IMPACT OF CLIMATE CHANGE AND WEATHER VARIABILITY ON NORTH DAKOTA AGRICULTURE

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"Impact of Climate Change and Weather Variability

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

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ABSTRACT

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This study used county-level yields and panel data (1950-2006) to explain the impact of climate change and weather variability on North Dakota agriculture by estimating the effect of variation in temperature and precipitation on the yields of four major crops: corn, durum, soybeans and wheat. In addition to yields, the study examined impacts of climate change on crop gross revenues per acre for all 53 counties in North Dakota.

An econometric model was developed to infer statistical relationships between weather variability and crop yields. Fixed and random effects models were employed to estimate the impacts of climate variables (temperature and precipitation) on crop yields. The Hausman test statistics was applied to test the preferred panel estimation approach: fixed versus random effects. Using mean values of precipitation and degree days for all counties, we calculated percentage changes in estimated crop yields for six climate change scenarios. The historical price data for the four crops (corn, soybeans, spring wheat and durum) were used to generate per acre gross returns under the six weather-change scenarios in order to provide preliminary evidence about the effects of precipitation and temperature changes on farmer returns for the four crops.

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Chol P. Mayom

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CHAPTER 1. INTRODUCTION

Background

Weather variability and climate change are major components that might influence crop production. By definition, "climate change is a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period of time" (IPCC, 2007). Therefore, climate change is any change in climate over a period of time whether due to natural variability or human activity.

The impact of climate change and weather variability on the economy and agricultural productivity has been a subject of many studies. Adams et al. (1990) estimated the economic impacts of climate change on U.S. agriculture using predicted yields with a partial equilibrium model. Their study investigated the potential agronomic and economic impacts of climate change on U.S. agriculture.

Previous studies of climate change have indicated that weather variability can affect prices and crop production (see Adams, 1989; Schlenker, Hanemann and Fisher, 2005). There is a growing consensus that climate and weather variability will lead to higher temperatures and changes in precipitation patterns. These changes in climate will have an impact on economic well being, especially the agriculture sector (Deschenes and Greenstone, 2007). The Intergovernmental Panel on Climate Change (IPCC) predicts that the average rate of global warming during the period of 1990 through 2100 will be greater than any other period seen in past centuries (IPCC, 2007).

Problem Statement

North Dakota's climate is known for its rapid unpredictability. Climate change can have significant effects on North Dakota's vital agriculture sector because weather variables such as temperature and rainfall are major determinants of crop yields. Climate affects every aspect of agricultural crop production from the time of planting to the time that the products are taken to market. Crop yields are directly affected by changes in climate factors such as temperature, precipitation and extreme events such as drought, floods and storms. For example, in 2002 North Dakota's economy suffered an estimated $223 million loss due to damages to agricultural crops caused by drought (Jossi, 2002). There is a concern that weather variability may increase risk in farm yields, revenues and profits. Climate change and weather variability represent a big burden on farmers due to increased production risks associated with crop yields. Risks associated with increasing climate variability create economic challenges to farmers who depend on agriculture for their livelihood. Weather variability affects crop yields and may cause negative economic impacts. As climate conditions vary, crop production patterns may also vary because different crops react differently to changes in weather variability. Change in weather variability from year to year is one of the major factors associated with crop yield variations. Analysis of the effects of weather on crop yields in North Dakota permits estimation of the effects of climate change on farmer revenues due to changing weather conditions. The analysis may also help to explain recent changes in North Dakota cropping decisions.

Objective

The objective of this paper is to analyze the agronomic and economic impact of weather variability on four major crops grown in North Dakota. The main focus of my research is to estimate how county yields and gross revenues for four crops are affected by changes in temperature and precipitation levels. The specific objective is to assess the impact of weather variability on crop yields and revenues in North Dakota counties between the years of 1950 to 2006.

Hypothesis

The hypothesis underlying the research is that change in temperatures and precipitation would affect crop yields and revenues. If evidence supports a relationship between temperature and precipitation and crop yields, future research might then estimate potential changes in farm level cropping decisions with climate change. Farmers' adaptation to weather variability through changing cropping patterns may reduce losses that might occur as a result of climate change.

Organization

This study consists of five different chapters. Chapter 1 is an Introduction to the study, including a brief history of climate change and weather variability and their effects on the agriculture sector. Chapter 2 focuses on reviewing relevant literature about the potential effects of climate change on agriculture. Chapter 3 deals with data collection, estimation considerations and also presents the model used to arrive at the results. Chapter 4 presents the results obtained from the model. Lastly, Chapter 5 concludes the study with a summary of the scope of the study, the results and their implications, as well as potential areas for further studying

CHAPTER 2. LITERATURE REVIEW

Introduction

There is a general consensus among scientists and economists that climate change and weather variability have in fact affected and will continue to affect agricultural productivity in the United States and around the world. The following sections focus on the direct impacts of climate change on various aspects of agriculture such as an impact on water availability and demand, climate and crop yields, global agriculture, and on U.S. agriculture.

Impact on Water Availability and Demand

Climate change is likely to affect water resources by increasing the demand for the world's water resources which puts the productivity and stability of agriculture at risk. Doll pointed out that the magnitude of the impact of water scarcity will not be the same in all regions. He said that regions with "a high interannual variability will suffer more from water scarcity than comparable areas with a more even climate" (Doll, 2002). Cordova et al. estimated that California would lose up to 1.5 billion dollars annually in the gross value of farm production because of water scarcity (Cordova et al., 2006).

Schlenker, Hanemann and Fisher establish a statistical link between the values of individual farms in California with a measure of water availability, climate change and other environmental variables such as soil quality and degree days to study the potential impacts of climate change on agriculture. They find a major effect of water availability on farmland values in California. Their analysis suggests that changes in water availability as a result of climate change have a potential to greatly impact the value of farmland (Schlenker, Hanemann and Fisher, 2007).

Sea level rise is another major factor of climate change affecting agriculture. Bosello, Roson and Tol (2007) estimated the implications of sea level changes on agriculture. The authors included only inundation and erosion in their study. The results of their study showed that "the economy-wide indirect effects of climate change are substantial compared to the direct effects" that dominate many studies of climate change. The authors stress that water availability is a critical factor in determining whether climate change positively or negatively affects agriculture.

Climate and Crop Yields

Weather factors such as temperature and precipitation can affect crop yields either positively or negatively depending on the level of carbon dioxide (CO_2). In general, increases in the temperature level have been found to reduce crop yields and quality. In their study of the impact of climate change on Kenyan crops, Mariara and Karanja (2007) stated that high summer temperatures are detrimental to crop production and crop growth.

One other way that climate change affects agricultural production is by limiting the length of the growing season if there is not enough rainfall during the growing season to ensure soil temperature and moisture are suitable for crop growth (Adams et al., 1998). Precipitation and temperature are the two weather variables that affect soil moisture the most. Precipitation affects water available to be absorbed by the soil, and is important in determining the productivity of crops. On the other hand, temperature determines the time that the water will remain in the soil prior to evaporation and it is important in defining the length of the growing season (Winters et al., 1996). All global climate models project an increase in the mean global precipitation. Rosenzweig et al. (2002) pointed out that "lower amounts of precipitation falling as snow and by earlier snowmelt" may cause drought conditions. These drought conditions caused by variability in weather patterns have a dramatic effect on crop yields and yield quality. Many implications of climate change on agriculture are likely to occur through changes in the extremes of natural variation in temperatures rather than as a result of changes in the mean temperatures (Harle et al., 2007).

Isik and Devadoss recently developed an econometric model of crop yields to explore the impacts of climate variables on crop yield levels and variability among crops. The results of their study suggest that the implications of climate change on crop yields vary from crop to crop (Isik and Devadoss, 2006). Researchers have shown that an increase in daily temperature variability has an ability to reduce crop yields (Rosenzweig et al., 2001). In a study of Taiwan agriculture, Chang found that both climate variations and increases in temperatures along with increase in precipitation can be harmful to yields (Chang, 2002).

A major impact on agriculture from climate change is a possible increase in the frequency of extreme events (Parry, 1990). More extreme precipitation events, whether wet or dry, can affect crop yields. For example, the drought of 1988 in the midwest and the southeastern parts of the United States reduced crop yields by nearly 37% (Rosenzweig at al., 2001). Also the 1998-99 drought in the United States caused 1.29 billion dollars in damages that resulted from the reduction of crop yields and other expenses related to the operation of farms (Rosenzweig at al., 2001). Change in agro-climatic conditions may have implications for the crops farmers choose to plant for a particular season (Smith, McNabb and Smithers, 1996).

Anderson et al. used crop simulation models to study the impact of weather on crops normally grown in the Great Lakes Region. Unlike other studies, the results of this study showed that the potential impacts of weather and climate on agriculture in this region is small (Anderson et al., 2001).

