect of demand, the largest SD value is obtained under the Fast demand scenarios while the Slow demand under the Corn and the CornRes settings and the Base demand under Control policy provide the lowest SD value. Hence, the Fast demand scenario influences more variability on cropland devoted to both crop production and livestock. Regarding the biofuel policy influence during 2020 to 2030, more variability (the largest SD) is found under the CornRes scenario, and less variability (the lowest SD) is shown under the Corn scenario, especially in the Fast and Slow demand setting.

In general, the relative variability of stochastic results of cropland devoted to biofuel, crop production, and livestock increases significantly in 2020, where the biofuel policy settings are imposed (figure 19 to figure 21). After that, the relative variability of stochastic results shows small changes as time progresses. We notice the slight reduction of the variation in 2020 and the small increase of the variation in 2030. As for the biofuel policy effect, the variability increases significantly as noticed by the wider range of percentile interval under the CornRes scenarios (figure 19) and the larger amount of IQR and SD (table 28). However, the impact of demand on the variation of land use results is barely seen in figure 19 to figure 21.

Concluding Remarks on Cropland Mean Results

Cropland use differs based on biofuel requirements, demand growth, and technological progress, U.S. cropland for biofuel production rises substantially in 2020, then follows by the decrease. Land use for crop production also increases in 2020, and after that, it falls slowly. This likely results from the increase in technological progress. Nevertheless, the area for livestock shows only a decrease until the end of the projection.

Among the biofuel policy and demand growth scenarios, the interesting finding is that the largest land use for livestock occurs under the Corn policy with Fast demand growth scenario, while the smallest one is under the Control policy with Base demand growth scenario. This finding is opposite the result of land use for crop production. Thus, there exists a land use change relationship between these two types of land i.e. when cropland demands are low for crop and biofuel then land goes into the pasture and vice versa.

The influence of biofuel policy on U.S. cropland use is significant during 2020 to 2030 for biofuel production land use, where the changes in the areas of land use under the Control and the Corn scenarios (with corn stover requirement) are around 30 to 50 percent larger those under the CornRes scenario (without corn stover requirement) probably due to the higher total biofuel production and also that the Corn scenario reduces land demand whereas the CornRes scenario leaves basic crop demand unchanged, reducing demand for a byproduct. The effect of biofuel policy is rather minor on livestock cropland pasture use, where the Corn scenario provides the largest movement of land out of cropland use and thus the greatest cropland pasture use. In other words, less requirement for corn for ethanol shifts more land to livestock and the lower requirement level of corn residues does not really affect the crop and use.

Besides biofuel policy, we also consider the influence of demand growth. However, the impact of demand growth on cropland for biofuel production, crop production, and livestock is small in terms of percentage changes.

Apart from the mean effect, the variability of U.S. Cropland results is also examined. The results of cropland for all types have more variation under the CornRes scenarios, but the influence is only significant on land used for biofuel production. For the demand growth scenarios, the influence seems to be small. Less variation is found under the Slow demand scenarios for all types of cropland. Additionally, the Fast demand case creates more dispersion on both cropland for crop production and cropland pasture for livestock.

Price Mean Results

One of the interesting places where the results show alterations is in commodity prices. Several categories of effects will be reviewed. The first category involves the cost of meeting the biofuel requirements in terms of crop ethanol price and cellulosic ethanol price. The other category is conventional commodity prices for corn, cotton, hay, sorghum, soybean, hard red winter wheat, beef, pork, and broiler. An average price trend, percent growth rate of price, and the impacts of biofuel policy and demand growth on price will be discussed in this section.

U.S. Ethanol Price

In general, the projection shows that average U.S. ethanol price has a wavy pattern (figure 22), where the price drops 5 percent in 2020, increases 8 percent in 2025, and then drops 5 percent again in 2030. In addition, biofuel policy and demand growth do not affect the U.S. ethanol price. Prices are equal among various scenarios in the same projected year (see table 29).

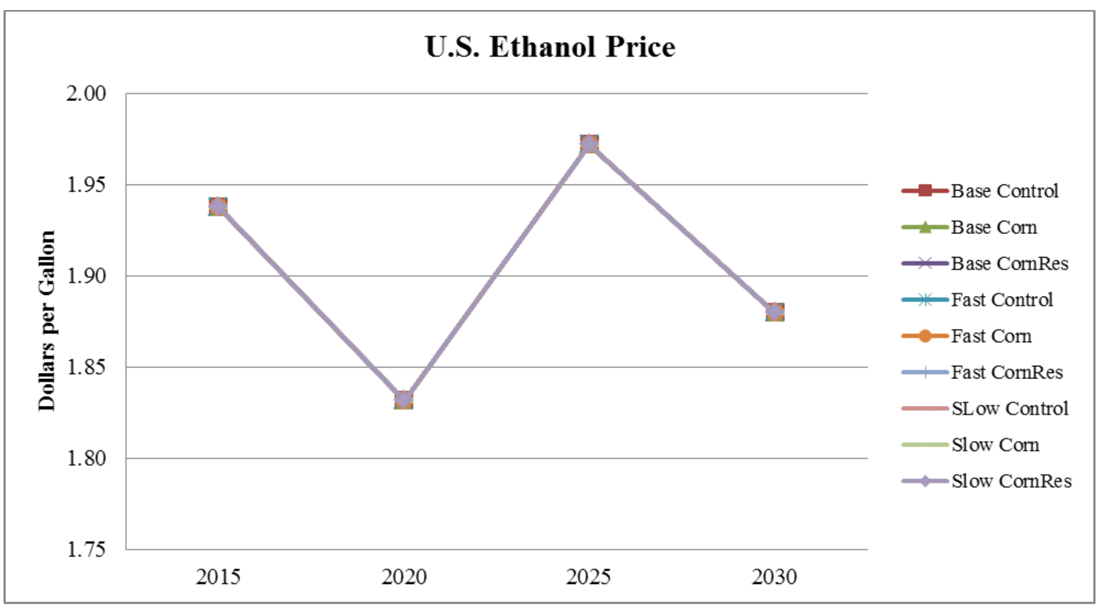

Figure 22. Average U.S. ethanol price projection during 2015 to 2030

Table 29. Average U.S. Ethanol Price Projection (Dollars per Gallon) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94
2020	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83
2025	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97
2030	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88

U.S. Cellulosic Ethanol Price

Overall, an average price of ethanol from cellulosic is volatile as presented by the wavy pattern in figure 23. Cellulosic ethanol prices are the same as the ethanol price and the price levels under various biofuel policy and demand growth settings are equal in the same projected year (table 30). This indicates that there is no evidence of the influence of biofuel requirements and demand growth on the ethanol price from cellulosic process during the projection period.

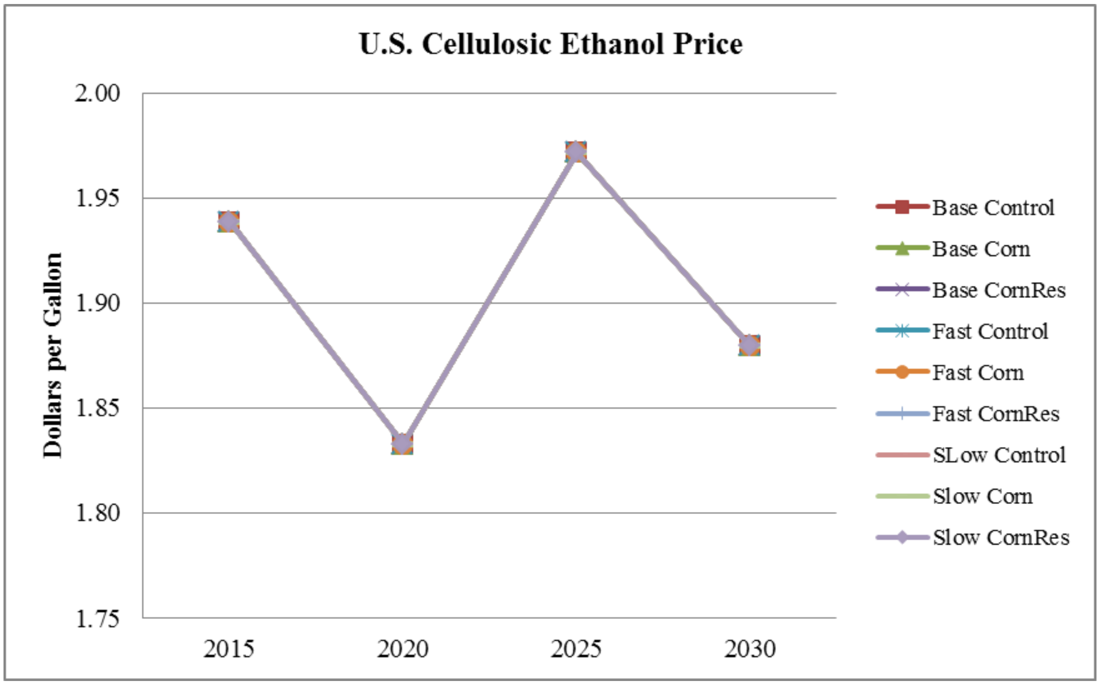

Figure 23. Average U.S. cellulosic ethanol price projection during 2015 to 2030

Table 30. Average U.S. Cellulosic Ethanol Price Projection (Dollars per Gallon) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94
2020	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83
2025	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97
2030	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88

U.S. Corn Price

The projection of average U.S. real corn price from 2015 to 2030 is shown in figure 24, where the price increases through the projection period. The percent growth rate of corn price is around 3 to 9 percent (see table 31). During all the projection period, U.S. corn price reaches the maximum price in 2030 and the price is around 24 to 34 percent increase from the 2015 price.

To see the impact of biofuel policy on the U.S. corn price, the changes in percentage of corn price are compared among different policy settings by keeping the setting of the demand growth constant. During 2015 to 2030, we notice the impact of biofuel mandate where the Corn scenario reduces the corn price by 6 to 8 percent. This is because reducing corn requirements under the Corn scenario lowers the overall demand for corn, thus the corn price decreases. Apart from the biofuel policy impact, the demand growth impact on the U.S. corn price is generally less than 2 percent. Hence, the influence of biofuel policy is larger than that of demand growth.

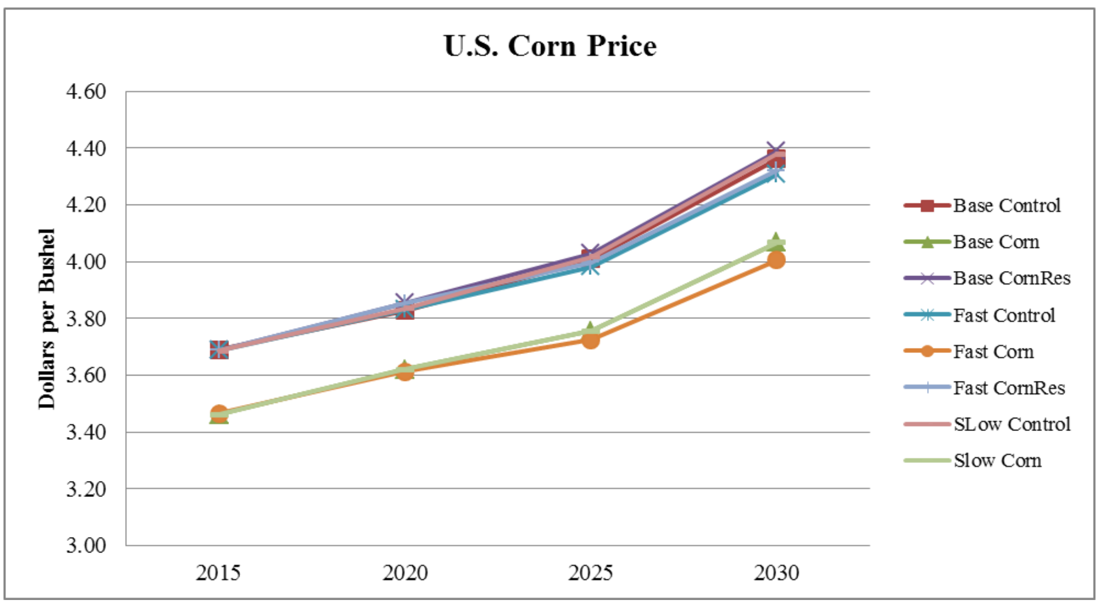

Figure 24. Average U.S. corn price projection during 2015 to 2030

Table 31. Average U.S. Corn Price Projection (Dollars per Bushel) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	3.69	3.46	3.69	3.69	3.47	3.69	3.69	3.46	3.69
2020	3.83	3.62	3.85	3.83	3.61	3.85	3.84	3.62	3.85
2025	4.01	3.76	4.03	3.98	3.73	4.00	4.02	3.76	4.03
2030	4.36	4.07	4.39	4.31	4.01	4.32	4.38	4.07	4.39

U.S. Cotton Price

Similarly, the average U.S. cotton price increases over time (see figure 25). The cotton price increases by more than 10 percent from 2015 to 2025. After that, the growth rate of cotton price becomes smaller. The cotton price sensitivity to various biofuel policy and demand growth scenarios can be divided into two groups. As shown in figure 25, there are two separate sets of results. The first group includes the results of the Base and the Slow demand scenarios regardless of biofuel policy setting, and the second group is the result of the Fast demand scenarios regardless of biofuel policy setting. The cotton price of the first group is more than the second group's price. This anomalous result indicates that the Fast demand scenarios provide the lower cotton price. This may arise from the increase in technological progress on the supply side, on which we will analyze later in this chapter. In short, the impact of demand growth seems to be more noticeable than the effect of biofuel policy.

The percentage change in price levels among various biofuel policies are less than 1 percent (table 32). This reflects a small effect of biofuel policy on the cotton price as shown in figure 25. In brief, the influence of biofuel policy is quite small while the demand growth effect is more evident. The Fast demand growth scenarios provide the lower cotton price.