Studies have projected that climate change is likely to increase yield variability (McCarl, Adams, and Hurd, 2001). Several empirical studies concerning the potential impacts of climate change on agricultural supply and price have been carried out at world, national, and regional levels. Changes in agricultural supply result from changes in crop acreage and yields, which is due to change in weather variation. Changes in acreage are affected by farmers' expectations of crop prices as well as expected growing conditions (Adams et al., 1998). Since climate change is a global phenomenon, the global supply and demand for agricultural commodities will be affected and this will also have an impact on world prices (Winters et al., 1996). It is expected that the world prices for most agricultural commodities would increase due to climate change. Corn and soybean prices would increase the most by as much as 36% and 34% because the production of these crops takes place in the areas most effected by global climate change (Kaiser, 1991).

Schlenker (2006) used a panel data set of corn yields to model the implications of mean weather change and year to year weather variability jointly on crop yields. Schlenker's study suggests that projected climate change will increase year to year variations in weather, which will reduce expected crop yields in the future. Schlenker's study pointed out that year to year variation in weather resulted in crop losses because crop varieties are sensitive to weather variations. In their analysis of the relationship between crop yields and two climate variables, temperature and precipitation for 12 major

California crops, Lobell, Cahill, and Field found that "climate changes have suppressed crop yield increases" (Lobell, Cahill, and Field, 2007).

Global Agriculture

Climate change and weather variability is likely to affect global agriculture. The impact is going to be different in different parts of the world depending on the current climatic and soil conditions, and on the resources available to deal with changes (Olesen and Bindi, 2002). Climate change affects different sectors of the economy directly or indirectly. To incorporate these interactions in different sectors of the economy, economists and other social scientists have used computable general equilibrium (CGE) models. The use of CGE models in the assessment of the impact of global change is expanding. Winters et al. (1996) used the CGE model to examine the effect of climate change on less developed countries in Africa, Asia, and Latin America. Their findings show that all the countries they studied would suffer a reduction in agricultural output due to the expected effect of climate change. This negative effect in agricultural output would be severe in Africa because the share of agriculture in GDP is large for most African countries.

By using a spatial equilibrium model, Adams et al. (1989) extended the previous work on the impact of climate change on agriculture. They included other crops such as fruits and vegetables into the regional agricultural analysis. They showed that climate change is expected to alter agriculture production patterns across the United States.

Unlike the previous studies, Kurukulasuriya et al. (2006) uses the Ricardian approach to measure the impacts of weather variability on the net revenues of African farmers. The approach is based on ideas of David Ricardo that "land rents reflect the net productivity of farmland." The authors examine the impact of climate variables on land values and farm revenues. The study uses farm level data collected from 11 African countries to examine how climate change affects African farmers. Like Winters et al., the results of this study suggests that Africa will be severely hit by climate change.

John, Pannell and Kingwell (2005) suggest that future climate change may reduce farm profits in south-west Australia by 50% or more. Using MUDAS (Model of an Uncertain Dryland Agricultural System) to study the economic implications of projected climate change on farm profits, the authors investigated two scenarios of climate change in that region. In scenario one, weather outcome probabilities of the standard model is based on CSIRO (the Commonwealth Scientific and Industrial Research Organization) estimates for the 1970-2000 time period. Scenario two is based on the same CSIRO models involving forecasts of climate change and climate variation over the 2000-2030 time period. The standard climate assumptions of the model are based on daily rainfall from 1908 through 1994. The results in scenario one indicate that farm profits would decline by 50%, while the results in scenario two indicate that farm profits would decline by as much as 80%. The study also suggests that the major factor responsible for the decline in farm profits is the projected decrease in crop production. As the frequency of dry weather years increases, the effects would be a decline in crop yields which contributed to the decline in farm profits.

Climate Change and U.S. Agriculture

The agriculture sector in the United States has experienced severe economic losses due to several weather extremes in the 1990s (Changnon, 2005). For example, Hurricane Andrew caused an estimated 30 million dollars in damages in Florida in 1992, whereas the 1993 floods in the Midwest caused an estimated 21 billion dollars in damages.

However, a major climate concern in the Midwest is drought resulting from elevated temperatures and decreased precipitation that lead to decreases in soil moisture. This region experienced agricultural losses during the drought of 1988, which cut the yields of wheat by 31% and corn by 45%. Some other potential impacts of climate change on agriculture in the Midwest include an increase in soil erosion and an extended growing season (CIER, 2007).

Wuebbles and Hayhoe conducted a study on climate change projections for the United States Midwest region in 2004. Their analyses of future climate changes for the Midwest are based on projections for the SRES scenarios (Special Reports on Emission Scenarios) model which was developed at the U.K. Meteorological Office's Hadley Center for Climate Modeling. Unlike previous studies, Wuebbles and Hayhoe's research includes both low and high scenarios for climate change. This study also examined historical climate records for the Midwest along with the frequency of extreme events such as heavy rainfall and temperature variations in the region. The authors concluded that temperature and precipitation changes will strongly change the regional climate. By the end of this century the Midwest average daily temperature might increase from 2 to 9 degrees Celsius (Wuebbles and Hayhoe, 2004).

Southworth et al. determined that corn yields across the southern areas of the United States would decrease sharply "due to the daily maximum temperatures becoming too high." Western Illinois would experience reductions in corn yields by as much as 50% for long season maize (Southworth et al., 2000). Also, Rosenzweig et al. (2001) showed that there is an inverse relationship between corn yields and annual temperature and precipitation. As temperature increases corn yields typically decline.

In the northeast and mid-Atlantic region of the United States, there has been an increase in major weather events over the last century. A warming of 2.2 degrees Celsius has been observed in Maine, and scientists have predicted this region will continue to warm up with an increase in precipitation levels. The economic impacts of climate change on coastal infrastructure in this region will be significant. For example, the flood of 1996,which flooded the Boston subway system, caused over 92 million dollars in damages (CIER, 2007). The economic effects of climate change on agriculture in the Northeast and Mid-Atlantic region will vary from state to state with New York expected to experience the most reduction in agricultural yield by as much as 40%, which amounts to 1.2 billion dollars in damages.

The southeast region of the United States might experience the greatest effects of climate change (CIER, 2007). During the last century, the climate in this region has undergone many cycles starting with a warm period in the 1920s through the 1940s and a cool period from the 1950s through the 1960s. Currently the region is under another warm period which started in the 1970s. The region has experienced an increase in precipitation during the last century by as much as 20-30%. According to the Canadian Climate Centre (CCC) model, the region will continue to experience an increase in the level of precipitation in a similar pattern through the 2090s, while the Hadley Centre model projected smaller increases in precipitation levels of 20% through 2100. In the 1990s, the southeast region was hit hard by extreme weather events including hurricanes, floods, heat waves, and droughts which caused the region an estimated total of 540 billion dollars in damages (CIER, 2007).

The Great Plains region has also experienced an increase in both temperature and precipitation in the past and it is been projected that the region will experience an increase in temperature and precipitation in the future (CIER, 2007). The overall impact of climate change on agriculture in this region has been projected to be a loss of 3.6 to 6.5 billion dollars by 2030. This loss would even be worse by 2090 with an estimated annual loss of 6.8 to 10.1 billion dollars. In 1995, drought conditions in the southern Great Plains caused 5.8 billion dollars in damages to the agricultural sector. The long run impact of climate change in the Southern Great Plains area is likely to be a reduction in productivity by certain crops. It has been projected that soybean productivity in this region will decrease by as much as 70%, and for wheat there will be up to a 50% reduction in productivity (CIER, 2007).

Just as lack of precipitation causes crop damages, excessive moisture can cause a reduction in crop yields due to pest infestations. Most importantly, excessive wet conditions can make it harder for farmers to work on their farms, and this hinders field operations, resulting in a reduction in crop yields (Rosenzweig et al., 2001). Damages to agricultural production caused by excessive precipitation can be devastating. The 1997 North Dakota Red River floods caused an estimated total of 1 billion dollars in damages (Rosenzweig et al., 2002).

During the past century, temperatures in the western United States have increased, and the snow season is currently shorter by 16 days in some states. It has been projected that there will be wetter winters and drier summers with a rise in sea level by 2100. Climate-change models show there will be a decline in accumulated snow, and snowmelt would occur earlier. This will result in water shortages for all users. According to CIER

(2007), by 2070 through 2099, there will be a shortage of water around the central valley area of California. This will result in the reduction of 254,000 acres of land currently used in crop production which will, in turn, generate a loss of 278.5 million dollars in net revenue.

A separate study of the western United States conducted by Adams et al. (1988) concluded that climate change would not result in agricultural production loss, but that there would be an impact on agricultural production, leading to adjustments in resource use in some, but not all, the agriculture regions of the United States.

Conclusion

Crop yields are directly affected by changes in climatic factors such as temperature, precipitation and extreme events like drought and floods. The literature suggests that all regions in the United States will not be affected to the same degree by projected climate changes.