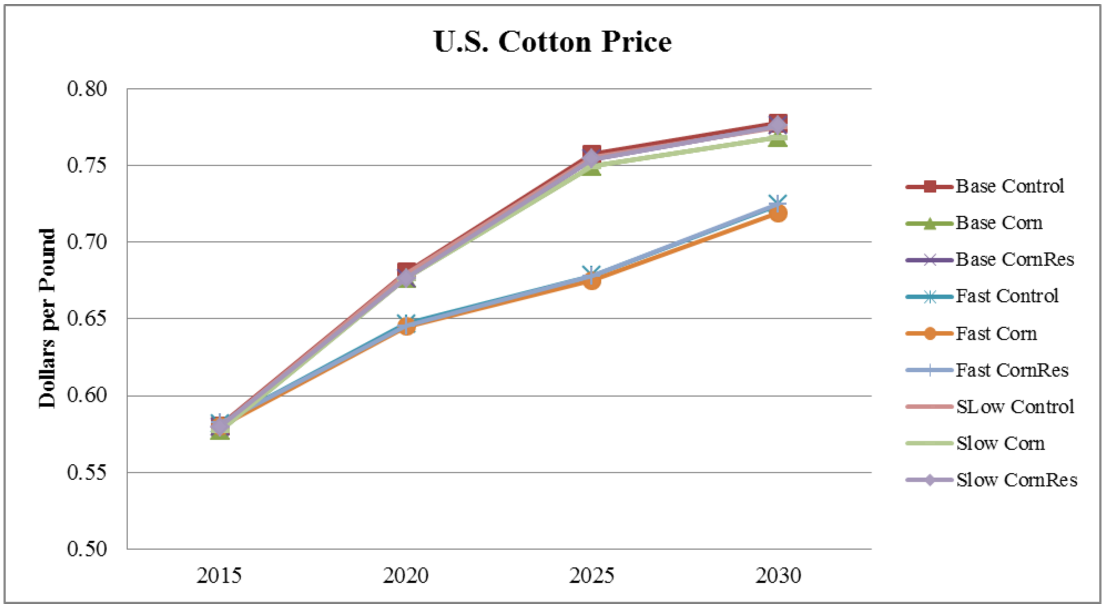

Figure 25. Average U.S. cotton price projection during 2015 to 2030

Table 32. Average U.S. Cotton Price Projection (Dollars per Pound) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
2020	0.68	0.68	0.68	0.65	0.65	0.65	0.68	0.68	0.68
2025	0.76	0.75	0.75	0.68	0.68	0.68	0.76	0.75	0.75
2030	0.78	0.77	0.78	0.72	0.72	0.72	0.78	0.77	0.78

U.S. Hay Price

In general, the average U.S. hay price increases through time (figure 26). The percent growth rate of hay price is mostly around 3 to 6 percent (see table 33). Additionally, the price growth rate is more than 10 percent by 2020. The price result indicates minor effects of biofuel policy and demand growth. As for the biofuel policy impact, during 2015 to 2030, hay price levels from the policy scenarios of Control and CornRes are 2 to 3 percent greater than the price levels from the Corn scenario. The possible explanation is that the lower level of corn mandates may create more land to plant other crops such as cotton, in turn, this leads to lower cotton prices. Regarding the effect of demand growth, in 2025 and 2030, the Fast demand scenario provides the lowest hay price, but the percentage difference of price level among various demand scenarios is very small (around 1 percent in 2025 and 2 percent in 2030). In conclusion, the Corn scenario and the Fast demand growth show the lowest hay price but their effects on hay price are small.

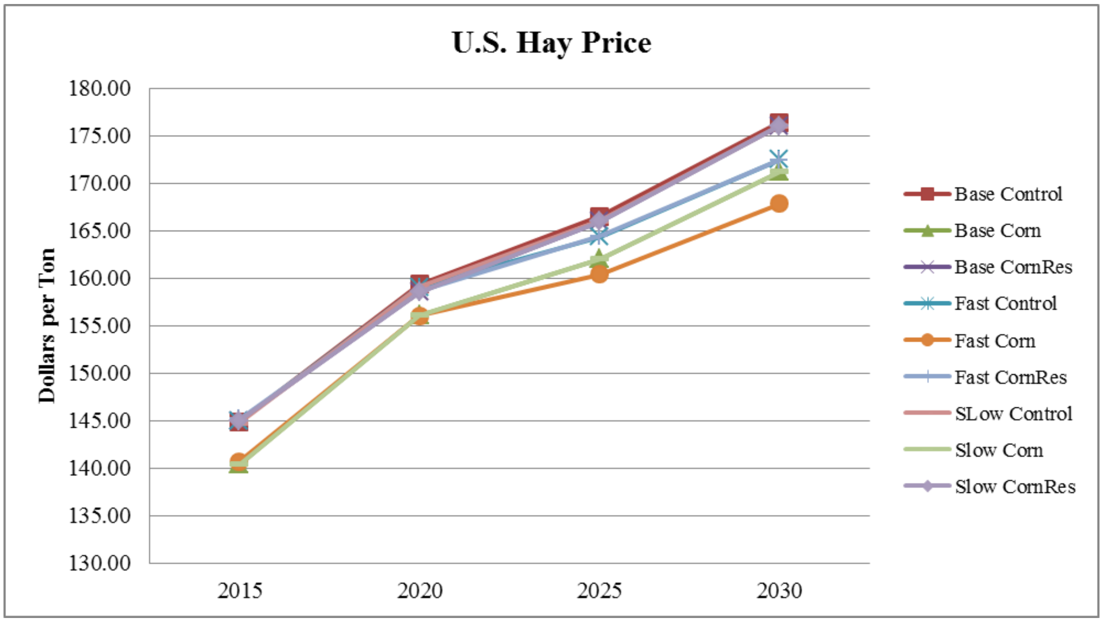

Figure 26. Average U.S. hay price projection during 2015 to 2030

Table 33. Average U.S. Hay Price Projection (Dollars per Ton) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	144.86	140.36	145.00	144.91	140.66	145.18	144.77	140.36	145.00
2020	159.33	156.10	158.56	159.04	156.03	158.59	159.05	156.10	158.56
2025	166.52	162.00	165.97	164.37	160.37	164.42	166.05	162.00	165.97
2030	176.40	171.19	176.07	172.46	167.86	172.43	176.04	171.19	176.07

U.S. Sorghum Price

The trend of average U.S. sorghum price projection is very similar to the trend of average U.S. corn price (see figure 24 and figure 27). The price rises over time. The percent growth rate of sorghum price ranges from 3 to 9 percent (see table 34). The maximum sorghum price in 2030 is around 17 to 20 percent increase from its 2015 level. Overall, the pattern of the sorghum price moves in the same trend as the corn price.

The Corn scenario gives the lowest price of sorghum (6 to 7 percent lower) among all biofuel policy scenarios in all the years. Concerning the demand growth impact, the results in 2025 and 2030 show that the Fast demand growth provides the lowest sorghum price. However, the price difference is marginal i.e. less than 2 percent. In general, the Corn policy setting has the lowest sorghum price. This conclusion agrees with the results of corn and hay prices.

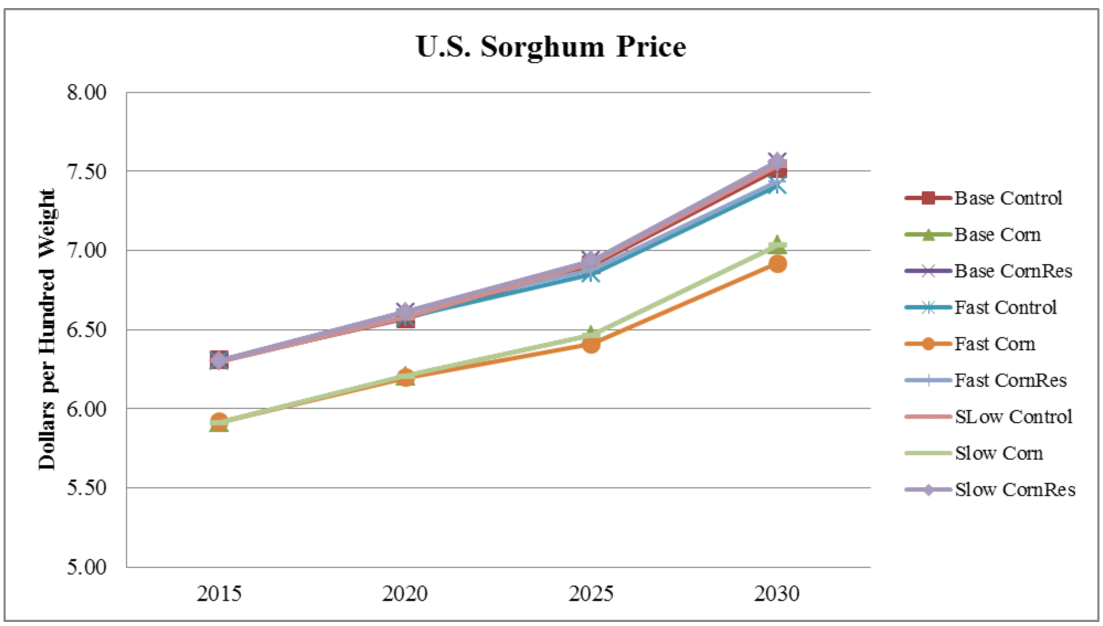

Figure 27.Average U.S. sorghum price projection during 2015 to 2030

Table 34. Average U.S. Sorghum Price Projection (Dollars per Hundred Weight) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	6.31	5.91	6.30	6.30	5.92	6.30	6.30	5.91	6.30
2020	6.57	6.20	6.61	6.57	6.20	6.61	6.58	6.20	6.61
2025	6.91	6.46	6.93	6.85	6.41	6.88	6.92	6.46	6.93
2030	7.51	7.03	7.56	7.41	6.92	7.43	7.54	7.03	7.56

U.S. Soybean Price

The pattern of the average U.S. soybean price moves differently from the other crops' prices. The soybean price tends to move downward after 2020 and through the end of the projection (figure 28). During the decreasing trend, the negative growth rate of soybean price ranges from 3 to 5 percent. Nevertheless, in 2020, the soybean price increases and the magnitude of price growth rate becomes smaller, ranging from 2 to 3 percent. Both biofuel policy and demand growth impacts are trivial. Among various biofuel policies in 2020 to 2030, the Corn policy gives the highest soybean price, less than 3 percent higher (table 35). This contradicts to the policy results of corn, hay, and sorghum prices. As for the demand scenarios, the soybean prices are very similar based on relatively small percentage changes in the price levels (mostly less than 1 percent). Hence, we only notice a difference under the Corn policy, but the effect is minimal.

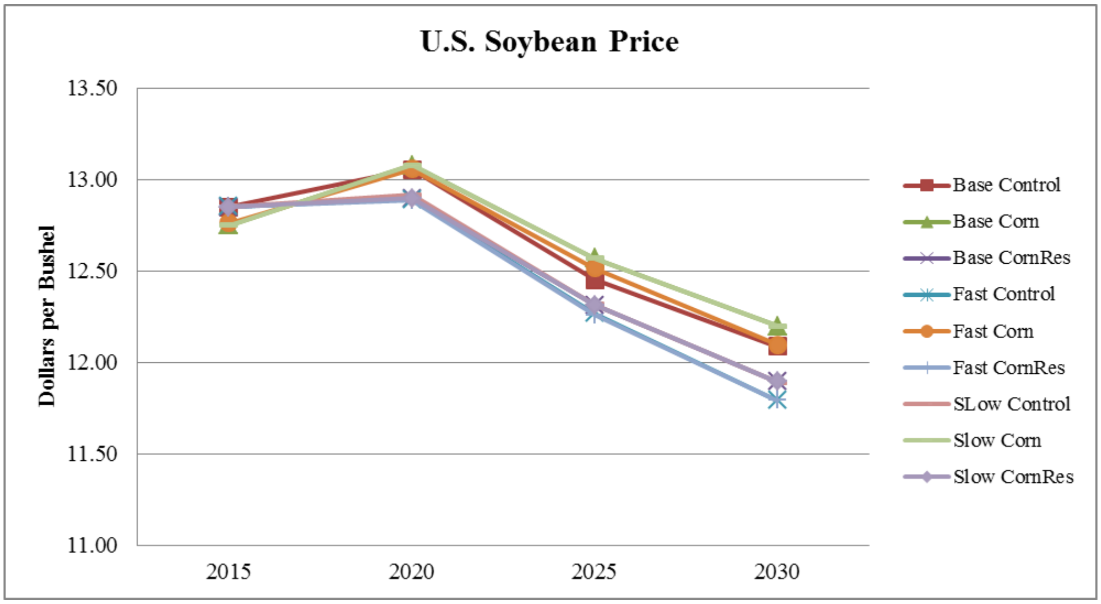

Figure 28.Average U.S. soybean price projection during 2015 to 2030

Table 35. Average U.S. Soybean Price Projection (Dollars per Bushel) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	12.85	12.75	12.85	12.85	12.76	12.85	12.85	12.75	12.85
2020	13.05	13.08	12.90	12.89	13.06	12.89	12.91	13.08	12.90
2025	12.45	12.57	12.32	12.27	12.51	12.26	12.32	12.57	12.32
2030	12.09	12.20	11.89	11.79	12.10	11.79	11.89	12.20	11.89

U.S. Hard Red Winter Wheat Price

The average U.S. hard red winter wheat price projections exhibit the increasing pattern of price during 2015 to 2025 and the slowdown in 2030 (figure 29). The price moves up by 21 to 23 percent by 2020, and 12 percent in 2025 (table 36). The price only decreases in the Fast demand scenario but with a small reduction. Furthermore, the result indicates trivial influences of biofuel policy and demand on the hard red winter wheat price.

As for the biofuel policy influence, the percentages changes of prices among various biofuel policy scenarios are small, not greater than 2 percent. In general, the Corn scenario provides the smallest wheat price among different biofuel policy scenarios. On the subject of demand effect, the percentages changes of prices among different demand scenarios are quite small, not larger than 2 percent. From 2015 to 2025, the Fast demand gives the highest wheat price. In summary, the influences of biofuel policy and demand growth are not large. Among various biofuel policy scenarios, the Corn case provides the lowest wheat price. While for the demand scenarios, the Fast demand provides the highest wheat price among other demand scenarios during 2015 to 2025.

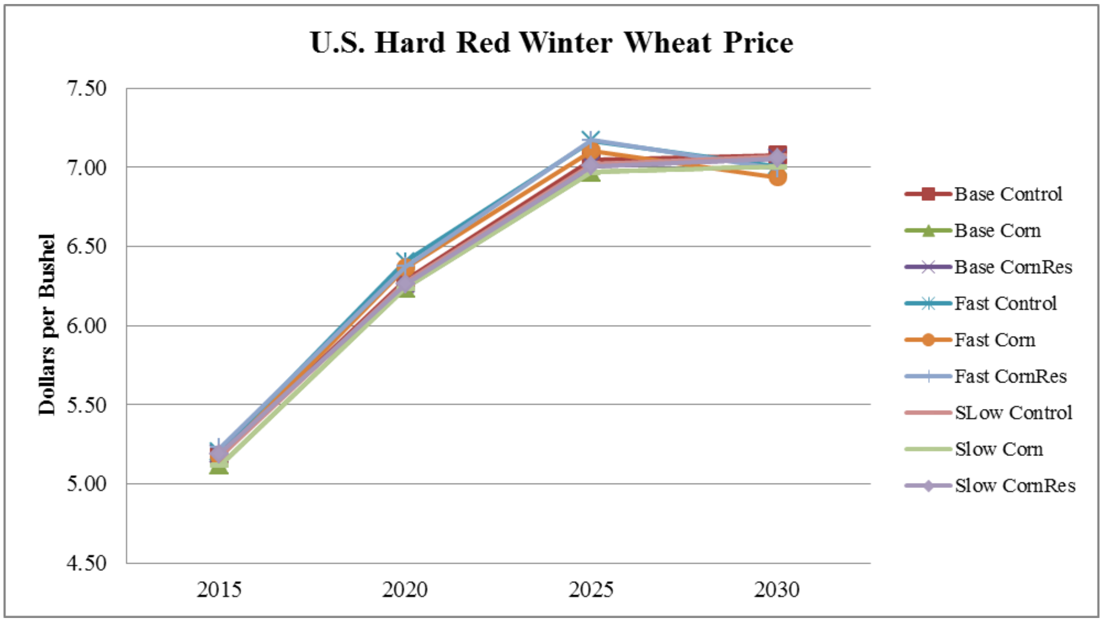

Figure 29.Average U.S. hard red winter wheat price projection during 2015 to 2030

Table 36. Average U.S. Hard Red Winter Wheat Price Projection (Dollars per Bushel) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	5.18	5.12	5.19	5.20	5.17	5.23	5.17	5.12	5.19
2020	6.29	6.24	6.26	6.41	6.36	6.37	6.27	6.24	6.26
2025	7.05	6.97	7.01	7.17	7.11	7.17	7.02	6.97	7.01
2030	7.08	7.00	7.06	7.01	6.94	6.99	7.07	7.01	7.06

U.S. Beef Prices

The two beef price results discussed are fed beef prices (in carcass weight) and non-fed (grass-fed) beef prices (in carcass weight) presented in table 37. The fed beef price is larger than the non-fed beef price. This is reasonable due to additional cattle feed costs. Both beef prices show increasing trends like in most of the feed crop price results.

However, the sizes of price growth rates drop through time. The rates are similar in fed beef prices exhibiting around 7, 6, and 4 to 5 percent in the year 2020, 2025, and 2030, respectively. Hence, in figure 30, all the scenarios' lines are close together. As for the non-fed beef price result, the increasing price rates are smaller through time under the Base and the Slow demand scenarios, i.e. 8 to 9, 5, and 3 percent in the year 2020, 2025, and 2030, respectively, while they are 8, 7, and 3 percent for the Fast demand scenario. The reduction in the rate of beef price growth in 2025 and 2030 under the Base and the Slow demand scenarios can be seen from the lower slope of their lines in figure 31.

Table 37. Average U.S. Beef Price Projection (Dollars per Pound) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Beef	Year	Base Demand			Fast Demand			Slow Demand		
		Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Nonfed Beef	2015	1.39	1.36	1.39	1.39	1.35	1.39	1.39	1.36	1.39
	2020	1.49	1.47	1.50	1.50	1.48	1.50	1.49	1.47	1.50
	2025	1.56	1.55	1.57	1.60	1.58	1.60	1.57	1.55	1.57
	2030	1.58	1.57	1.58	1.64	1.62	1.64	1.58	1.57	1.58
Fed beef	2015	2.36	2.34	2.36	2.36	2.34	2.36	2.36	2.34	2.36
	2020	2.52	2.51	2.52	2.52	2.50	2.52	2.52	2.51	2.52
	2025	2.67	2.65	2.67	2.68	2.66	2.68	2.67	2.65	2.67
	2030	2.78	2.77	2.78	2.81	2.79	2.81	2.78	2.77	2.78

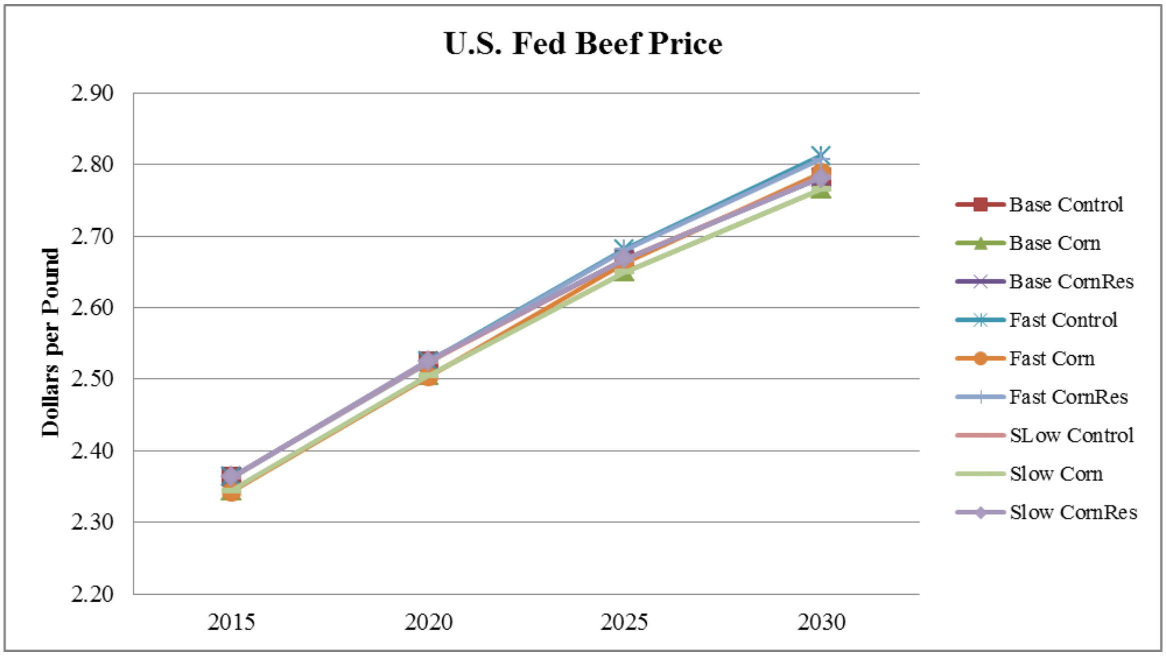

Figure 30. Average U.S. fed beef price projection during 2015 to 2030

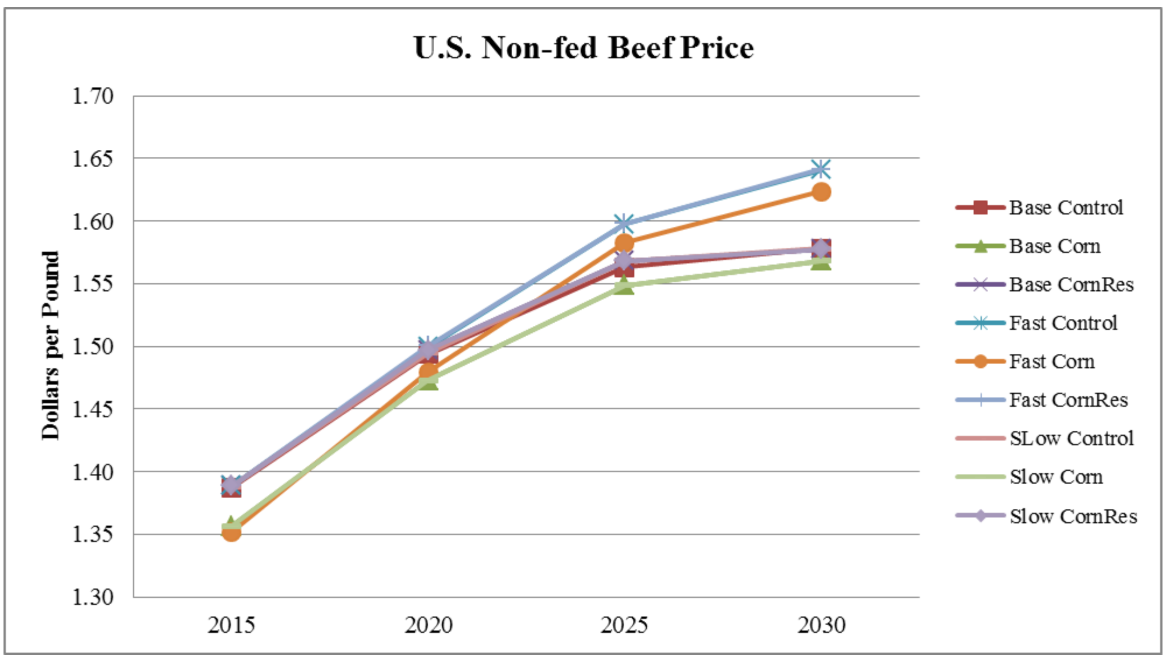

Figure 31. Average U.S. non-fed beef price projection during 2015 to 2030

During 2020 to 2030, the effect of the biofuel policy is obvious for both of the beef prices where the Corn policy scenario provides the lowest beef prices. This is because reducing the requirement of ethanol from corn lowers the demand and price for corn. Since corn is a primary feed for livestock, lowering corn price leads to a lower feed cost for cattle and, in turn, fed beef price reduces. However, the relative percentage changes of other prices from the lowest beef price under the Corn scenario are small, around 1 to 2 percent. In addition, the prices under policy the Control and the CornRes scenarios are similar.

Regarding the influence of demand, most of the results indicate the highest beef price under the Fast demand scenario. The demand influence is only obvious during 2025 to 2030, where the relative percentage changes are around 1 percent or less for the fed beef price and less than 1 to 4 percent for the non-fed beef price. The relative percentage changes of beef prices under the Fast demand increase through time. The relative percentage changes of the prices are 0.5, and 1 percent for the fed beef price in the year 2025 and 2030 and less than 1, 2, and 4 percent for the non-fed beef price in the year 2020, 2025, and 2030, respectively. In addition, the price levels under the Base and Slow demand scenarios are close. Furthermore, for the non-fed beef price, the Slow demand with the Corn scenario and the Fast demand with the CornRes scenarios provide the lowest and the largest levels of the non-fed beef prices, respectively. In short, the positive effect of demand on the non-fed beef price seems to be larger than that on the fed beef price. In addition, the effect also tends to increase through time.

In summary, the influences of biofuel policy and demand growth are small. Among various biofuel policy scenarios, the Corn scenario provides the lowest beef price for both fed and non-fed beef, while for the demand scenarios, the Fast demand provides the largest beef price level. Additionally, this demand influence tends to be greater in the non-fed beef price.

U.S. Pork Price

The average pork price exhibits an increasing trend. The growth rates of pork prices for all cases increase through time (see figure 32). The increasing rates are similar, exhibiting around 3 to 4, 4, and 4 to 5 percent in the year 2020, 2025, and 2030, respectively (table 38). Similarly, the Corn case provides the lowest pork prices, which is possibly due to the lower feed cost for swine. However, the influence of policy on pork price is small (i.e. the relative percentage changes are around 1 percent). Furthermore, the prices under the Control and the CornRes scenarios are similar. Regarding the demand effect, the Fast demand scenario delivers the largest pork price, where the relative percentage changes are around 0.5 to 1 percent. The positive effect of demand on the pork price agrees with beef price results. Also, the price levels under the Base and the Slow demand scenarios are similar.

In summary, as for biofuel policy influence, the lowest pork price is obtained under the Corn policy scenario. Among alternative demand scenarios, the Fast demand case delivers the largest pork price. Nevertheless, the impacts of both biofuel policy and demand growth are small.

Table 38. Average U.S. Pork Price Projection (Dollars per Pound) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	2.36	2.34	2.36	2.36	2.34	2.36	2.36	2.34	2.36
2020	2.52	2.51	2.52	2.52	2.50	2.52	2.52	2.51	2.52
2025	2.67	2.65	2.67	2.68	2.66	2.68	2.67	2.65	2.67
2030	2.78	2.77	2.78	2.81	2.79	2.81	2.78	2.77	2.78

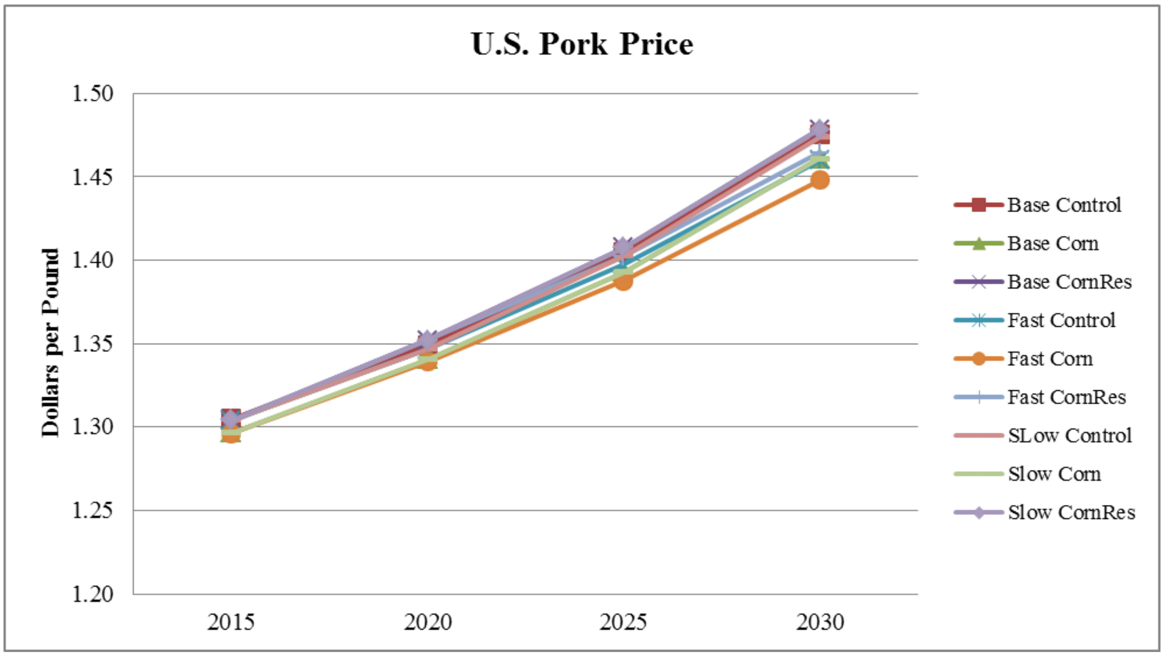

Figure 32. Average U.S. pork price projection during 2015 to 2030

U.S. Broiler Price

The average broiler prices drop in 2020 (around 1 percent) and then increase (around 1 percent) in 2025 and 2030 (figure 33 and table 39). As for the biofuel mandate effect, the Corn scenario provides the lowest broiler price, except under the Base demand case where the lowest price is shown under the CornRes scenario. Nevertheless, the relative percentage changes of prices are small (1 percent or less). The lowest price under the Corn case is similar to beef and pork price results. Regarding the effect of demand, the relative percentage changes of prices are smaller, mostly less than 0.5 percent, as compared among the alternative demand scenarios. The broiler prices under the Fast and the Slow demand cases are very similar, while the Base provides the highest price under both the Control and the Corn cases. Hence, the biofuel effect on broiler price tends to be larger than the demand effect, but both effects are trivial.