CHAPTER 3. DATA SOURCES, ESTIMATION CONSIDERATIONS AND METHODOLOGY

Introduction

The first part of this chapter describes data used in the research. The second part focuses on the econometric strategy used to assess the impacts of climate on agriculture. The third part describes methodology. Fixed and random effects models are employed to assess the influence of climatic growing conditions on crop yields.

Cropping Data

In this paper we use county level panel data to estimate the effect of weather on agricultural yields. The bulk of the county level data on crop yields and acres planted and state level crop prices from 1950-2006 were obtained from the USDA National Agricultural Statistics Service (NASS, 2007). I focus on the impacts of climate variables (temperature and precipitation) on yields of four major crops in North Dakota: corn, durum, soybeans, and wheat. These four crops represent the largest value of production in North Dakota. Table 3.1 presents the 2006 total value of production for corn, soybeans, durum and wheat. All four crops contributed 5786.7 million dollars to North Dakota economy in 2006. Not all four crops are grown throughout North Dakota. Soybeans are a relatively new crop grown commercially in North Dakota. Therefore, the data for soybeans county yields were only available for 10 Eastern counties from 1977-2006. Corn data was also not available for all 53 counties. Corn yields were thus modeled for 19 counties for the years 1950-2006. Figure 3.1 presents the map of all 53 North Dakota counties considered for this study.

Table 3.1. 2006 Value of Crop Production in North Dakota

Crop	Value of Production (Millions)
Corn	$ 430.5
Soybean	$ 717.4
Durum	$ 144.3
Spring Wheat	$ 953.5
Total Crops	$ 3,685.3

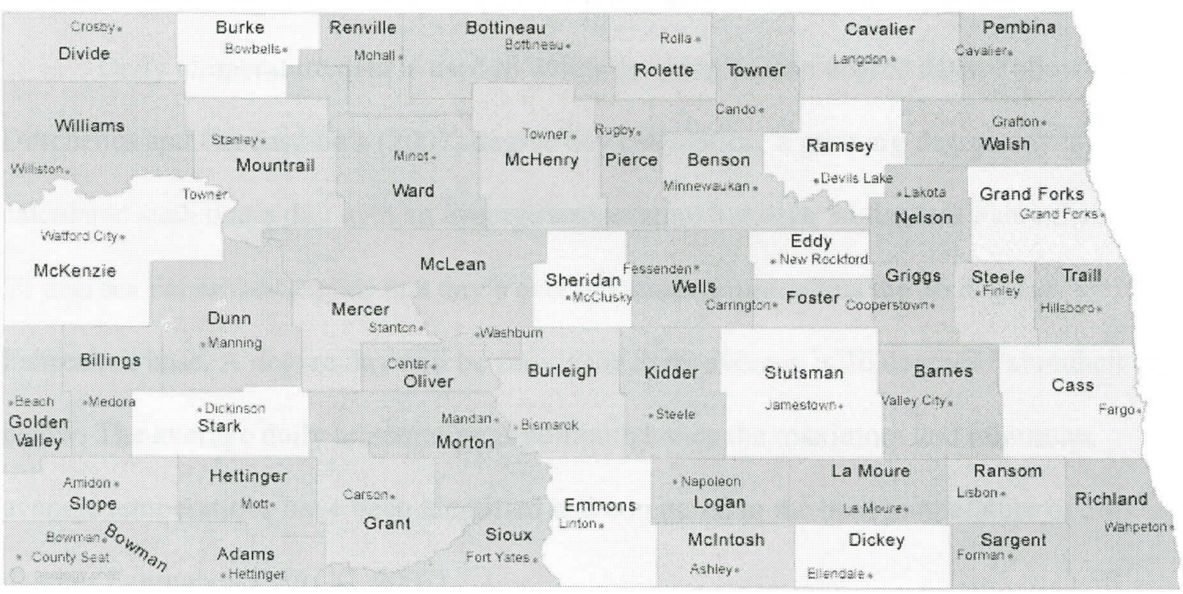

Figure 3.1. Map of 53 North Dakota Counties

Weather Data

Monthly weather data on degree days and precipitation were obtained for all 53 North Dakota counties from the Midwestern Regional Climate Center (MRCC) from January 1950 through December 2006 (MRCC, 2007). In cases where observations were missing for a county weather station, the missing values were replaced by averaging precipitation and/or degree data from all other counties within the climate district. The temperature data include the average observations for growing season degree days from April to September. Precipitation tables for October to December, January to April, May to June and July to September were created to model seasonal precipitation effects.

Daily temperature data is used to define growing season degree days. Following Deschenes and Greenstone's (2007) degree day calculation, a growing degree day is calculated such that a day with an average temperature between 36 degrees Fahrenheit and 50 degrees Fahrenheit equals that day's average temperature minus the 36 degrees Fahrenheit base. A degree day will be zero if the daily average is 36 degrees Fahrenheit or below. The average daily temperature is computed once the maximum and minimum average temperatures have been identified and compared to the base temperature of 36 degrees Fahrenheit (MRCC, 2007).

Econometric Strategy

This section describes the econometric method used to assess the impacts of climate on crop yields. When analyzing time series data, it is important to account for trends in the data. Analysis of time series requires testing stationarity properties of the data. Panel unit root tests were therefore conducted to determine if the individual series were stationary or if they contained unit roots. The panel unit test developed by Im, Pesaran and Shin was used as an appropriate testing approach to determine common trends when panel data is analyzed. The Im, Pesaran and Shin procedure allows heterogeneity in the panels by basing the test statistics on the mean of individual series' unit root statistics. The test is valid when the errors in the regressions are not serially correlated. The Im, Pesaran and Shin procedure also requires that series are normally and independently distributed (Chang, 2002). If all series are stationary, then the original data can be used to estimate the regression models. If at least one of the series is determined to be nonstationary, then the data would have to be differenced.

The Methodology

Although the approach will depend on the results of the unit root tests, we initially assume the individual data series are trend stationary. This allows use of deterministic trend in yields for corn, durum, spring wheat, and soybeans. Following Chen, McCarl and Schimmelpfennig (2004), we use degree days as the temperature variable determining plant growth. We estimate equation (1) for each crop *i*:[1]

$$(1)\quad Y_{ct} = \beta_0 + \beta_Y Y_{c,t-1} + \beta_T \mathrm{Time} + \beta_{T2}\mathrm{Time}^2$$
$$+ \alpha_{p1}\mathrm{Prec1}_{c,t-1} + \alpha_{p2}\mathrm{Prec2}_{ct} + \alpha_{p3}\mathrm{Prec3}_{ct} + \alpha_{p4}\mathrm{Prec4}_{ct}$$
$$+ \alpha_{p12}\mathrm{Prec1}^2_{c,t-1} + \alpha_{p22}\mathrm{Prec2}^2_{ct} + \alpha_{p32}\mathrm{Prec3}^2_{ct} + \alpha_{p42}\mathrm{Prec4}^2_{ct}$$
$$+ \alpha_{d1}\mathrm{DD1}_{ct} + \alpha_{d2}\mathrm{DD2}_{ct} + \alpha_{d12}\mathrm{DD1}^2_{ct} + \alpha_{d22}\mathrm{DD2}^2_{ct} + \varepsilon_{ct}$$

where c is county and t is the index for time. β_0, β_Y, β_T, α_p, and α_d are parameters to be estimated. Prec1 through Prec4 are precipitation totals for October to December for year t-1, and January to April, May to June and July to September precipitation totals for growing year *t*. DD1 is the total degree days for April to June and DD2 is degree days totals for July

[1] We suppress index *i* for notational simplicity.

to September. The last term in equation (1) is the error term, ε_{ct}. Yields and weather variables represent a panel for C counties and N years. Given county level differences perhaps not explained by precipitation and degree day factors, panel regression techniques allow separation of the county-specific effects not included in the dataset.

Panel estimation techniques present a considerable number of econometric challenges. Panel analysis allows us to study how variation in changes in the independent variables (time, precipitation, degree days) is associated with variation in changes in the dependent variable (yield). Panel data estimation techniques allow for control for unobservable heterogeneity that can affect cross sectional estimation and cause bias in estimation results.

The possibility of correlation between unobserved effects and the explanatory variables is one of the major challenges when analyzing panel data. There are a number of models that can be used to remedy the problems of correlation in panel data. Two alternative approaches allow explicit consideration of county-level effects: fixed effects and random effects.

The fixed effects model assumes that differences in county yields can be captured by determining a county-specific constant term. The fixed effects model is typically estimated using a least squares dummy variable (LSDV) approach. Summarizing equation 1 by letting all exogenous variables, excepting the intercept, by represented by X, and letting D be a matrix of dummy variables with the rows of each column corresponding to specific county *i* equaling 1, yields for county *C* at time *t* are estimated:

(2) $$y_{ct} = x_{ct}\beta + \alpha_c + \varepsilon_{ct}$$

County effects from unobserved factors influencing yields will be expressed in the values of parameter vector **α**. The fixed effects model does not assume that unobserved effects are uncorrelated with the explanatory variables. With the fixed effects model, we treat unobserved effects as fixed for each county.