Table 39. Average U.S. Broiler Price Projection (Dollars per Pound) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	0.82	0.82	0.81	0.82	0.81	0.82	0.82	0.81	0.82
2020	0.81	0.81	0.80	0.81	0.80	0.81	0.81	0.80	0.81
2025	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
2030	0.82	0.82	0.82	0.82	0.81	0.82	0.82	0.82	0.82

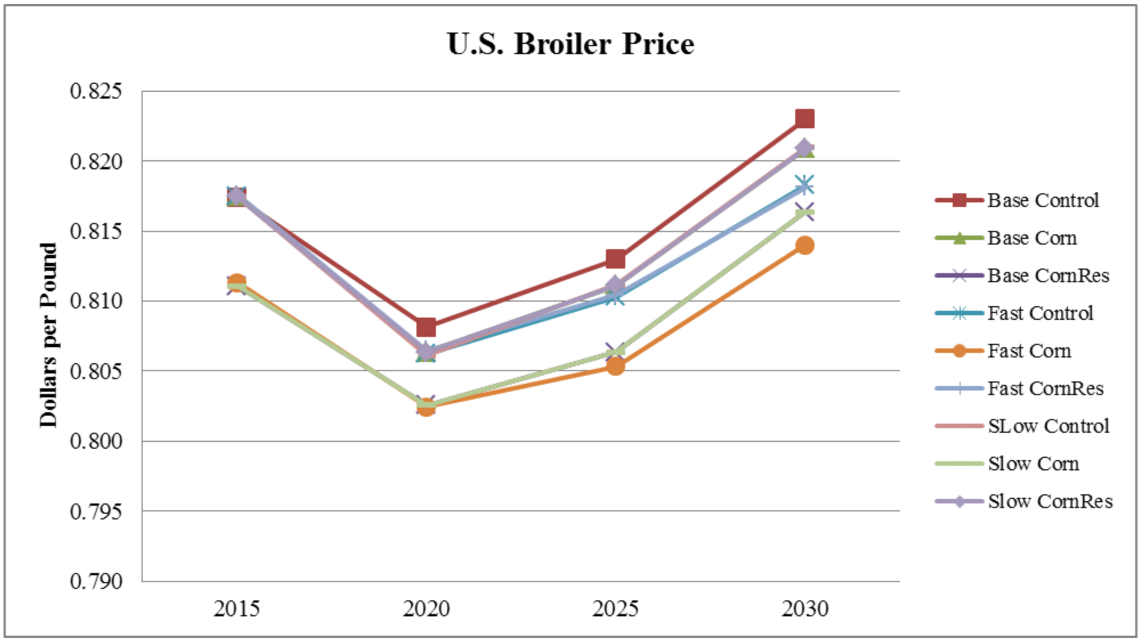

Figure 33. Average U.S. broiler price projection during 2015 to 2030

Concluding Remarks on Price Results

The price results show that the average prices tend to increase over time for most commodities, including corn, cotton, hay, sorghum, hard red winter wheat, beef, and pork, whereas the broiler price drops in 2020 and then quickly increases after 2020. Only the soybean price exhibits a downward price trend. Clearly, corn and sorghum have a very similar pattern price trend (see figure 24 and figure 27). The different pattern of average price trend is found in the ethanol and cellulosic ethanol prices where patterns are wavy.

To examine the influence of biofuel policy and demand on U.S. average commodity prices, we compared the average prices among various biofuel policy scenarios (Control, Corn, and CornRes scenarios) and different demand settings (Base, Fast, and Slow settings), respectively. Surprisingly, there is little influence of biofuel policy and demand growth on ethanol and cellulosic ethanol prices. Both ethanol prices are the same for all various biofuel policy and demand growth scenarios for each projected year. Thus, it is difficult to draw a conclusion of the impacts of biofuel policy and demand growth on ethanol and cellulosic ethanol prices.

For corn, hay, sorghum, soybeans, and hard red winter wheat the influence of demand is quite small but shown in the same way. For most of the projected years, Fast demand settings provide the lowest price but in the relatively small percentage changes (mostly 1 percent or less) as compared to the others. However, these results contrast with beef and pork prices, which the Fast demand provides the largest price level with a small effect. As for the cotton price results, the demand growth impact is only noticed. Base and Slow demand growth price results are similar but clearly different from the Fast demand growth price result. The Fast demand growth scenario provides the lower cotton price as compared to other demand growth scenarios.

The influence of biofuel policy is obvious for corn, hay, sorghum, hard red winter wheat, beef, pork, and broiler. The Corn policy scenario provides the lowest price among other biofuel policy scenarios as it reduced corn demand. The relatively percentage changes of other prices from the lowest price differ among agricultural commodities i.e. 6 to 7 percent for corn and sorghum, 2 to 3 percent for hay, 1 to 4 percent for non-fed beef, 1 percent or less for hard red winter wheat, fed beef, pork, and broiler.

GHG Emissions Mean Results

Results on the average level of total GHG emission levels are presented in table 40. In this study, we focus on GHG emissions from the agricultural and biofuel sectors. Overall, the total level of GHG emissions indicates a decreasing trend, which is what we expect from the increasing biofuel mandates in the scenarios. The results can be separated into three groups based on the different settings of biofuel mandates, regardless of the demand settings (see figure 34). The first group includes the Corn policy scenario, which their emission levels are the largest and clearly different from the other two groups. The second contains the CornRes scenarios, and the third group contains Control scenarios. From figure 34, the emission levels from these two groups are similar, but are different from the Control cases as they are higher.

In 2020, the decreasing rates of GHG emissions are around 70 percent under the Control and the CornRes cases, while they are around 50 percent under the Corn case. In 2025, the results show the slowdown of the decreasing rate to around 50 to 56 percent under the Control and the CornRes scenarios; and 43 percent under the Corn scenario. Lastly, in 2030, the decreasing rate increases significantly under the Control case to around 121 to 123 percent, which drives the GHG emission level to be negative. Additionally, for the Corn and the CornRes cases, the decreasing rate also increases to 60 and 87 percent, respectively (see table 40).

Table 40. Average GHG Emissions Projection (Million Ton per CO2e) during 2015 to 2030 under Various Biofuel Policy and Demand Growth Scenarios

Year	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
2015	231.892	230.660	240.148	231.799	230.660	240.148	231.258	230.235	239.535
2020	66.832	118.298	77.372	66.804	118.298	77.372	67.359	118.593	78.616
2025	29.168	67.752	39.187	29.172	67.752	39.186	29.375	67.749	39.464
2030	-6.068	26.886	5.183	-6.169	26.887	5.181	-6.729	27.136	4.680

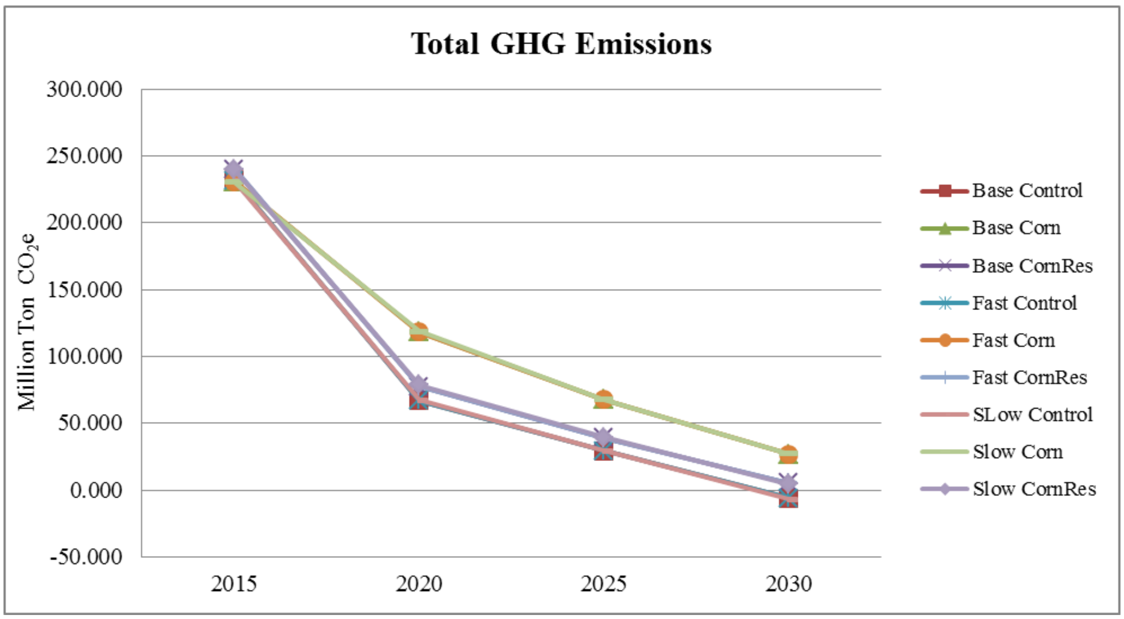

Figure 34. Average total GHG emissions projection during 2015 to 2030

The influence of biofuel policy is very obvious. During 2020 to 2030, the Control scenario provides the lowest GHG emission levels, while the Corn cases give the highest levels. This result of the Control case is reasonable due to full biofuel mandates setting. In 2020, the emissions under the Corn and the CornRes scenarios are 77 and 16 percent larger than those under the Control case. After that in 2025, the percentage changes increase to 132 and 34 under the Corn and the CornRes scenarios. And the changes are much larger in 2030. From these percentage changes, it indicates that GHG emission levels under the CornRes scenarios are closer to the levels from the Control case, while the GHG emission levels under the Corn case are much greater than those under the Control scenario as can be noticed in figure 34. However, we should note that these scenarios by no means are of the same size with the CornRes scenario reducing the total ethanol production by 4 billion gallons and the Corn scenario reducing it by 2.6 billion gallons. This suggests that requirement of ethanol from corn is more effective in reducing the overall GHG emissions than producing corn residue based ethanol. It may be the case that agricultural technological improvement provides more benefits to corn production for biofuel rather than corn residue.

As for the demand influence, the percentages changes of GHG emission levels among various demand scenarios during 2015 to 2025 are small, not greater than 1 percent. The difference is only noticed in 2030 where the Slow demand in Control and CornRes settings provide less GHG emissions around 8 to 11 percent as compared to the other cases. This result agrees to what we expected because slow demand leads to less overall products and also less GHG emissions.

In summary, the influence of biofuel policy on total GHG emissions is very evident, where the Control and the Corn scenarios provide the lowest and the largest GHG emission levels, respectively. The possible explanation may involve technological progress, which is analyzed later in this chapter. Additionally, GHG emission levels for all scenarios drop through time, so biofuel policy seems to be a promising policy to decrease GHG emission level in the long-term. As for the demand scenarios, the effect of demand growth is not obvious. Only in 2030, we notice that the Slow demand with the Control and the CornRes policy settings provide the lowest GHG emission levels among other demand scenarios.

Regression Analysis

In this section, we analyze the results using regression to take into account the technological progress effects. In particular, we used regressions to develop estimates of the marginal effect of technological progress of various crops.

The simple linear regression models for pooled data used are listed as follows:

(10) $y_{it} = \beta_0 + \beta_1 Tech_{it1} + \beta_2 Tech_{it2} + \cdots + \beta_6 Tech_{it6} + \varepsilon_{it},$

(11) $y_{it} = \alpha_0 + \gamma_1 Tech_{it1} + \gamma_2 Tech_{it2} + \cdots + \gamma_6 Tech_{it6} + \alpha_1 D25 + \alpha_2 D30 + \varepsilon_{it},$

where y_{it} denotes the interested land or other values in year *t*; $Tech_{it1}$, $Tech_{it2}$,…, $Tech_{it6}$ are average technical progress across regions of corn, cotton, hay, sorghum, soybeans, and winter wheat, respectively in year *t*; D25 and D30 represent dummy variables for years 2025 and 2030, respectively; *i* = 1, 2, …, 50 where *i* denotes the number of technical progress 50-random draw; *t* is interested year including 2020, 2025, and 2030; *αs, βs,* and *ɤs* are estimated parameters; and ε_{it} is the error term. The two models were analyzed, but we selected only one model to present the result considering statistics of the goodness of fit for the model and the significance of dummy variables in the model.

The results from the selected models are discussed in three sections. The first section is cropland regression results where the interested value (y_{it}) is cropland use for biofuel production, crop production, and livestock. The second section is the price regression results for all examined crops and meat commodities. Finally, the last section presents the results of GHG emissions from the regressions.

Cropland Regression Results

Cropland for Biofuel Production

The model chosen to analyze land is the simple linear regression model without dummy variables. The results in table 41 show that technological progress of corn, cotton, soybeans, and winter wheat have significant negative effects on biofuel production land. In other words, as technological progress increases, the biofuel land decreases. This shows increasing technological progress results in less land being allocated to biofuel with more land left to other croppings. For corn and cotton, the size of negative effect is larger under the CornRes policy scenario as compared to other biofuel policy scenarios. Nevertheless, the effects of technological progress are not significant in the CornRes cases for both hay and winter wheat.

Table 41. Biofuel Production Land Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	-13.39*	-13.55*	-32.55**	-14.64**	-13.55*	-32.67**	-13.46*	-13.56*	-32.55**
	(7.076)	(6.905)	(13.01)	(7.055)	(6.881)	(13.00)	(7.074)	(6.905)	(13.01)
Cotton	-32.46***	-29.38**	-62.81***	-32.96***	-30.42***	-62.91***	-32.54***	-29.37**	-62.81***
	(11.55)	(11.27)	(21.23)	(11.51)	(11.23)	(21.22)	(11.54)	(11.27)	(21.23)
Hay	7.719	7.477	30.69	8.412	7.244	31.37	7.544	7.477	30.69
	(12.24)	(11.94)	(22.50)	(12.20)	(11.90)	(22.48)	(12.23)	(11.94)	(22.50)
Sorghum	5.749	5.660	11.06	5.743	5.251	10.79	5.748	5.659	11.06
	(5.241)	(5.114)	(9.636)	(5.226)	(5.097)	(9.630)	(5.240)	(5.115)	(9.636)
Soybeans	-21.14**	-22.13***	-19.51	-22.02***	-21.54***	-19.31	-21.50***	-22.13***	-19.51
	(8.135)	(7.938)	(14.96)	(8.111)	(7.910)	(14.95)	(8.132)	(7.938)	(14.96)
Winter Wheat	-19.85**	-19.76**	8.039	-18.41**	-19.74**	8.747	-19.84**	-19.76**	8.041
	(9.267)	(9.042)	(17.04)	(9.239)	(9.011)	(17.03)	(9.264)	(9.043)	(17.04)
Constant	185.3***	182.5***	155.0***	186.1***	183.7***	153.7***	186.1***	182.5***	155.0***
	(18.19)	(17.75)	(33.44)	(18.13)	(17.69)	(33.42)	(18.18)	(17.75)	(33.44)
N	150	150	150	150	150	150	150	150	150
R^2	0.297	0.296	0.205	0.305	0.300	0.204	0.300	0.296	0.205
Adjusted R^2	0.268	0.267	0.171	0.276	0.271	0.171	0.270	0.267	0.171
Root MSE	10.96	10.96	10.96	10.96	10.96	20.14	10.96	10.70	20.15

Note: 1) ***, **, and *are significant at the 1, 5, and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

Cropland for Crop Production

In analyzing cropland usage, we selected the linear regression model with the dummy variables, where all dummy variables are statistically significant at the 1 percent level (table 42). The significance of dummy variables indicates the effect of time in the data. Technical progress for corn and cotton increase the cropland used for crop production across all scenarios. We also find a significant positive effect of soybean technical progress on cropland used for crop production in some scenarios.

We notice the larger effect size under the Fast demand cases as compared to other demand cases with the same biofuel policy (see table 42). In particular, the Fast demand scenario leads to more cropland land used for crop production. However, this result is in the opposite direction of the result found in the Effect on the Mean section. Thus, the mean may not capture enough information to fully explain the results. Nevertheless, the other results in the Effect on the Mean section comply with the regression result in this section. The Corn biofuel policy scenario still provides the smallest crop production land use (see table 42). Hence, with the same technological progress and demand setting, less of a gain in cropland use occurs under the Corn biofuel case possibly mainly due to the reduction in the ethanol produced from corn.

In summary, agricultural technical progress especially in corn and cotton leads to an expansion of cropland used for crop production. The effect of technical progress results in a larger expansion under the Fast demand setting, and we find a lower expansion in land use under the Corn policy scenario as compared with the other biofuel policy settings.

Table 42. Crop Production Land Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	10.26**	9.689*	10.85**	10.81**	10.32**	11.16**	10.36**	9.689*	10.85**
	(4.957)	(5.002)	(5.114)	(5.189)	(5.124)	(5.258)	(5.022)	(5.002)	(5.114)
Cotton	28.93**	29.08**	29.84**	30.67***	28.73**	30.80**	29.86***	29.08**	29.84**
	(11.12)	(11.22)	(11.47)	(11.64)	(11.49)	(11.80)	(11.27)	(11.22)	(11.47)
Hay	-11.26	-10.26	-11.65	-9.910	-10.41	-10.68	-10.82	-10.26	-11.65
	(8.030)	(8.102)	(8.284)	(8.406)	(8.300)	(8.517)	(8.135)	(8.102)	(8.284)
Sorghum	-2.793	-3.030	-2.922	-3.036	-3.133	-3.178	-2.792	-3.030	-2.922
	(3.407)	(3.437)	(3.515)	(3.566)	(3.521)	(3.614)	(3.452)	(3.437)	(3.515)
Soybeans	9.483	9.427	10.09*	9.949	10.77*	9.971	9.814*	9.426	10.09*
	(5.757)	(5.809)	(5.939)	(6.027)	(5.951)	(6.107)	(5.833)	(5.809)	(5.939)
Winter Wheat	-1.341	-3.498	-1.671	-1.244	-2.864	-1.409	-1.434	-3.498	-1.670
	(6.194)	(6.249)	(6.390)	(6.484)	(6.402)	(6.570)	(6.275)	(6.249)	(6.390)
Constant	-4.754**	-4.372**	-4.794**	-5.334**	-4.915**	-5.225**	-4.863**	-4.371**	-4.794**
	(2.004)	(2.021)	(2.067)	(2.097)	(2.071)	(2.125)	(2.030)	(2.021)	(2.067)
D25	-10.18***	-9.513***	-10.40***	-11.32***	-10.51***	-11.20***	-10.43***	-9.513***	-10.40***
	(3.297)	(3.326)	(3.401)	(3.451)	(3.408)	(3.497)	(3.340)	(3.326)	(3.401)
D30	279.1***	278.2***	277.1***	274.2***	275.6***	274.4***	277.0***	278.2***	277.1***
	(18.36)	(18.52)	(18.94)	(19.21)	(18.97)	(19.47)	(18.60)	(18.52)	(18.94)
N	150	150	150	150	150	150	150	150	150
R^2	0.086	0.084	0.087	0.092	0.088	0.090	0.088	0.084	0.087
Adjusted R^2	0.035	0.032	0.036	0.040	0.037	0.039	0.036	0.032	0.036
Root MSE	7.064	7.127	7.288	7.395	7.302	7.493	7.157	7.127	7.288

Note: 1) ***, **, and *are significant at the 1, 5, and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

Cropland Pasture Used for Livestock

The linear model with the dummy variables was selected to analyze the amount of cropland pasture used. Most of the dummy variables are statistically significant, so there is a time effect in the model. Significant negative effects of corn and cotton technical progress show in all scenarios (table 43). This indicates that as technological progress increases, livestock land reduces, with more land moving into cropland uses likely due to both higher productivity and a larger gain feed supply reducing demand for pasture. Additionally, soybean technical progress also provides a significant negative effect on cropland pasture use in some scenarios.

For policy scenarios, the result shows the Corn biofuel policy case increases cropland pasture use again freeing up possible land leading to more cropland pasture use. This corresponds to the result found in the Effect on the Mean section. This confirms that reduction in corn ethanol mandates increases livestock use of cropland pasture. In general, for demand scenarios, the Fast demand case provides the largest negative effect on cropland pasture area. Thus, there is the largest reduction in cropland pasture under the Fast demand scenario as compared to the other demand settings.

Generally, one moves more cropland pasture use to cropping use in order to satisfy the greater demand for agricultural commodities. This result is in contrast with the result found in Effect on the Mean section, where Fast demand mostly has the largest cropland for livestock. Thus, the mean result may not provide truly understanding in the aspect of technological progress.

In summary, faster agricultural technical progress especially in corn and cotton leads to a reduction in cropland pasture for livestock as does Fast demand growth. Relaxing the corn ethanol mandate has the opposite effect, moving land from cropping to livestock.

Table 43. Livestock Production Land Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	-10.87**	-10.34**	-11.34**	-11.55**	-10.99**	-11.74**	-10.99**	-10.34**	-11.34**
	(4.897)	(4.904)	(5.023)	(5.107)	(5.009)	(5.161)	(4.955)	(4.904)	(5.023)
Cotton	-29.03***	-29.18***	-30.05***	-30.96***	-29.15**	-31.16***	-29.98***	-29.17***	-30.05***
	(10.99)	(11.00)	(11.27)	(11.46)	(11.24)	(11.58)	(11.12)	(11.00)	(11.27)
Hay	11.20	10.42	11.64	10.17	10.66	10.83	10.83	10.42	11.64
	(7.933)	(7.943)	(8.136)	(8.273)	(8.114)	(8.361)	(8.027)	(7.943)	(8.136)
Sorghum	2.731	3.132	2.837	3.149	3.163	3.132	2.808	3.132	2.837
	(3.366)	(3.370)	(3.452)	(3.510)	(3.443)	(3.547)	(3.405)	(3.370)	(3.452)
Soybeans	-9.302	-9.099	-9.836*	-9.721	-10.38*	-9.699	-9.621*	-9.097	-9.837*
	(5.687)	(5.695)	(5.833)	(5.931)	(5.817)	(5.994)	(5.755)	(5.695)	(5.833)
Winter Wheat	1.360	3.740	1.692	1.642	3.144	1.643	1.541	3.740	1.691
	(6.119)	(6.127)	(6.276)	(6.381)	(6.258)	(6.449)	(6.191)	(6.127)	(6.276)
Constant	2.607	2.213	2.697	3.155	2.712	3.091	2.721	2.213	2.697
	(1.979)	(1.982)	(2.030)	(2.064)	(2.024)	(2.086)	(2.003)	(1.982)	(2.030)
D25	6.276*	5.540*	6.530*	7.326**	6.554*	7.282**	6.512*	5.540*	6.530*
	(3.257)	(3.261)	(3.341)	(3.397)	(3.331)	(3.433)	(3.296)	(3.261)	(3.341)
D30	102.4***	102.5***	104.2***	106.7***	105.4***	106.7***	104.2***	102.5***	104.2***
	(18.13)	(18.16)	(18.60)	(18.91)	(18.55)	(19.11)	(18.35)	(18.16)	(18.60)
N	150	150	150	150	150	150	150	150	150
R^2	0.111	0.117	0.114	0.105	0.107	0.106	0.113	0.117	0.114
Adjusted R^2	0.061	0.066	0.063	0.054	0.056	0.055	0.062	0.066	0.063
Root MSE	6.979	6.988	7.158	7.278	7.138	7.355	7.061	6.988	7.158

Note: 1) ***, **, and *are significant at the 1, 5, and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

Concluding Remarks on Cropland Regression Results

The main result from the cropland regression analysis is the significant effect of technological progress on cropland devoted to biofuel, crop production, and livestock, where the effect is negative on land devoted to biofuel and livestock and the positive on land for crop production. The effects on biofuel area are strong for corn, cotton, soybeans and winter wheat technical progress while the effects on land use for livestock and crop production are significant only for corn and cotton technical progress. There are only a few of significant effects of soybean technical progress.

The negative effect on biofuel land is much larger under the CornRes scenario as compared with the other biofuel policy scenarios. The marginal negative effect on livestock land and the marginal positive effect on cropland are larger under the Fast demand and smaller under the Corn policy scenario. This shows the rather obvious result that demand increases lead to land use change from livestock and crop, while decreases move land in the opposite direction.

These results show the importance of technological progress in meeting growing food and energy global demands.

Price Regression Results

The results of all prices for examined crops and meat commodities are presented in table 44 to table 53. The linear regression model without the dummy variables was employed to estimate the effect of technological progress for most of the crops and meat commodities. Nevertheless, the dummy variables were included in the model for cotton, fed beef, non-fed beef, and pork prices because the variables are statistically significant.

Table 44. Corn Price Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	0.829	0.687	0.856	0.789	0.670	0.795	0.851	0.687	0.856
	(0.729)	(0.623)	(0.729)	(0.720)	(0.616)	(0.719)	(0.731)	(0.623)	(0.729)
Cotton	3.112***	2.679***	3.081**	2.970**	2.554**	2.915**	3.127***	2.679***	3.081**
	(1.189)	(1.017)	(1.190)	(1.175)	(1.005)	(1.173)	(1.193)	(1.017)	(1.190)
Hay	-1.283	-1.023	-1.244	-1.255	-0.949	-1.248	-1.266	-1.023	-1.244
	(1.260)	(1.078)	(1.261)	(1.245)	(1.065)	(1.243)	(1.265)	(1.078)	(1.261)
Sorghum	-0.617	-0.421	-0.639	-0.634	-0.434	-0.645	-0.630	-0.421	-0.639
	(0.540)	(0.462)	(0.540)	(0.533)	(0.456)	(0.532)	(0.542)	(0.462)	(0.540)
Soybeans	0.284	0.132	0.295	0.230	0.0531	0.229	0.302	0.132	0.295
	(0.838)	(0.716)	(0.838)	(0.827)	(0.708)	(0.826)	(0.841)	(0.716)	(0.838)
Winter Wheat	-1.534	-1.285	-1.528	-1.555	-1.354*	-1.568*	-1.529	-1.285	-1.528
	(0.954)	(0.816)	(0.955)	(0.943)	(0.806)	(0.941)	(0.958)	(0.816)	(0.955)
Constant	2.723	2.577	2.716	2.991	2.823*	3.087*	2.658	2.577	2.716
	(1.873)	(1.602)	(1.874)	(1.850)	(1.583)	(1.847)	(1.879)	(1.602)	(1.874)
N	150	150	150	150	150	150	150	150	150
R^2	0.096	0.091	0.096	0.090	0.085	0.089	0.097	0.091	0.096
Adjusted R^2	0.058	0.053	0.058	0.052	0.047	0.051	0.059	0.053	0.058
Root MSE	1.129	0.965	1.130	1.115	0.954	1.113	1.133	0.965	1.130

Note: 1) ***, **, and *are significant at the 1, 5, and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

Table 45. Cotton Price Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	-0.0575	-0.0588	-0.0623	-0.0632	-0.0774	-0.0693	-0.0573	-0.0588	-0.0623
	(0.0737)	(0.0713)	(0.0729)	(0.0689)	(0.0683)	(0.0688)	(0.0732)	(0.0713)	(0.0729)
Cotton	0.0324	0.0124	0.0127	0.0207	0.00785	0.0186	0.0299	0.0124	0.0127
	(0.165)	(0.160)	(0.163)	(0.155)	(0.153)	(0.154)	(0.164)	(0.160)	(0.163)
Hay	0.0365	0.0334	0.0390	0.0408	0.0494	0.0443	0.0345	0.0334	0.0390
	(0.119)	(0.115)	(0.118)	(0.112)	(0.111)	(0.111)	(0.119)	(0.115)	(0.118)
Sorghum	0.00800	0.0115	0.0156	0.0129	0.00316	0.0166	0.0123	0.0115	0.0156
	(0.0506)	(0.0490)	(0.0501)	(0.0473)	(0.0469)	(0.0473)	(0.0503)	(0.0490)	(0.0501)
Soybeans	0.0336	0.0253	0.0193	0.0567	0.0403	0.0512	0.0321	0.0253	0.0193
	(0.0856)	(0.0828)	(0.0846)	(0.0800)	(0.0793)	(0.0799)	(0.0850)	(0.0828)	(0.0846)
Winter Wheat	0.173*	0.165*	0.165*	0.168*	0.167*	0.168*	0.175*	0.165*	0.165*
	(0.0921)	(0.0890)	(0.0911)	(0.0861)	(0.0853)	(0.0860)	(0.0915)	(0.0890)	(0.0911)
Constant	0.0622**	0.0616**	0.0671**	0.0169	0.0191	0.0187	0.0610**	0.0616**	0.0671**
	(0.0298)	(0.0288)	(0.0295)	(0.0278)	(0.0276)	(0.0278)	(0.0296)	(0.0288)	(0.0295)
D25	0.0717	0.0729	0.0818*	0.0531	0.0578	0.0567	0.0701	0.0729	0.0818*
	(0.0490)	(0.0474)	(0.0485)	(0.0458)	(0.0454)	(0.0458)	(0.0487)	(0.0474)	(0.0485)
D30	0.442	0.479*	0.479*	0.399	0.448*	0.405	0.441	0.479*	0.479*
	(0.273)	(0.264)	(0.270)	(0.255)	(0.253)	(0.255)	(0.271)	(0.264)	(0.270)
N	150	150	150	150	150	150	150	150	150
R^2	0.167	0.162	0.174	0.131	0.126	0.136	0.165	0.162	0.174
Adjusted R^2	0.120	0.114	0.127	0.082	0.077	0.087	0.118	0.114	0.127
Root MSE	0.105	0.102	0.104	0.0982	0.0973	0.0980	0.104	0.102	0.104