In contrast, the random effects model assumes unobserved effects are zero and the expected value of all explanatory variables is constant (Wooldridge, 2006). This assumption ensures that there is no correlation between unobserved effects and the explanatory variables. Random effects models again assume unobserved county effects underlie yields. However, the random effects model assumes that heterogeneity due to unobserved county effects is uncorrelated with the observed independent variables. Instead, county effects are included in a composed error term, and feasible generalized least squares is used to provide consistent estimates. The random effects model is represented as follows:

(3) $$y_{ict} = x_{ict}\beta + \alpha + (u_{ic} + \varepsilon_{ict})$$

The error term, u_{ic}, is the random heterogeneity associated with county i and is assumed constant over time.

CHAPTER 4. CROP YIELDS AND WEATHER

Introduction

This chapter presents and interprets the regression analysis results based on equation 1 in the methodology section. Crop yield is the dependent variable, with time trend, lagged yields, and weather variables hypothesized to affect yields. Coefficient estimates and test statistics are presented in Table 4.1. Hausman test statistics to test the hypothesis of fixed versus random effects are also reported in Table 4. 2.

One of the major objectives of this research is to determine the effects of weather and climate change on crop yields. Therefore, we calculated the effects on predicted yields for each crop and county using six weather change scenarios. Results are presented in Table 4.3 for corn, Table 4.4 for soybeans, Table 4.5 for durum and Table 4.6 for wheat.

Results of the Unit Root Tests

The panel unit root test procedure is individually applied to all dependent (yield) and independent variables (precipitation and degree days). Results are reported in Table 4.1. According to the Im, Pesaran, and Shin procedures, all seven series for each crop (yield, four precipitation and two degree day-series) are stationary. Stationarity rules out problems arising from spurious correlations among variables and allow panel regression to be conducted on the undifferenced series.

Results of the Hausman Test

We apply the Hausman test to determine the correct panel data model by testing the random effects model versus the fixed effects model. The Hausman test is based on a chi-squared test statistic with K degrees of freedom, where K equals the number of explanatory variables. The null hypothesis is that there is no misspecification under the random effects model (Isik and Devadoss, 2006).

Table 4.1. Im, Pesaran, and Shin Panel Unit Root Test Statistics

Variables	Corn	Durum	Soybean	Wheat
Yield	-11.5112 -12.0800	-10.4194 -12.374	-3.82379 -8.5849	-10.9312 -20.2980
Precip1 Oct-Dec	-11.5899 -10.4118	-16.9174 -15.5999	-3.98238 -1.70123	-21.2523 -19.6918
Precip2 Jan-Apr	-14.1491 -12.0805	-20.7402 -18.8522	-7.80079 -5.78901	-25.7256 -23.3146
Pre3 May-Jun	-19.2057 -17.9574	-24.7009 -22.6246	-5.0934 -5.4591	-32.0962 -29.8738
Precip4 July Sept	-18.6629 -17.8414	-27.1580 -26.1500	-7.28924 -6.60487	-33.6175 -31.9412
DegreeDays1 Apr-Jun	-18.0895 -16.7302	-21.3857 -19.6766	-8.24559 -6.19222	-27.7985 -25.5070
DegreeDays2 July-Sept	-18.7859 -17.6442	-24.4285 -23.7931	-7.69834 -6.26676	-30.8379 -29.9345

Notes: The top number in each cell represents the results of the unit root test without a trend variable while the bottom number represents the results with a trend variable. The null hypothesis of a unit root is rejected with 99% confidence.

The Hausman test is used to test the presence of correlation between the explanatory variables and the error term in the random effects model. If the critical value from the chi-squared is greater than the test statistic, then we do not reject the null hypothesis. This means the assumption in the random effects model, namely that the unobserved county effects are uncorrelated with the observed variables X, cannot be rejected. Under this condition, the random effects model would be the better choice (Greene, 2003).

The results of the Hausman test indicate that we fail to reject at the five percent level the null hypothesis that the random effects model is consistent and efficient for corn and soybeans. We therefore us the random effects model for the analysis of corn and soybeans. For durum and wheat, we reject the null hypothesis of the Hausman test. We therefore use a fixed effects model for the analysis of durum and wheat yields. Table 4.2 presents coefficient estimates and the results of the Hausman test statistics.

The Estimated Results for Corn

The estimated coefficients of both the time and time squared variables are positive and significant in the corn yield model, indicating that yields over the 1950-2006 period are increasing over time at an increasing rate (Table 4.2 next page).

Signs on the estimated coefficients for precipitation are positive during the May to September (Prec3 and Prec4) growing season. However, coefficient signs for each period's precipitation squared terms are negative. Although corn yields respond positively to precipitation during the growing season, negative and significant coefficients on the precipitation squared terms indicate too much rainfall has a negative effect on yields. Maximal yield based on May and June precipitation (Prec3) occurs when rainfall equals 10.61 inches. Similarly, maximal yields based on July to September precipitation (Prec4) occur when rainfall equals 10.06 inches. By comparison, long run precipitation averages for these time periods are 5.98 inches and 7.15 inches respectively.

The impact of degree days on corn yields is mixed. The coefficients for degree days and degree days squared for April to June are not statistically significant. For the months of July through September, the estimated coefficient for the degree days and degree days squared terms are statistically significant, though differ in sign. The degree day results imply corn responds positively to moderate temperature levels while higher temperature levels have negative effects on corn yields during the latter part of the growing season.

Table 4.2. Coefficient Estimates and Test Statistics

Parameters	Corn	Durum	Soybean	Wheat
Intercept	-107.803 (-5.04)	0.8649 (0.24)	-32.4527 (-2.53)	-0.0159 (-0.00)
L1yield	0.1952 (7.91)	0.2089 (10.20)	0.0441 (0.81)	0.1724 (10.79)
Time	0.9320 (8.27)	0.7501 (18.14)	0.1391 (1.01)	0.5862 (21.58)
Time2	0.0073 (3.51)	-0.0089 (-12.71)	0.0079 (1.67)	-0.0054 (-11.82)
L1prec1	0.1241 (0.14)	-0.2270 (-0.67)	-0.2834 (-0.55)	1.0882 (5.18)
Prec2	-0.0614 (-0.05)	0.0636 (0.15)	0.0506 (0.08)	1.3810 (5.02)
Prec3	1.7165 (2.40)	0.8469 (3.21)	0.0160 (0.32)	2.2036 (12.67)
Prec4	1.9012 (2.79)	0.1394 (0.57)	0.2087 (0.37)	0.4706 (2.83)
L1precsq	0.1364 (1.15)	-0.0237 (-0.45)	0.0858 (1.47)	-0.1557 (-5.24)
Prec2sq	0.1115 (0.81)	-0.0445 (-0.80)	0.0950 (1.28)	-0.1718 (-4.77)
Prec3sq	-0.0809 (-1.64)	-0.0465 (-2.35)	0.0044 (0.14)	-0.1178 (-9.30)
Prec4sq	-0.0945 (-2.28)	-0.0147 (-0.96)	0.0040 (0.12)	-0.0373 (-3.53)
DD1	0.0151 (0.76)	0.0027 (1.02)	0.0354 (2.97)	-0.0119 (-2.34)
DD2	0.0125 (4.44)	0.0027 (0.73)	0.0418 (2.66)	0.0061 (0.72)
DD1sq	-3.86E-6 (-0.31)	-0.2.85E-6 (-0.95)	-0.00002 (-2.91)	2.847E-6 (1.99)
DD2sq	-0.00004 (-4.25)	-4.86E-7 (-0.42)	-0.00001 (-2.34)	-1.874E-6 (-0.74)
R^2	0.7931	0.4698	0.4996	0.6287
Hausman test Statistics *	16.56 (0.341)	34.70 (0.0027)	8.79 (0.8881)	49.75 (0.0001)
H_O : RE vs. FE	RE	FE	RE	FE
# of counties	19	35	10	53
Years	1950-2006	1950-2005	1977-2006	1950-2005

Maximal yield based on July through September degree days (DD2) occur when degree days equal 156.3. Over the study period of July to September, degree days average 1487 per day. Overall, moderate levels of precipitation and temperature during the growing season positively affect corn yields, yet yields are reduced with higher levels of precipitation and temperatures. Table 4.3 presents the results.

The Estimated Results for Soybeans

Like corn yields, the results of the regression model for soybean yields indicate an upward trend over the 1978-2006 period. Soybean yields are also increasing at an increasing rate over the periods analyzed. However, neither trend nor the trend squared coefficients are statistically significant. There is thus weaker evidence than in the case of corn that soybean yields are increasing over the relatively shorter time period for which county-level soybean yield data are available.