Note: 1) ** and *are significant at the 5and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

Table 46. Hay Price Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	9.709	6.647	10.42	6.567	4.336	7.085	9.839	6.646	10.43
	(14.61)	(13.46)	(14.51)	(14.37)	(13.41)	(14.34)	(14.55)	(13.46)	(14.51)
Cotton	51.86**	42.80*	51.86**	44.85*	37.84*	44.96*	51.27**	42.80*	51.86**
	(23.85)	(21.96)	(23.69)	(23.45)	(21.88)	(23.40)	(23.75)	(21.96)	(23.69)
Hay	-44.58*	-44.44*	-46.59*	-44.09*	-40.96*	-45.04*	-45.85*	-44.44*	-46.59*
	(25.28)	(23.27)	(25.10)	(24.85)	(23.19)	(24.80)	(25.16)	(23.27)	(25.10)
Sorghum	-9.830	-8.629	-10.23	-10.17	-8.400	-10.85	-9.681	-8.629	-10.23
	(10.83)	(9.968)	(10.75)	(10.64)	(9.932)	(10.62)	(10.78)	(9.968)	(10.75)
Soybeans	18.15	17.20	19.49	15.61	11.87	16.54	19.09	17.20	19.49
	(16.80)	(15.47)	(16.69)	(16.52)	(15.41)	(16.48)	(16.73)	(15.47)	(16.69)
Winter Wheat	-3.267	1.969	-2.871	-6.785	-1.226	-5.911	-3.374	1.971	-2.871
	(19.14)	(17.62)	(19.01)	(18.82)	(17.56)	(18.78)	(19.06)	(17.62)	(19.01)
Constant	132.0***	136.0***	131.1***	148.9***	149.0***	147.7***	132.4***	136.0***	131.1***
	(37.57)	(34.59)	(37.31)	(36.93)	(34.47)	(36.86)	(37.40)	(34.59)	(37.31)
N	150	150	150	150	150	150	150	150	150
R^2	0.099	0.093	0.105	0.076	0.067	0.080	0.101	0.093	0.105
Adjusted R^2	0.061	0.055	0.068	0.037	0.028	0.042	0.063	0.055	0.068
Root MSE	22.64	20.85	22.48	22.26	20.77	22.21	22.54	20.85	22.48

Note: 1) ***, **, and *are significant at the 1, 5, and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

Table 47. Sorghum Price Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	1.294	1.071	1.318	1.220	0.981	1.220	1.335	1.071	1.318
	(1.205)	(1.025)	(1.208)	(1.190)	(1.010)	(1.190)	(1.207)	(1.025)	(1.208)
Cotton	5.474***	4.790***	5.461***	5.186***	4.637***	5.134***	5.503***	4.790***	5.461***
	(1.966)	(1.673)	(1.971)	(1.942)	(1.648)	(1.941)	(1.970)	(1.673)	(1.971)
Hay	-2.203	-1.765	-2.096	-2.058	-1.624	-2.040	-2.157	-1.765	-2.096
	(2.083)	(1.773)	(2.089)	(2.058)	(1.747)	(2.057)	(2.088)	(1.773)	(2.089)
Sorghum	-0.989	-0.676	-1.017	-1.008	-0.697	-1.032	-1.002	-0.676	-1.017
	(0.892)	(0.759)	(0.895)	(0.882)	(0.748)	(0.881)	(0.894)	(0.759)	(0.895)
Soybeans	0.429	0.197	0.466	0.324	0.0162	0.350	0.458	0.197	0.466
	(1.385)	(1.178)	(1.389)	(1.368)	(1.161)	(1.368)	(1.388)	(1.178)	(1.389)
Winter Wheat	-2.500	-1.995	-2.518	-2.547	-2.162	-2.579	-2.500	-1.995	-2.518
	(1.578)	(1.342)	(1.582)	(1.559)	(1.323)	(1.558)	(1.581)	(1.342)	(1.582)
Constant	4.526	4.096	4.451	4.958	4.608*	5.066*	4.390	4.096	4.451
	(3.097)	(2.634)	(3.105)	(3.059)	(2.597)	(3.058)	(3.103)	(2.634)	(3.105)
N	150	150	150	150	150	150	150	150	150
R^2	0.102	0.101	0.102	0.094	0.094	0.093	0.103	0.101	0.102
Adjusted R^2	0.064	0.063	0.064	0.056	0.056	0.055	0.066	0.063	0.064
Root MSE	1.866	1.588	1.871	1.844	1.565	1.843	1.870	1.588	1.871

Note: 1) ***and ** are significant at the 1 and 5 percent level, respectively.
2) Numbers in parentheses are standard errors.

Table 48. Soybean Price Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	0.359	0.473	0.197	0.136	0.399	0.161	0.171	0.473	0.197
	(0.840)	(0.807)	(0.772)	(0.762)	(0.791)	(0.764)	(0.772)	(0.807)	(0.772)
Cotton	-4.896***	-4.491***	-4.834***	-5.114***	-4.643***	-5.151***	-4.897***	-4.491***	-4.834***
	(1.370)	(1.317)	(1.259)	(1.243)	(1.291)	(1.246)	(1.260)	(1.317)	(1.259)
Hay	0.496	0.554	0.640	0.607	0.694	0.700	0.560	0.554	0.640
	(1.452)	(1.396)	(1.335)	(1.317)	(1.368)	(1.321)	(1.335)	(1.396)	(1.335)
Sorghum	0.250	0.0352	0.371	0.377	0.112	0.374	0.395	0.0352	0.371
	(0.622)	(0.598)	(0.572)	(0.564)	(0.586)	(0.566)	(0.572)	(0.598)	(0.572)
Soybeans	-1.663*	-1.348	-1.539*	-1.606*	-1.471	-1.577*	-1.515*	-1.348	-1.539*
	(0.965)	(0.928)	(0.887)	(0.876)	(0.909)	(0.878)	(0.888)	(0.928)	(0.887)
Winter Wheat	1.247	1.049	1.029	1.025	0.998	1.081	1.022	1.049	1.029
	(1.100)	(1.057)	(1.011)	(0.997)	(1.036)	(1.000)	(1.011)	(1.057)	(1.011)
Constant	17.69***	17.19***	17.48***	17.95***	17.38***	17.77***	17.63***	17.19***	17.48***
	(2.158)	(2.075)	(1.984)	(1.958)	(2.033)	(1.963)	(1.985)	(2.075)	(1.984)
N	150	150	150	150	150	150	150	150	150
R^2	0.147	0.128	0.169	0.191	0.146	0.190	0.172	0.128	0.169
Adjusted R^2	0.112	0.091	0.134	0.157	0.110	0.156	0.137	0.091	0.134
Root MSE	1.301	1.251	1.196	1.180	1.225	1.183	1.196	1.251	1.196

Note: 1) *** and *are significant at the 1and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

Table 49. Hard Red Winter Wheat Price Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	1.955	1.755	1.904	1.669	1.554	1.709	1.919	1.755	1.904
	(1.807)	(1.769)	(1.799)	(1.853)	(1.824)	(1.847)	(1.803)	(1.769)	(1.799)
Cotton	-1.598	-1.740	-1.666	-1.993	-2.075	-2.010	-1.615	-1.740	-1.666
	(2.949)	(2.887)	(2.936)	(3.024)	(2.977)	(3.014)	(2.942)	(2.887)	(2.936)
Hay	6.205**	6.105**	6.062*	6.056*	6.060*	5.912*	6.119*	6.105**	6.062*
	(3.125)	(3.060)	(3.111)	(3.205)	(3.155)	(3.194)	(3.118)	(3.060)	(3.111)
Sorghum	-0.250	-0.216	-0.323	-0.223	-0.115	-0.308	-0.242	-0.216	-0.323
	(1.339)	(1.310)	(1.333)	(1.373)	(1.351)	(1.368)	(1.335)	(1.310)	(1.333)
Soybeans	0.427	0.552	0.498	0.263	0.158	0.210	0.574	0.552	0.498
	(2.077)	(2.034)	(2.068)	(2.131)	(2.097)	(2.123)	(2.072)	(2.034)	(2.068)
Winter Wheat	3.973*	4.187*	4.084*	3.948	4.032*	4.041*	3.971*	4.187*	4.084*
	(2.366)	(2.317)	(2.356)	(2.427)	(2.389)	(2.419)	(2.361)	(2.317)	(2.356)
Constant	-4.668	-4.647	-4.540	-3.455	-3.371	-3.306	-4.708	-4.647	-4.540
	(4.645)	(4.548)	(4.624)	(4.764)	(4.689)	(4.748)	(4.634)	(4.548)	(4.624)
N	150	150	150	150	150	150	150	150	150
R^2	0.060	0.062	0.060	0.051	0.051	0.051	0.060	0.062	0.060
Adjusted R^2	0.021	0.022	0.021	0.011	0.011	0.011	0.020	0.022	0.021
Root MSE	2.799	2.741	2.787	2.871	2.826	2.861	2.793	2.741	2.787

Note: 1) ** and *are significant at the5 and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

Table 50. Fed Beef Price Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	0.0667	0.0642	0.0671	0.0569	0.0388	0.0416	0.0615	0.0642	0.0671
	(0.0444)	(0.0441)	(0.0455)	(0.0456)	(0.0466)	(0.0467)	(0.0447)	(0.0441)	(0.0455)
Cotton	0.222**	0.164*	0.231**	0.270***	0.261**	0.251**	0.236**	0.164*	0.231**
	(0.0995)	(0.0990)	(0.102)	(0.102)	(0.105)	(0.105)	(0.100)	(0.0990)	(0.102)
Hay	-0.161**	-0.133*	-0.167**	-0.119	-0.123	-0.118	-0.167**	-0.133*	-0.167**
	(0.0719)	(0.0715)	(0.0737)	(0.0739)	(0.0756)	(0.0757)	(0.0723)	(0.0715)	(0.0737)
Sorghum	-0.0341	-0.0415	-0.0318	-0.0373	-0.0350	-0.0429	-0.0357	-0.0415	-0.0318
	(0.0305)	(0.0303)	(0.0313)	(0.0313)	(0.0321)	(0.0321)	(0.0307)	(0.0303)	(0.0313)
Soybeans	0.0533	0.0543	0.0661	0.0706	0.0536	0.0735	0.0634	0.0543	0.0661
	(0.0515)	(0.0513)	(0.0528)	(0.0530)	(0.0542)	(0.0543)	(0.0519)	(0.0513)	(0.0528)
Winter Wheat	-0.0216	-0.0273	-0.0204	-0.0542	-0.0317	-0.0500	-0.0243	-0.0273	-0.0205
	(0.0554)	(0.0551)	(0.0568)	(0.0570)	(0.0583)	(0.0584)	(0.0558)	(0.0551)	(0.0568)
Constant	0.114***	0.122***	0.112***	0.125***	0.129***	0.129***	0.112***	0.122***	0.112***
	(0.0179)	(0.0178)	(0.0184)	(0.0184)	(0.0189)	(0.0189)	(0.0180)	(0.0178)	(0.0184)
D25	0.196***	0.212***	0.190***	0.220***	0.222***	0.222***	0.193***	0.212***	0.190***
	(0.0295)	(0.0294)	(0.0303)	(0.0303)	(0.0310)	(0.0311)	(0.0297)	(0.0294)	(0.0303)
D30	2.371***	2.402***	2.350***	2.306***	2.311***	2.340***	2.361***	2.402***	2.350***
	(0.164)	(0.163)	(0.168)	(0.169)	(0.173)	(0.173)	(0.165)	(0.163)	(0.168)
N	150	150	150	150	150	150	150	150	150
R^2	0.753	0.757	0.741	0.781	0.770	0.768	0.751	0.757	0.741
Adjusted R^2	0.739	0.743	0.727	0.769	0.757	0.755	0.737	0.743	0.727
Root MSE	0.0632	0.0629	0.0648	0.0650	0.0665	0.0666	0.0636	0.0629	0.0648

Note: 1) ***, **, and *are significant at the 1, 5, and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