Precipitation has a slight positive impact on soybean yields during the growing (May through September) season, though none of coefficients are statistically significant.

Instead of precipitation, soybean yields appear to be more significantly affected by temperatures or degree days during the months of April to September. The coefficients for degrees days in April to September are both positive and statistically significant, indicating a yield enhancing effect of greater temperatures during the growing season. However, the estimated coefficients for the degree days squared terms are negative and statistically significant. Similar to corn, too many degree days or too many days of high temperatures, negatively affect yields. Maximal soybean yield occurs when degree days for the July to September period equals 2090. Over the study period, July-September degree days average 1498. The results seem to indicate that there is potential for further soybean yield enhancement should temperatures over the growing season continue to increase. Conversely, the results seem to indicate little yield effects from changes in precipitation levels in North Dakota during the growing season.

The Estimated Results for Durum

In contrast to results from corn and soybean yield models, durum yields have been increasing at a decreasing rate over the 1950-2006 time period. Coefficients on both time and time squared variables are statistically significant.

The only precipitation variables having a statistically significant effect on durum yields are for the May to June period (Prec3). Assume that planting is not delayed in the spring by excess moisture, the results indicate that precipitation favors the emerging and growing durum crop during the early season. However, excess precipitation during the period negatively affects yields given the statistically negative coefficient on the square of the precip3 variable. Maximal yield based on May through June precipitation (Prec3) occurs when rainfall equals 9.11 inches. By comparison, the long-run averages for May to June are 5.68 inches.

Degree days have a positive, although insignificant impact on durum yields. Coefficients for the degree days squared terms are negative, although similarly significant. There is thus slight support for the positive effect of growing season temperatures on durum yields, although the effects are small based on the insignificance of the estimates.

The Estimated Results for Wheat

Like durum, wheat yields increased at a decreasing rate over the 1950-2005 time period. The time variable has a positive impact on wheat yields while the time squared variable has a negative impact. Both coefficients on the variables are statistically significant.

In contrast to durum, precipitation totals for all time periods had significant impacts on wheat yields. Precipitation during October through December of the year preceding wheat planting increased soil moisture, therefore positively impacting yields. The estimated coefficients on precipitation during wheat planting and the growing season up to harvest (from April to September) are positive and statistically significant. The squared terms on the precipitation variables have negative coefficients and are also statistically significant. These findings suggest that some rainfall positively affects wheat yields while too much rainfall negatively affects wheat yields. Maximal yield based on May and June precipitation (Prec3) occurs when rainfall equals 9.35 inches. Maximal yields based on July to September precipitation (Prec4) occur when rainfall equals 6.31 inches. The long run averages for these time periods are 5.73 inches and 6.56 inches, respectively.

The effect of degree days on wheat yields is mixed. The estimated coefficient for the degree days in April to June (DD1) is negative and significant. The squared value for degree days during April to June period is also significant, though is negative. Thus, wheat yields appear to be positively affected by cooler temperatures during the first two months of the growing season, though the negative squared term indicates that there is a limit on the degree to which cooler temperatures positively affect yields.

Sensitivity Analysis

This section summarizes the estimated elasticities of yields with respect to precipitation and degree days for corn, soybeans, durum and wheat. Elasticities estimate the impact of weather change on crop yields. Using mean values of precipitation and degree days, percentage changes in estimated crop yields for eight climate change scenarios are calculated for each county. Scenarios considered are: (1) a 10% increase in county mean precipitation holding degree days constant; (2) a 20% increase in county mean precipitation holding degree days constant; (3) a 10% change in county mean degree days holding precipitation constant; (4) a 20% change in mean degree days holding precipitation constant; (5) a 5% change in both county mean precipitation and degree days for each county; (6) a 10% change in both mean precipitation and degree days for each county; (7) a 10% decrease in county mean precipitation holding degree days constant; and (8) a 20% decrease in county mean precipitation holding degree days constant. The expected percentage changes in crop yields using eight climate change scenarios for each county are reported in Tables 4.3 through 4.6.

For corn, the range of yield changes resulting from a 10% increase in precipitation range from a drop in Burleigh County of 0.84% to an increase in expected yields in Dickey County of 1.39%. On average, the predicted yields would increase by 1.16% following a 10% increase in precipitation levels. On the other hand, a 10% decrease in precipitation levels result in a negative impact on predicted yields. On average, the predicted yields would decrease by 2.68% following a 10% decrease in precipitation levels. The range of yield changes associated with a 20% change in precipitation level is from a low of a 0.33% increase in Burleigh County to a high of 2.67% in Dickey County. The average increase in predicted yields as a result of a 20% increase in annual precipitation levels is 2.32%. On average, increasing precipitation levels with no change in average degree days have a positive impact on corn yields.

Increasing degree days by 10% while holding precipitation levels constant varies corn's predicted yields or elasticities from -2.02% in Burleigh County to an increase of 2.01% in Emmons county. The impact of a 10% increase in degree days averaged over all counties is an increase in corn yields by 0.51%. Unlike a 10% increase in degree days, decreasing degree days by 10% result in a negative impact on predicted corn yields. The average decrease in predicted yields following a 10% decrease in degree days is 1.51%. Conversely a 20% increase in degree days have a negative impact on expected corn yields. On average, the expected yields would decrease by 0.81% with a 20% increase in degree days.

We also increase both mean precipitation and mean degree days to estimate corn yields impacts. The results of a 5% increase in both precipitation and degree days in corn's yields range from a 1.17% fall in expected yields in Burleigh County to a 1.86% increase in expected yields in Emmons County. The mean impact of a 5% increase in both precipitation and degree days is a 1.10% increase in expected corn yield on average. The percentage changes in corn yields when both precipitation and degree days are increased by 10% vary from a 0.74% fall in Burleigh County to a 3.26% increase in predicted corn yields in Emmons County. On average, a 10% increase in both degree days and precipitation levels result in 1.79% increase in predicted corn yields. Table 4.3 presents the estimated elasticities for corn yields as a result of climate change.

The percentage change in soybean yields as a result of climate change is similar to the corn results. A 10% increase in precipitation level with no change in degree days results in a 1.36% increase in Walsh County to a 1.99% increase in expected yields in Cass County.

Table 4.3. Elasticities of Precipitation and Degree Days for Corn

County	10%Prec	20%Prec	10%DD	20%DD	5%Prec&DD	10%Prec &DD	10% decrease in Prec	10%decrease in DD
Burns	1.33%	2.56%	1.43%	1.03%	1.62%	2.76%	-1.43%	-3.3%
Burleigh	-0.84%	0.33%	-2.02%	-3.92%	-1.17%	-0.74%	-3.52%	-4.2%
Cass	1.35%	2.57%	-0.51%	-3.14%	0.70%	0.84%	-1.48%	-1.6%
Dickey	1.39%	2.67%	-0.60%	-3.37%	0.68%	0.79%	-1.49%	-1.6%
Emmons	1.25%	2.38%	2.01%	2.31%	1.86%	3.26%	-1.38%	-3.7%
Grand F.	1.19%	2.24%	1.45%	1.11%	1.57%	2.65%	-1.35%	-3.2%
Griggs	1.26%	2.39%	1.45%	1.10%	1.60%	2.71%	-1.39%	-3.3%
Kidder	1.24%	2.36%	0.47%	-1.05%	1.12%	1.71%	-1.37%	-2.4%
La Moure	1.29%	2.46%	1.04%	0.20%	1.42%	2.33%	-1.41%	-2.9%
Logan	1.29%	2.46%	1.40%	0.98%	1.59%	2.69%	-1.41%	-3.2%
McIntosh	1.24%	2.36%	0.87%	-0.20%	1.31%	2.11%	-1.36%	-2.8%
Morton	1.29%	2.48%	1.41%	0.99%	1.59%	2.70%	-1.40%	-3.2%
Oliver	1.31%	2.50%	1.12%	0.37%	1.46%	2.42%	-1.42%	-3.0%
Ransom	1.27%	2.40%	-0.61%	-3.37%	0.62%	0.66%	-1.39%	-1.6%
Richland	1.34%	2.55%	-0.75%	-3.66%	0.58%	0.59%	-1.47%	-1.4%
Sargent	1.37%	2.62%	-0.07%	-2.19%	0.92%	1.30%	-1.49%	-2.0%
Stutsman	1.20%	2.25%	0.13%	-1.77%	0.94%	1.33%	-1.33%	-2.2%
Traill	1.31%	2.50%	1.49%	1.18%	1.64%	2.80%	-1.43%	-3.3%
Walsh	1.05%	1.95%	0.00%	-2.07%	0.80%	1.05%	-1.21%	-2.1%
Averages	1.16%	2.32%	0.51%	-0.81%	1.10%	1.79%	-1.51%	-2.68%

On average, the predicted yields would increase by 1.77% with a 10% increase in precipitation levels. A 10% decrease in precipitation level results in a negative impact in expected yields for soybeans. On average, the predicted yields would decrease by 1.65% over all counties as a result of a 10% decrease in precipitation levels. The range of yields associated with a 20% change in precipitation level is from a low of a 2.81% increase in Walsh County to a high of 4.19% increase in Sargent County. The average increased in predicted yields as a result of a 20% increase in precipitation level is 3.65%.

Increasing degree days by 10% with no change in precipitation levels has a positive impact for soybeans. The range of yield changes resulting from a 10% increase in degree days range from a 2.77% increase in expected yields in Richland county to a 6.33% increase in expected yields in Barnes County. The impact of a 10% increase in degree days averaged over all counties is an increase in soybean's yields by 4.56%. Decreasing degree days by 10% has a negative impact on soybean yields. Overall, the predicted soybean yields would decrease by 6.05% following a 10% decrease in degree days.

Similarly, a 20% increase in degree days has a positive impact on expected soybean yields. The range of yield changes resulting from a 20% increase in degree days range from a 3.49% increase in Richland County to an 11.2% increase in Barnes County. The impact of a 20% increase in degree days averaged over all counties is an increase in soybean yields by 7.33%.

Increasing both precipitation and degree days by 5% results in an increase in soybean yields ranging from a 2.52% increase in expected yields in Richland County to a 4.17% increase in expected yields in Barnes County. A ten percent increases in both precipitation and degree days result in a 4.91% increase in expected yields in Walsh Count to a 7.98% increase in expected yields in Barnes County. By comparison, the long run averages for a 5% and a 10% increase in degree days are 3.37% and 6.32% respectively. Table 4.4 next page presents the estimated elasticities for soybeans.

For durum, the range of yield changes resulting from a 10% increase in precipitation range from a 0.45% fall in expected yields in Griggs County to a 0.30% increase in expected yields in Divide County. Increasing precipitation level results in a decrease in predicted durum yields. On average, increasing precipitation levels by 10% result in a 0.10% decrease in expected yields over all counties. Also, decreasing precipitation levels by a 10% result in a 0.46% fall in expected durum yields in Divide County to a 0.21% increase in expected yields in Grand Forks County. By comparison, decreasing precipitation levels by a 10% result in a 0.15% decrease in expected yields over all counties. The resulted elasticities for durum associated with weather changes are posted in Table 4.5.

The range of yields changes associated with a 20% increase in precipitation levels range from a 0.95% decrease in expected yields in Eddy County to a 0.43% increase in expected yields in Divide County. By comparison, increasing precipitation levels by 20% results in a 0.43% decrease in expected yields averaged over all counties. Overall, increasing precipitation levels with constant degree days have a negative impact on durum's yields.

Increasing degree days by 10% while holding precipitation level constant result in a 0.24% increase in the expected durum yields in Ward County to a 0.78% increase in Mountrail County. On average, the impact of a 10% increase in degree days is a 0.52% increase in expected yields over all counties.

Table 4.4. Elasticities of Precipitation and Degree Days for Soybeans

County	10%Prec	20%Prec	10%DD	20%DD	5% Prec & DD	10%Prec&DD	10%decrease in Prec	10%decrease in DD
Barnes	1.65%	3.40%	6.33%	11.12%	4.17%	7.98%	-1.54%	-9.41%
Cass	1.99%	4.12%	4.60%	7.47%	3.50%	6.59%	-1.84%	-5.88%
Dickey	1.89%	3.90%	3.50%	5.09%	2.92%	5.39%	-1.75%	-4.91%
Grand F	1.88%	3.89%	5.55%	9.47%	3.90%	7.43%	-1.75%	-6.68%
Ransom	1.73%	3.58%	4.23%	6.62%	3.19%	5.96%	-1.61%	-5.61%
Richlad	1.79%	3.70%	2.77%	3.49%	2.52%	4.56%	-1.66%	-4.36%
Sargent	2.02%	4.19%	4.02%	6.22%	3.23%	6.04%	-1.87%	-5.36%
Steele	1.52%	3.14%	6.28%	10.99%	4.08%	7.80%	-1.43%	-7.30%
Trail	1.83%	3.79%	4.73%	7.72%	3.48%	6.56%	-1.70%	-5.98%
Walsh	1.36%	2.81%	3.55%	5.10%	2.69%	4.91%	-1.28%	-5.01%
Average	1.77%	3.65%	4.56%	7.33%	3.37%	6.32%	-1.65%	-6.05%

On the other hand, the impact of a 10% decrease in degree days is a fall in expected durum yields. The average decrease in expected durum yields following a 10% decrease in degree days is 0.71% over all counties.

A 20% increase in degree days has a positive impact on durum's expected yields. The average increase in durum yields with a 20% increase in degree days is 0.86% over all counties. Elasticities range from a 0.15% increase in durum's yields in Ramsey County to a 0.98% increase in yields in Divide County when degree days are increased by 20%.

When both precipitation and degree days levels are increased by 5%, the expected durum yields would increase from a low of a 0.01% increase in Ramsey County to a high of 0.49% in Burke County. However, increasing both precipitation and degree day levels by 10% results in a 0.06% fall in expected durum yields in Griggs County to 0.90% increase in expected yields in Burke County. The average yields would increase by 0.27% when both precipitation and degree day are increased by 5% while the average durum yields would increase by 0.43% when both precipitation and degree days levels are increased by 10%.

Unlike durum, increasing precipitation levels has a positive impact on predicted spring wheat yields. Increasing precipitation level by 10% would result in a 1.08% increase in expected wheat yields in Cass County up to a 3.55% increase in predicted yields in Sioux County. On average, expected wheat yields would increase by 2.17% over all counties with a 10% increase in precipitation level. The impact of a 10% decrease in precipitation level for wheat is a decrease in the expected yields over all counties. On average, expected wheat yields would decrease by 2.76% following a 10% decrease in precipitation level.

Table 4.5. Elasticities of Precipitation and Degree Days for Durum

County	10%Prec	20%Prec	10%DD	20%DD	5%Prec&DD	10%Prec &DD	10%Decrease in Prec	10%Decrease in DD
Benson	-0.22%	-0.70%	0.62%	1.06%	0.25%	0.39%	-0.02%	-0.79%
Bottineau	-0.07%	-0.39%	0.67%	1.18%	0.35%	0.60%	-0.18%	-0.83%
Burke	0.24%	0.30%	0.65%	1.15%	0.49%	0.90%	-0.43%	-0.81%
Burleigh	0.05%	-0.13%	0.52%	0.79%	0.35%	0.57%	-0.29%	-0.76%
Cavalier	-0.21%	-0.66%	0.63%	1.13%	0.25%	0.42%	-0.02%	-0.76%
Divide	0.30%	0.43%	0.58%	0.98%	0.48%	0.88%	-0.46%	-0.76%
Eddy	-0.33%	-0.95%	0.64%	1.09%	0.22%	0.31%	0.03%	-0.83%
Foster	-0.32%	-0.91%	0.59%	1.00%	0.19%	0.27%	0.05%	-0.76%
Grand F.	-0.45%	-1.14%	0.39%	0.62%	0.02%	-0.06%	0.21%	-0.56%
Griggs	-0.45%	-1.18%	0.39%	0.57%	0.03%	-0.06%	0.17%	-0.59%
Hettinger	0.04%	-0.14%	0.54%	0.90%	0.34%	0.58%	-0.27%	-0.72%
Kidder	-0.21%	-0.72%	0.52%	0.79%	0.22%	0.31%	-0.09%	-0.77%
La Moure	-0.26%	-0.79%	0.36%	0.50%	0.12%	0.11%	-0.02%	-0.60%
Logan	-0.21%	-0.69%	0.41%	0.59%	0.16%	0.20%	-0.05%	-0.63%
McHenry	-0.26%	-0.83%	0.53%	0.83%	0.20%	0.27%	-0.04%	-0.77%
McIntosh	-0.15%	-0.57%	0.55%	0.89%	0.26%	0.40%	-0.13%	-0.74%
McLean	-0.12%	-0.54%	0.51%	0.75%	0.26%	0.39%	-0.18%	-0.77%
Mercer	0.09%	-0.04%	0.50%	0.80%	0.35%	0.59%	-0.31%	-0.70%
Morton	0.09%	-0.05%	0.46%	0.70%	0.33%	0.55%	-0.31%	-0.67%
Mountrail	-0.20%	-0.71%	0.78%	1.36%	0.36%	0.59%	-0.12%	-0.98%
Nelson	-0.31%	-0.90%	0.72%	1.30%	0.26%	0.41%	0.04%	-0.87%
Pembina	-0.24%	-0.72%	0.52%	0.86%	0.19%	0.28%	0.00%	-0.69%
Pierce	-0.06%	-0.31%	0.40%	0.64%	0.21%	0.33%	-0.12%	-0.55%
Ramsey	-0.05%	-0.39%	0.01%	0.01%	0.01%	-0.04%	-0.24%	-0.01%
Renville	0.03%	-0.15%	0.66%	1.17%	0.39%	0.69%	-0.25%	-0.81%
Rolette	-0.16%	-0.58%	0.70%	1.26%	0.31%	0.53%	-0.08%	-0.82%
Sheridan	-0.09%	-0.42%	0.66%	1.17%	0.33%	0.57%	-0.14%	-0.81%
Slope	0.27%	0.33%	0.49%	0.74%	0.44%	0.76%	-0.49%	-0.72%