Table 51. Non-Fed Beef Price Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	0.103**	0.0384	0.0921**	0.0739	0.0603	0.0737	0.0940**	0.0384	0.0921**
	(0.0439)	(0.0386)	(0.0426)	(0.0475)	(0.0438)	(0.0482)	(0.0420)	(0.0386)	(0.0426)
Cotton	0.0804	0.127	0.0855	0.181*	0.165*	0.193*	0.0829	0.127	0.0855
	(0.0984)	(0.0866)	(0.0957)	(0.106)	(0.0982)	(0.108)	(0.0943)	(0.0866)	(0.0957)
Hay	-0.0889	-0.144**	-0.109	-0.0943	-0.0673	-0.0969	-0.0969	-0.144**	-0.109
	(0.0710)	(0.0625)	(0.0691)	(0.0769)	(0.0709)	(0.0781)	(0.0681)	(0.0625)	(0.0691)
Sorghum	-0.0312	-0.0340	-0.0301	-0.0473	-0.0312	-0.0471	-0.0338	-0.0340	-0.0301
	(0.0301)	(0.0265)	(0.0293)	(0.0326)	(0.0301)	(0.0331)	(0.0289)	(0.0265)	(0.0293)
Soybeans	0.0805	0.0953**	0.0762	-0.00234	0.0465	0.00727	0.0704	0.0953**	0.0762
	(0.0509)	(0.0448)	(0.0495)	(0.0551)	(0.0509)	(0.0560)	(0.0488)	(0.0448)	(0.0495)
Winter Wheat	-0.0102	-0.0432	-0.0176	-0.0169	0.0164	-0.0194	-0.0124	-0.0432	-0.0176
	(0.0548)	(0.0482)	(0.0533)	(0.0593)	(0.0547)	(0.0602)	(0.0525)	(0.0482)	(0.0533)
Constant	0.0486***	0.0568***	0.0516***	0.0765***	0.0778***	0.0747***	0.0544***	0.0568***	0.0516***
	(0.0177)	(0.0156)	(0.0172)	(0.0192)	(0.0177)	(0.0195)	(0.0170)	(0.0156)	(0.0172)
D25	0.0396	0.0555**	0.0379	0.0941***	0.0907***	0.0906***	0.0419	0.0555**	0.0379
	(0.0292)	(0.0257)	(0.0284)	(0.0316)	(0.0291)	(0.0321)	(0.0280)	(0.0257)	(0.0284)
D30	1.337***	1.415***	1.379***	1.384***	1.264***	1.367***	1.370***	1.415***	1.379***
	(0.162)	(0.143)	(0.158)	(0.176)	(0.162)	(0.179)	(0.156)	(0.143)	(0.158)
N	150	150	150	150	150	150	150	150	150
R^2	0.300	0.403	0.300	0.466	0.512	0.458	0.320	0.403	0.300
Adjusted R^2	0.260	0.369	0.260	0.435	0.484	0.427	0.282	0.369	0.260
Root MSE	0.0625	0.0550	0.0608	0.0676	0.0624	0.0687	0.0599	0.0550	0.0608

Note: 1) ***, **, and *are significant at the 1, 5, and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

Table 52. Pork Price Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	0.0566	0.0414	0.0585	0.0491	0.0366	0.0541	0.0581	0.0414	0.0585
	(0.0411)	(0.0375)	(0.0410)	(0.0410)	(0.0374)	(0.0407)	(0.0410)	(0.0375)	(0.0410)
Cotton	0.208**	0.172**	0.203**	0.200**	0.168**	0.205**	0.213**	0.172**	0.203**
	(0.0922)	(0.0840)	(0.0919)	(0.0920)	(0.0840)	(0.0913)	(0.0920)	(0.0840)	(0.0919)
Hay	-0.0831	-0.0719	-0.0818	-0.0771	-0.0681	-0.0763	-0.0817	-0.0719	-0.0818
	(0.0665)	(0.0607)	(0.0663)	(0.0664)	(0.0606)	(0.0659)	(0.0665)	(0.0607)	(0.0663)
Sorghum	-0.0360	-0.0298	-0.0340	-0.0367	-0.0305	-0.0362	-0.0339	-0.0298	-0.0340
	(0.0282)	(0.0257)	(0.0281)	(0.0282)	(0.0257)	(0.0280)	(0.0282)	(0.0257)	(0.0281)
Soybeans	0.0192	0.00909	0.0240	0.0208	0.00636	0.0222	0.0241	0.00910	0.0240
	(0.0477)	(0.0435)	(0.0476)	(0.0476)	(0.0435)	(0.0473)	(0.0476)	(0.0435)	(0.0476)
Winter Wheat	-0.0712	-0.0544	-0.0692	-0.0645	-0.0572	-0.0657	-0.0702	-0.0544	-0.0692
	(0.0513)	(0.0468)	(0.0512)	(0.0512)	(0.0468)	(0.0508)	(0.0513)	(0.0468)	(0.0512)
Constant	0.0352**	0.0360**	0.0348**	0.0310*	0.0332**	0.0295*	0.0343**	0.0360**	0.0348**
	(0.0166)	(0.0151)	(0.0166)	(0.0166)	(0.0151)	(0.0164)	(0.0166)	(0.0151)	(0.0166)
D25	0.0811***	0.0843***	0.0807***	0.0703**	0.0754***	0.0670**	0.0792***	0.0843***	0.0807***
	(0.0273)	(0.0249)	(0.0272)	(0.0273)	(0.0249)	(0.0271)	(0.0273)	(0.0249)	(0.0272)
D30	1.236***	1.259***	1.231***	1.235***	1.269***	1.229***	1.216***	1.259***	1.231***
	(0.152)	(0.139)	(0.152)	(0.152)	(0.139)	(0.151)	(0.152)	(0.139)	(0.152)
N	150	150	150	150	150	150	150	150	150
R^2	0.475	0.492	0.476	0.426	0.445	0.425	0.478	0.492	0.476
Adjusted R^2	0.445	0.463	0.446	0.394	0.413	0.393	0.448	0.463	0.446
Root MSE	0.0585	0.0534	0.0584	0.0584	0.0533	0.0580	0.0585	0.0534	0.0584

Note: 1) ***, **, and *are significant at the 1, 5, and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

Table 53. Broiler Price Regression Results

Crop Tech / Variable	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	0.0292	0.0268	0.0287	0.0259	0.0262	0.0265	0.0282	0.0268	0.0287
	(0.0189)	(0.0172)	(0.0186)	(0.0186)	(0.0172)	(0.0185)	(0.0187)	(0.0172)	(0.0186)
Cotton	0.0712**	0.0636**	0.0720**	0.0657**	0.0582**	0.0634**	0.0735**	0.0636**	0.0720**
	(0.0308)	(0.0281)	(0.0304)	(0.0303)	(0.0280)	(0.0302)	(0.0305)	(0.0281)	(0.0304)
Hay	-0.0192	-0.0171	-0.0168	-0.0199	-0.0144	-0.0186	-0.0199	-0.0171	-0.0168
	(0.0327)	(0.0298)	(0.0322)	(0.0321)	(0.0297)	(0.0320)	(0.0323)	(0.0298)	(0.0322)
Sorghum	-0.0175	-0.0127	-0.0176	-0.0167	-0.0124	-0.0175	-0.0165	-0.0127	-0.0176
	(0.0140)	(0.0128)	(0.0138)	(0.0138)	(0.0127)	(0.0137)	(0.0138)	(0.0128)	(0.0138)
Soybeans	-0.000488	-0.000662	0.000483	-0.000590	-0.00365	-0.00114	0.00157	-0.000660	0.000482
	(0.0217)	(0.0198)	(0.0214)	(0.0214)	(0.0197)	(0.0213)	(0.0215)	(0.0198)	(0.0214)
Winter Wheat	-0.0249	-0.0202	-0.0268	-0.0280	-0.0219	-0.0276	-0.0273	-0.0202	-0.0268
	(0.0247)	(0.0226)	(0.0244)	(0.0243)	(0.0225)	(0.0242)	(0.0245)	(0.0226)	(0.0244)
Constant	0.761***	0.755***	0.758***	0.772***	0.763***	0.774***	0.758***	0.755***	0.758***
	(0.0485)	(0.0443)	(0.0479)	(0.0477)	(0.0441)	(0.0476)	(0.0480)	(0.0443)	(0.0479)
N	150	150	150	150	150	150	150	150	150
R^2	0.093	0.089	0.095	0.080	0.077	0.079	0.096	0.089	0.095
Adjusted R^2	0.055	0.051	0.057	0.041	0.038	0.040	0.058	0.051	0.057
Root MSE	0.0293	0.0267	0.0289	0.0288	0.0266	0.0287	0.0289	0.0267	0.0289

Note: 1) *** and ** are significant at the 1 and 5 percent level, respectively.
2) Numbers in parentheses are standard errors.

Overall, most of the technological progress coefficients of the main six field crops are not statistically significant at the 10 percent level especially, sorghum, and corn. However, the results show that technological progress for cotton is statistically significant. Additionally, in some cases, technological progress of hay, wheat, and soybean are shown to have significant coefficients.

There are positive effects of technological progress of cotton on corn, hay, sorghum, fed beef, pork, and broiler prices. Thus, as the technical progress of cotton increases, all these prices also increase. Nevertheless, the marginal positive effects are smaller under the Corn policy scenario comparing with the effects under the other biofuel policies. Thus, under the mandated lower level of ethanol from corn, increasing technical progress tends to increase the prices in the lower levels. This result is similar to the positive effect of technical progress of wheat on cotton price under both Corn and CornRes policy settings (table 45) and the positive effect of technical progress of hay on hard red winter wheat price under the CornRes policy scenario (table 49). Thus, lowering the requirement level of corn or corn residue for ethanol provides smaller price increases comparing to the control case as it reduces the overall demand of for corn or corn residue. Regarding the effect of demand growth, the marginal positive effects of technological progress of cotton on corn, hay, sorghum, and broiler prices are smaller under the Fast demand scenarios. This suggests that the effect of growing demand on increasing price is likely to be smaller by agricultural technological progress.

Oppositely, the results show the negative effects of technological progress on the prices for crops and meat commodities in some cases i.e. the effect technical progress of hay on hay, fed beef, and non-fed beef prices; and the effects of technical advance of soybean and cotton on soybean price. These results indicate that as technological progress increases, the prices of crops and meats decrease. Nevertheless, it is difficult to draw a conclusion of the marginal negative effect of a technical progress on the prices of crops and meats under various biofuel policy and demand growth scenarios because the results are different depending on the examined price.

The insignificant effects of technological progress of the main field crops on commodity prices mostly exhibit in the results. The effects are different depending on the crop type of technological progress and commodity prices. Hence, the influence of technological progress on the prices of crops and meat commodities is still ambiguous and needs more research studies.

GHG Emission Regression Results

The results of analyzing total GHG emissions are presented in table 54 and show that technological progress of corn, cotton, soybeans, and winter wheat have significant negative effects on total GHG emissions. In other words, as technological progress increases, the total GHG emission level reduces. However, there is a positive effect of hay technological progress on GHG emissions perhaps due to livestock production and emission increases.

The main finding in this section suggests that growing technological progress tends to reduce the overall GHG emission. This supports that technological progress coupled with effective bioenergy policy are crucial factors to preserve environmental quality in the long-run.

Table 54. GHG Emission Regression Results

Crop	Base Demand			Fast Demand			Slow Demand		
	Control	Corn	CornRes	Control	Corn	CornRes	Control	Corn	CornRes
Corn	-47.32***	-50.61***	-46.16***	-48.15***	-50.61***	-46.15***	-46.83***	-49.17***	-47.07***
	(16.83)	(16.77)	(16.88)	(16.80)	(16.77)	(16.88)	(16.90)	(16.79)	(16.76)
Cotton	-162.4***	-225.7***	-163.9***	-163.8***	-225.7***	-163.9***	-170.1***	-226.0***	-168.9***
	(27.47)	(27.37)	(27.55)	(27.42)	(27.37)	(27.55)	(27.58)	(27.41)	(27.36)
Hay	91.54***	84.09***	98.01***	91.06***	84.09***	98.01***	88.16***	81.04***	100.6***
	(29.11)	(29.00)	(29.20)	(29.06)	(29.00)	(29.20)	(29.23)	(29.04)	(28.99)
Sorghum	-1.264	1.858	0.945	-1.507	1.857	0.946	-1.881	0.963	1.832
	(12.47)	(12.42)	(12.51)	(12.45)	(12.42)	(12.51)	(12.52)	(12.44)	(12.42)
Soybeans	-66.98***	-80.26***	-63.58***	-64.38***	-80.26***	-63.59***	-65.15***	-82.03***	-66.37***
	(19.35)	(19.28)	(19.41)	(19.32)	(19.28)	(19.41)	(19.43)	(19.31)	(19.27)
Winter Wheat	-39.10*	-44.83**	-33.82	-38.33*	-44.82**	-33.83	-38.99*	-44.32**	-33.77
	(22.04)	(21.96)	(22.11)	(22.01)	(21.96)	(22.11)	(22.14)	(21.99)	(21.95)
Constant	312.5***	459.3***	304.6***	312.0***	459.3***	304.6***	323.0***	463.6***	311.6***
	(43.27)	(43.10)	(43.40)	(43.19)	(43.10)	(43.40)	(43.45)	(43.17)	(43.09)
N	150	150	150	150	150	150	150	150	150
R^2	0.526	0.643	0.515	0.526	0.643	0.515	0.533	0.642	0.533
Adjusted R^2	0.506	0.628	0.495	0.506	0.628	0.495	0.513	0.627	0.513
Root MSE	26.07	25.98	26.15	26.03	25.98	26.15	26.19	26.02	25.97

Note: 1) ***, **, and *are significant at the 1, 5, and 10 percent level, respectively.
2) Numbers in parentheses are standard errors.

CHAPTER V

CONCLUSIONS

This study addresses the effects of agricultural technological progress on both agricultural and biofuel markets. To do this, we went through several phases. First, we estimated crop yield growth rates for six main field crops (i.e. corn, cotton, hay, sorghum, soybeans, and winter wheat) at the regional level using U.S. historical crop yield data during 1950 to 2014 (Chapter II). Second, we formed scenarios reflective of the effect of technological progress, agricultural demand, and energy policy (Chapter III). Third, we used a simulation framework to investigate the effect of technological progress, agricultural demand, and energy policy on both agricultural and bioenergy markets plus resource usage and GHG emissions (Chapter IV). The simulation is performed over the alternative scenarios set up in Chapter III.

Several main findings emerge. The first finding is that there is a slowdown in technical progress in many cases especially for corn, cotton, and winter wheat. This finding of the slowdown technical progress is in line with findings by Alston et al. (2009), Feng (2012), Baker et al. (2013), and Villavicencio et al. (2013). At first, the technological progress rates for regions are 3 to 4 percent for corn and winter wheat. However, after the break year, those rates become less than 2 percent for most cases and a decreasing rate in some cases. In addition, the technological progress rates for regions are 1 to 2 percent for hay. This slowing technical progress may have implications for both the production and the use of biofuel and food.

The second finding is that we find non-uniform technical progress that varies across regions for all examined crops, especially cotton and soybeans. This is possibly due to regional differences such as degrees of suitability for the crops due to varying altitudes, soil types, and weather. Nevertheless, in terms of long-term technical progress correlations, most of the regions advance together.

The third finding is that technological progress is a significant determinant of cropland allocation between biofuel, crop production, and livestock. As technological progress increases, the biofuel land and cropland pasture for livestock decreases, whereas land for crop production increases. This finding supports that technological improvement is an influential factor in meeting increased global demand for food and energy.

The fourth finding is that biofuel mandates have significant influences on land use for biofuel production with lesser effects on cropland used for pasture and cropland used for crop production. Land for biofuel production is larger under the basis EISA mandates, and when the corn mandate is reduced this moves land to pasture use as it is a leftward shift in the corn and cropland demand curves. On the other hand, a mandate with less corn residue based ethanol has little land use effect likely due to the fact that stover is a crop byproduct.