Table 4.5. (continued)

County	10%Prec	20%Prec	10%DD	20%DD	5%Prec&DD	10%Prec &DD	10%Decrease in Prec	10%Decrease in DD
Stark	0.11%	-0.01%	0.61%	1.02%	0.41%	0.71%	-0.33%	-0.81%
Stutsman	-0.24%	-0.75%	0.54%	0.88%	0.21%	0.30%	-0.03%	-0.75%
Towner	0.00%	-0.23%	0.47%	0.73%	0.29%	0.47%	-0.23%	-0.67%
Walsh	-0.18%	-0.60%	0.60%	1.05%	0.26%	0.43%	-0.07%	-0.76%
Ward	-0.03%	-0.25%	0.24%	0.26%	0.16%	0.21%	-0.17%	-0.45%
Wells	0.02%	-0.17%	0.46%	0.72%	0.29%	0.48%	-0.24%	-0.65%
Williams	0.26%	0.37%	0.42%	0.61%	0.39%	0.68%	-0.42%	-0.63%
Average	-0.09%	-0.43%	0.52%	0.86%	0.27%	0.43%	-0.15%	-0.71%

Increasing precipitation by 20% results in a 1.51% increase in expected yields in Dickey County to a 6.53% increase in expected yields in Sioux County. By comparison, the average change when the precipitation level is increased by 20 percent is 3.76% over all counties.

However, increasing degree days has a negative impact on predicted wheat yields. A 10% increase in degree days results in a 2.43% decrease in expected wheat yields in Sioux county to a 1.23% decrease in expected yields in Richland County. The average impact of a 10% increase in degree days is a 4.89% decrease in expected wheat yields over all counties. Decreasing degree days levels by 10% has a negative impact on expected wheat yields. The average increase in expected yields as a result of a ten percent decrease in degree days is 1.68% over all counties. Also, increasing the degree days level by 20% results in a decrease in expected yields, ranging from a 4.89% decrease in expected yields in Sioux County to a 2.42% decrease in expected yields in Richland County. The average decrease in expected yields when total degree days are increased by 20% is 3.37% over all counties.

A 5% increase in both precipitation and degree days results in a 0.12% decrease in expected yields in Dickey County up to a 0.67% increase in expected yields in McKenzie County. The average impact of a 5% increase in both precipitation and degree days is a 0.32% increase in expected wheat yields in all counties. Similarly, a 10% increase in both precipitation and degree days results in a 0.44% fall in expected wheat yields in Dickey County to a 1.25% increase in expected yields in McKenzie County. The mean impact of a 10% increase in both precipitation and degree days levels is a 0.49% increase in expected yields. Overall, increasing both precipitation and degree days has a positive impact on predicted wheat yields. The estimated elasticities for wheat as a result of climate change are posted in Table 4.6 next page.

Weather and Crop Returns

This section investigates the effects of precipitation and temperature on gross returns of corn, soybeans, spring wheat and durum. Yield changes are important in determining the effect of climate changes, but farmers are more interested in determining the effects of weather on returns per acre from the different crops. Therefore, the next step in the analysis of the effects of weather on crops is to use historical price data for the four crops to generate per acre gross crop returns under the weather scenarios (1)-(6) considered previously.

Nominal North Dakota average prices were obtained for the four crops and converted to real prices using the consumer price index. Following Clements, Mapp and Eidman's (1971) procedures, we detrended the four real price series by regressing price on various polynomial specifications of time trend. Then the best detrending model for each price was used to estimate price variation from trend over the 57 years of data.

The Clements, Mapp, and Eidman procedure begins with a Cholesky decomposition of the variance-covariance matrix. The coefficients of the resulting matrix can then be used along with mean values and randomly generated standard normal deviates to create correlated observations. Simulated prices are then generated by adding the correlated deviates to the estimated wheat, durum, corn and soybean prices for base year 2006. Estimated crop yields from the base year and the first six weather scenarios are multiplied by the simulated price distributions for the four crops.

Table 4.6. Elasticities of Precipitation and Degree Day for Wheat

County	10%Prec	20%Prec	10%DD	20%DD	5% Prec & DD	10%Prec &DD	10%Decrease in Prec	10%Decrease in DD
Adams	2.60%	4.51%	-2.00%	-4.04%	0.39%	0.60%	-3.29%	1.97%
Barnes	1.64%	2.68%	-1.37%	-2.71%	0.21%	0.27%	-2.23%	1.39%
Benson	2.06%	3.50%	-1.64%	-3.28%	0.29%	0.42%	-2.66%	1.63%
Billings	3.03%	5.51%	-2.18%	-4.43%	0.50%	0.85%	-3.58%	2.12%
Bottineau	2.07%	3.61%	-1.55%	-3.11%	0.33%	0.52%	-2.61%	1.54%
Bowman	2.98%	5.38%	-2.15%	-4.35%	0.50%	0.83%	-3.57%	2.10%
Burke	2.61%	4.78%	-1.65%	-3.33%	0.54%	0.96%	-3.06%	1.62%
Burleigh	2.78%	4.98%	-1.98%	-3.96%	0.47%	0.80%	-3.37%	1.99%
Cass	1.08%	1.56%	-1.31%	-2.61%	-0.04%	-0.23%	-1.68%	1.33%
Cavalier	1.65%	2.77%	-1.38%	-2.77%	0.21%	0.28%	-2.19%	1.36%
Dickey	1.16%	1.51%	-1.60%	-3.18%	-0.12%	-0.44%	-1.97%	1.63%
Divide	2.88%	5.32%	-1.68%	-3.35%	0.65%	1.19%	-3.31%	1.70%
Dunn	2.67%	4.73%	-1.94%	-3.91%	0.44%	0.73%	-3.28%	1.91%
Eddy	1.90%	3.14%	-1.71%	-3.44%	0.18%	0.19%	-2.56%	1.70%
Emmons	2.80%	4.94%	-1.80%	-3.56%	0.58%	1.00%	-3.47%	1.85%
Foster	1.74%	2.86%	-1.58%	-3.19%	0.16%	0.15%	-2.36%	1.56%
GoldenV.	2.90%	5.30%	-2.00%	-4.02%	0.52%	0.91%	-3.41%	1.97%
Grand F.	1.18%	1.81%	-1.31%	-2.63%	0.01%	-0.13%	-1.74%	1.31%
Grant	3.01%	5.43%	-2.06%	-4.15%	0.55%	0.95%	-3.60%	2.03%
Griggs	1.39%	2.12%	-1.49%	-2.98%	0.03%	-0.11%	-2.04%	1.50%
Hettinger	2.44%	4.29%	-1.86%	-3.73%	0.37%	0.58%	-3.02%	1.84%
Kidder	2.46%	4.17%	-1.96%	-3.91%	0.34%	0.50%	-3.21%	1.97%
LaMoure	1.85%	3.09%	-1.48%	-2.93%	0.26%	0.37%	-2.46%	1.50%
Logan	2.33%	3.92%	-2.02%	-4.06%	0.25%	0.31%	-3.07%	2.01%
McHenry	2.19%	3.74%	-1.56%	-3.09%	0.39%	0.63%	-2.84%	1.60%
McIntosh	2.50%	4.23%	-2.05%	-4.10%	0.32%	0.45%	-3.28%	2.05%
McKenze	2.91%	5.38%	-1.67%	-3.29%	0.67%	1.25%	-3.35%	1.71%
McLean	2.16%	3.73%	-1.61%	-3.22%	0.35%	0.55%	-2.77%	1.62%

Table 4.6. (continued)