The fifth finding is that biofuel policy has a major effect on commodity prices for most of the field crops and meat commodities (i.e. corn, hay, sorghum, hard red winter wheat, beef, pork, and broiler). Lowering the requirement level of corn for ethanol lowers corn and other prices because it reduces the overall demand for corn.

Nevertheless, the impact is rather minor for wheat, fed beef, pork, and broilers. This finding implies that the amount of biofuel production from corn has effects on the prices of field crops and meats, which policy makers have to concern when imposing biofuel policies or mandates.

The final finding is that technical progress and biofuel policy have significant impacts on agricultural GHG emissions. Increasing technological progress on field crops reduces the overall GHG emissions allowing less land and cropped acres to meet demand, especially for corn, cotton, soybeans, and winter wheat. As for the biofuel effect, GHG emission levels drop through time with the larger decreasing rates. Additionally, a lower corn ethanol mandate provides larger GHG emissions as compared with the control case implying on the margin corn ethanol is emissions reducing. Nevertheless, lower corn residue from ethanol mandate delivers a similar level of GHG emissions as compared with the control case. This implies producing corn ethanol is effective in reducing emissions but that corn stover is not. This final finding supports that technological improvement together with effective bioenergy policy has a key influence on climate change mitigation.

These above findings from the study confirm that agricultural technological advance along with biofuel policy jointly influences our ability to meet growing food and energy global demands while preserving environmental quality. While the findings are relevant to both technological progress and biofuel policy influences, the effect of agricultural demand on field crops, livestock, land usage and GHG emissions seems to be small and ambiguous. Thus, more research is needed to clarify about the demand effect.

The findings from this study can have implications for policy makers and also bioenergy sectors. The policy makers should not consider only biofuel policy but also technological improvement as a greenhouse gas management approach.

The study also has limitations, so we discuss and propose some further possible research as follows:

1. The crop growth rate estimation has a limitation on the data in that limited or no observations are observed for some crops in some regions, and also there are some missing crop yields data in the Pacific region for both cotton and hay, which, in turn, does not allow us to test the presence of structural break. Perhaps a way could be found to add to these series. Further research could also use different regional definitions.
2. In the demand analysis, we use a simple demand model for field crops using only their own price in the model. Future research may add more explanatory variables such as substitute commodity prices. Additionally, one could employ more complex demand models such as a Rotterdam model or an Almost Ideal Demand System (AIDS).
3. The investigation of technological growth rate could be expanded by adding more explanatory variables such as temperature and level of precipitation or fertilizer usage to see their influence on the technological growth rate.

4. The further possible research could develop different technical progress scenarios such as High Tech and Low Tech scenarios based on the coefficients for time to have more understanding about the technical progress.

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APPENDIX A

Table 55. Correlation Matrix of Ratios of Three-Year Average Corn Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP	MT	PA
NE	1	0.22	0.36*	0.28	0.64*	0.22	0.15	0.26	0.19	-0.03
LS		1	0.61*	0.69*	-0.02	-0.20	-0.19	0.07	0.36*	0.23
CB			1	0.74*	0.30*	0.02	0.00	0.19	0.35*	0.12
NP				1	0.14	-0.06	-0.04	0.41*	0.49*	0.17
AC					1	0.65*	0.31*	0.30*	0.27	-0.05
SE						1	0.53*	0.06	0.31*	0.15
DS							1	0.09	0.43*	0.44*
SP								1	0.36*	0.18
MT									1	0.70*
PA										1
No. of Obs.	60									

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 56. Correlation Matrix of Ratios of Three-Year Average Cotton Yield across Regions

Ratio	CB	NP	AC	SE	DS	SP	MT	PA
CB	1	0.41	0.49*	0.28	0.40	0.27	0.43*	0.42
NP		1	0.06	-0.18	0.11	0.40	0.53*	-0.32
AC			1	0.65*	0.31	0.12	-0.08	0.10
SE				1	0.41	-0.17	-0.16	0.05
DS					1	0.11	-0.23	0.05
SP						1	0.37	-0.01
MT							1	0.04
PA								1
No. of Obs.	28							

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 57. Correlation Matrix of Ratios of Three-Year Average Hay Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP	MT	PA
NE	1	0.27*	0.34*	0.03*	0.39*	0.35*	0.36*	0.38*	0.25	0.29
LS		1	0.73*	0.60*	0.37*	0.33*	0.10	0.23	0.28	0.30*
CB			1	0.50*	0.49*	0.52*	0.44*	0.43*	0.43*	0.45*
NP				1	-0.03	0.19	0.14	0.22	0.49	0.25
AC					1	0.59*	0.35*	0.18	0.05	0.23
SE						1	0.61*	0.46*	0.40*	0.60*
DS							1	0.56*	0.28	0.42*
SP								1	0.40*	0.25
MT									1	0.59*
PA										1
No. of Obs.	60									

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 58. Correlation Matrix of Ratios of Three-Year Average Sorghum Yield across Regions

Ratio	CB	NP	AC	SE	DS	SP	MT	PA
CB	1	0.65*	0.58*	0.15	0.43*	0.60*	0.56*	0.47*
NP		1	0.65*	0.15	0.38*	0.73*	0.73*	-0.01
AC			1	0.63*	0.61*	0.77*	0.66*	0.13
SE				1	0.71*	0.46*	0.38*	0.13
DS					1	0.47*	0.37*	0.12
SP						1	0.86*	0.19
MT							1	0.30
PA								1
No. of Obs.	39							

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 59. Correlation Matrix of Ratios of Three-Year Average Soybean Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP
NE	1	0.18	0.32*	0.03	0.38*	0.11	0.30*	0.18
LS		1	0.50*	0.41*	-0.19	-0.47*	-0.29	-0.14
CB			1	0.57*	0.31*	0.06	0.15	0.24
NP				1	0.08	0.03	0.04	0.00
AC					1	0.69*	0.72*	0.54*
SE						1	0.79*	0.52*
DS							1	0.60*
SP								1
No. of Obs.	60							

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 60. Correlation Matrix of Ratios of Three-Year Average Winter Wheat Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP	MT	PA
NE	1	0.30*	0.29*	0.15	0.53*	0.14	0.11	-0.03	0.39*	-0.07
LS		1	0.18	0.44*	-0.02	0.06	0.00	0.43*	0.27	-0.02
CB			1	-0.15	0.50*	0.29*	0.46*	-0.02	0.00	0.02
NP				1	-0.08	-0.13	-0.27	0.59*	0.68*	0.15
AC					1	0.63*	0.52*	0.00	0.26	0.13
SE						1	0.63*	0.25	0.08	0.20
DS							1	-0.05	-0.14	-0.03
SP								1	0.45*	0.16
MT									1	0.47*
PA										1
No. of Obs.	60									

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 61. Correlation Matrix of Ratios of Five-Year Average Corn Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP	MT	PA
NE	1	0.17	0.65*	0.45*	0.71*	0.48*	0.21	0.35*	0.45*	0.20
LS		1	0.51*	0.64*	0.02	-0.04	-0.02	0.10	0.46*	0.32*
CB			1	0.77*	0.68*	0.48*	0.17	0.26	0.55*	0.14
NP				1	0.49*	0.31*	0.16	0.55*	0.69*	0.34*
AC					1	0.73*	0.18	0.50*	0.46*	-0.01
SE						1	0.52*	0.12	0.52*	0.25
DS							1	-0.01	0.57*	0.69*
SP								1	0.40*	0.19
MT									1	0.74*
PA										1
No. of Obs.	56									

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 62. Correlation Matrix of Ratios of Five-Year Average Cotton Yield across Regions

Ratio	CB	NP	AC	SE	DS	SP	MT	PA
CB	1	0.21	0.65*	0.57*	0.84*	0.58*	0.51*	0.53*
NP		1	0.01	-0.01	0.22	0.48*	0.70*	-0.42
AC			1	0.74*	0.55*	0.27	0.07	0.08
SE				1	0.50*	-0.01	0.14	0.12
DS					1	0.51*	0.30	0.37
SP						1	0.59*	0.16
MT							1	0.16
PA								1
No. of Obs.	24							

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 63. Correlation Matrix of Ratios of Five-Year Average Hay Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP	MT	PA
NE	1	0.57*	0.62*	0.35*	0.39*	0.48*	0.60*	0.59*	0.56*	0.53*
LS		1	0.78*	0.73*	0.27	0.50*	0.29	0.44*	0.61*	0.67*
CB			1	0.58*	0.51*	0.75*	0.63*	0.73*	0.76*	0.80*
NP				1	0.06	0.36*	0.10	0.30	0.63*	0.48*
AC					1	0.59*	0.67*	0.54*	0.28	0.33*
SE						1	0.78*	0.78*	0.70*	0.69*
DS							1	0.71*	0.50*	0.58*
SP								1	0.65*	0.55*
MT									1	0.70*
PA										1
No. of Obs.	56									

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 64. Correlation Matrix of Ratios of Five-Year Average Sorghum Yield across Regions

Ratio	CB	NP	AC	SE	DS	SP	MT	PA
CB	1	0.85*	0.83*	0.57*	0.59*	0.86*	0.79*	0.87*
NP		1	0.80*	0.49*	0.44*	0.90*	0.85*	0.66*
AC			1	0.83*	0.69*	0.93*	0.87*	0.70*
SE				1	0.75*	0.75*	0.72*	0.62*
DS					1	0.59*	0.51*	0.64*
SP						1	0.95*	0.70*
MT							1	0.71*
PA								1
No. of Obs.	31							

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 65. Correlation Matrix of Ratios of Five-Year Average Soybean Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP
NE	1	0.14	0.41*	-0.10	0.48*	0.21	0.38*	0.35*
LS		1	0.47*	0.42*	-0.36*	-0.37*	-0.33*	-0.09
CB			1	0.59*	0.40*	0.39*	0.44*	0.43*
NP				1	0.05	0.23	0.09	0.25
AC					1	0.79*	0.82*	0.71*
SE						1	0.85*	0.70*
DS							1	0.68*
SP								1
No. of Obs.	56							

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 66. Correlation Matrix of Ratios of Five-Year Average Winter Wheat Yield across Regions

Ratio	NE	LS	CB	NP	AC	SE	DS	SP	MT	PA
NE	1	0.26	0.17	0.44*	0.72*	0.25	0.02	0.10	0.70*	0.06
LS		1	0.45*	0.50*	0.05	0.37*	0.35*	0.64*	0.38*	0.15
CB			1	0.15	0.37*	0.24	0.31*	0.36*	0.32*	0.02
NP				1	0.33*	-0.01	-0.17	0.47*	0.68*	0.29
AC					1	0.50*	0.08	0.09	0.66*	0.09
SE						1	0.57*	0.38*	0.25	0.06
DS							1	0.14	-0.08	-0.05
SP								1	0.56*	0.34*
MT									1	0.48*
PA										1
No. of Obs.	56									

Note: 1) * is significant at the 5 percent level.
2) The correlation matrix is in a reduced form, with duplicate values pulled out.

Table 67. The Best Fitting Demand Models for Estimated Meat and Poultry Demands

Explanatory Variables	Meat and Poultry Products		
	Beef	Broiler	Pork
Functional Form (Model Number)	Log-Lin (4.4)	Lin-Log (1.3)	Linear (3.4)
Model Type	Time and Lag	Lag	Time
Intercept	19.27**	115.7***	1.433***
Lagged Quantity demanded	0.569***	0.724***	—
Natural Log of Lagged Quantity Demanded	—	—	—
Real GDP per Capita	9.146*	—	0.344*
Natural Log of Real GDP per Capita	—	19.89***	—
Beef Price	-0.0518***	—	0.00528***
Natural Log of Beef Price	—	-0.476	—
Broiler Price	-5.88E-05	—	4.33E-05
Natural Log of Broiler Price	—	-6.934***	—
Pork Price	0.00084	—	-0.00029***
Natural Log of Pork Price	—	-0.218	—
Year	-0.0103**	—	-0.00069***
Number of Observations	39	39	39
R^2	0.925	0.997	0.934
Adjusted R^2	0.911	0.996	0.924
Root MSE	0.00297	1.315	0.00116
Test for Autocorrelation			
Durbin-Watson Statistic	—	—	1.856
Durbin's Alternative Test (Ho: No First-Order Autocorrelation at 5% Confidence)	Fail to Reject	Fail to Reject	—

Note: 1) ***, **, and * are significant at the 1, 5, and 10 percent level, respectively.

Table 68. The Best Fitting Demand Models for Estimated Field Crop Demands

Model/Explanatory Variables	Field Crop Commodity							
	Barley	Corn	Cotton	Oats	Rice	Sorghum	Soybeans	Wheat
Functional Form	Double-Log	Lin-Log	Double-Log	Double-Log[a]	Lin-Log	Lin-Log	Lin-Log	Linear
(Model Number)	(4.4)	(1.3)	(3.4)	(1.4)	(3.3)	(4.3)	(3.3)	(3.1)
Model Type	Time and Lag	Main	Lag	Main	Lag	Time and Lag	Lag	Lag
Intercept	18.85***	0.0106**	0.0329	-11.27***	0.0005***	-0.0194***	0.0020***	0.0004**
Lagged Quantity demanded	—	—	—	—	0.632***	0.525***	0.333**	0.846***
Natural Log of Lagged Quantity Demanded	0.871***	—	0.992***	—	—	—	—	—
Real GDP per Capita	—	—	—	—	—	—	—	0.00217
Natural Log of Real GDP per Capita	0.419***	0.00029	0.0276	-0.989***	0.00010***	-0.00038***	0.00043*	
Own Price	—	—	—	—	—	—	—	-2.19E-06
Natural Log of Own Price	0.00936	-0.00332**	0.0705	-0.0159	-0.00002*	-0.00001	-0.00002	—
Year	-0.00925***	—	—	—	—	0.00001***	—	—
Number of Observations	59	60	60	60	59	59	59	59
R^2	0.899	0.294	0.947	0.939	0.979	0.677	0.336	0.848
Adjusted R^2	0.891	0.269	0.945	0.936	0.978	0.653	0.299	0.840
Root MSE	2.19E-05	0.00252	0.00347	8.31E-05	1.89E-05	3.05E-05	0.00042	0.00011
Test for Autocorrelation								
Durbin-Watson Statistic	—	1.885	—	1.721	—	—	—	—
Durbin's Alternative Test (Ho: No First-Order Autocorrelation at 5% Confidence)	Fail to Reject	—	Fail to Reject	—	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject

Note: 1) ***, **, and * are significant at the 1, 5, and 10 percent level, respectively.
2) [a] denotes the model after being corrected for the first-order autocorrelation