County	10%Prec	20%Prec	10%DD	20%DD	5% Prec & DD	10%Prec &DD	10%Decrease in Prec	10%Decrease in DD
Mercer	2.58%	4.60%	-1.76%	-3.51%	0.48%	0.83%	-3.15%	1.77%
Morton	2.70%	4.80%	-2.02%	-4.07%	0.41%	0.67%	-3.30%	2.00%
Mountral	2.12%	3.58%	-1.73%	-3.48%	0.28%	0.39%	-2.78%	1.69%
Nelson	1.66%	2.74%	-1.48%	-2.97%	0.17%	0.18%	-2.24%	1.46%
Oliver	2.43%	4.24%	-1.76%	-3.52%	0.41%	0.67%	-3.05%	1.77%
Pembina	1.54%	2.58%	-1.29%	-2.59%	0.18%	0.24%	-2.03%	1.29%
Pierce	2.34%	4.07%	-1.75%	-3.48%	0.37%	0.59%	-2.95%	1.76%
Ramsey	2.05%	3.59%	-1.61%	-3.24%	0.29%	0.44%	-2.57%	1.60%
Ransom	1.39%	2.13%	-1.43%	-2.82%	0.06%	-0.03%	-2.05%	1.45%
Renville	2.25%	4.00%	-1.52%	-3.04%	0.43%	0.73%	-2.74%	1.51%
Richland	1.30%	2.00%	-1.23%	-2.42%	0.10%	0.07%	-1.91%	1.28%
Rolette	1.94%	3.29%	-1.64%	-3.33%	0.23%	0.30%	-2.52%	1.59%
Sargent	1.12%	1.52%	-1.49%	-2.97%	-0.10%	-0.37%	-1.85%	1.51%
Sheridan	2.35%	4.05%	-1.85%	-3.69%	0.33%	0.50%	-2.99%	1.85%
Sioux	3.55%	6.53%	-2.43%	-4.89%	0.63%	1.12%	-4.11%	2.39%
Slope	2.78%	5.06%	-2.05%	-4.16%	0.43%	0.73%	-3.28%	1.99%
Stark	2.65%	4.74%	-1.97%	-3.98%	0.41%	0.68%	-3.21%	1.94%
Steele	1.67%	2.85%	-1.32%	-2.63%	0.24%	0.35%	-2.17%	1.33%
Stutsman	1.86%	3.12%	-1.56%	-3.12%	0.23%	0.30%	-2.47%	1.56%
Towner	2.00%	3.51%	-1.45%	-2.89%	0.33%	0.55%	-2.47%	1.45%
Traill	1.13%	1.68%	-1.26%	-2.52%	0.00%	-0.14%	-1.69%	1.27%
Walsh	1.60%	2.72%	-1.25%	-2.49%	0.23%	0.35%	-2.09%	1.28%
Ward	2.19%	3.88%	-1.58%	-3.15%	0.37%	0.61%	-2.70%	1.58%
Wells	2.24%	3.96%	-1.46%	-2.89%	0.45%	0.78%	-2.75%	1.49%
Williams	2.68%	4.99%	-1.71%	-3.43%	0.54%	0.97%	-3.07%	1.71%
Average	2.17%	3.76%	-1.68%	-3.37%	0.32%	0.49%	-2.76%	1.68%

The resulting revenue distributions show the relative changes in expected crop gross revenues per acre under the different weather scenarios. Results are reported in Table 4.7 for the four crops and for representative counties.

Effects of climate change on the gross returns are consistent with the yield elasticities discussed earlier. For corn, increasing precipitation levels by 10% and 20% results in an increase in expected corn gross revenues per acre in Cass County. The expected corn gross revenues per acre would increase by 1.35% with 10% increase in precipitation level. Increasing precipitation level by 20% would cause the expected corn gross revenues to increase by 2.58% per acre.

Increasing degree days by 10% and 20% would cause the expected gross revenues to fall below the base scenario of $268.27 per acre. The expected corn gross revenues would decrease by 0.50% and 3.14%, respectively. On the other hand, increasing both precipitation and degree days levels by 5% and 10% has a positive impact on expected corn gross revenues. The mean increase in expected gross revenues per acre when both precipitation and degree days are increase is 0.70% and 0.84%, respectively.

The six weather change scenarios indicate positive impacts on expected soybean gross revenues in Cass County. Similar to corn, increasing precipitation levels has a positive impact on expected soybean gross revenues. The effect of ten percent and 20% increase in precipitation levels is a 1.99% and a 4.12% increase in expected soybeans gross revenues per acre, respectively.

Unlike the negative impact that the degree days have on the expected corn gross revenues, increasing degree days has a positive impact on expected soybean gross revenues. Increasing degree days by 10% would results in a 4.60% increase in expected soybean gross revenues per acre. Also, increasing degree days by 20% would results in a 7.47% increase in expected soybean gross revenues per acre.

Similar to corn, increasing both precipitation and degree days levels have a positive impact on expected soybeans yields. The results of a 5% increase in both precipitation and degree days in expected soybean gross revenues is a 3.49% increase in gross revenues per acre while increasing both precipitation and degree days by ten percent result in a 6.59% increase in expected soybean gross revenues per acre.

The relative profitability of wheat in Cass County under six weather change scenarios range from a low of $174.75 in expected wheat gross revenues per acre under a 20% increase in degree days to a high of $182.24 in expected wheat gross revenues per acre under a 20% increase in precipitation level.

Increasing precipitation levels by ten percent and 20% have a positive impact on expected wheat gross revenues per acre. The expected wheat gross revenues would increase by 0.01% and 1.57%, respectively. However, increasing degree days have a negative impact on expected wheat gross revenues. Increasing degree days by 10% and 20% would reduce the expected wheat gross revenues per acre by 1.30% and 2.60%, respectively. The expected wheat gross revenues per acre are slightly below the base of $179.43 under the two weather scenarios of a 5% and a 10% increase in both precipitation and degree days. The expected wheat gross revenues would decrease by 0.03% and 0.22%, respectively.

Unlike corn, soybeans, and wheat, the expected durum gross revenues slightly decline with an increase in precipitation levels. Increasing precipitation levels by 10% and 20% would result in a 0.03% and a 0.24% fall in expected gross revenues per acre. In contrast to wheat, increasing degree days has a positive impact in expected durum gross revenues. When degree days are increased by 10% and 20%, the expected durum gross revenues would increase by 0.24% and 0.25%, respectively. In comparison to wheat, increasing both precipitation and degree days levels have a positive impact on expected durum gross revenues. With a 10% and a 20% increase in both precipitation and degree days levels, the expected durum gross revenues would increase by 0.15% and 0.21% respectively.

Table 4.7. Gross Returns per Acre for Corn, Soybeans, Wheat, and Durum, Select Counties (Standard deviations of returns in parentheses)

Crop & County	Base Scenario	+10% Prec	+20% Prec	+10% DD	+20% DD	+5% Prec & DD	+10% Prec & DD
Corn – Cass	$268.27 (60.40)	$271.89 (61.22)	$275.18 (61.96)	$266.91 (60.10)	$259.84 (58.51)	$270.16 (60.83)	$270.53 (60.91)
Soybean– Cass	$232.91 (37.27)	$237.54 (38.01)	$242.51 (38.81)	$243.63 (38.99)	$250.30 (40.06)	$241.04 (38.57)	$248.26 (39.73)
Wheat– Cass	$179.43 (16.06)	$181.37 (16.23)	$182.24 (16.31)	$177.08 (15.85)	$174.75 (15.64)	$179.36 (16.05)	$179.02 (16.02)
Durum– Ward	$140.89 (27.56)	$140.85 (27.49)	$140.54 (27.49)	$141.23 (27.62)	$141.25 (27.63)	$141.11 (27.60)	$141.19 (27.61)

CHAPTER 5. SUMMARY, CONCLUSIONS AND IMPLICATIONS

Fixed and random effects models were employed to estimate the impacts of climate variables (temperature and precipitation) on the yields of four major crops in North Dakota: corn, durum, soybeans, and wheat. County level crop yield data from 1950-2006 for all 53 counties throughout the state were used in the study. State level crop prices were also obtained. Weather data on degree days and temperature were obtained for all 53 counties.

To account for the trend in the data, panel unit root tests were conducted to determine if the individual series were stationary or if they contained unit roots. The panel unit test developed by Im, Pesaran and Shin was used to determine stationarity properties of the data. The results indicated that all seven series for each crop (yield, four precipitation and two degree day-series) are stationary. Therefore, we did not have to difference the data to correct for unit roots.

We also applied the Hausman test to test the hypothesis of fixed versus random effect underlying the panel regression models. We failed to reject the null hypothesis for corn and soybeans and therefore, used the random effects model for the analysis of corn and soybean yields. For durum and wheat, we rejected the null hypothesis and the fixed effects model was used for the analysis of yields.

Crop yield is the dependent variable, with time trend, lagged yields, and weather variables hypothesized to affect yields. Weather variables included precipitation and degree days. The four precipitation variables were October through December precipitation (Prec1), January through April (Prec2) precipitation, May through June (Prec3) precipitation and July through September (Prec4) precipitation. The two degree days variables are April through June degree days (DD1) and July through September degree days level (DD2).

Using mean values of precipitation and degree days, we calculated percentage changes in estimated crop yields for six climate change scenarios for each county. In order to determine the effects of weather and climate change on crop yields, we calculated the effects on predicted yields for each crop and county using eight weather change scenarios. We also used historical price data for the four crops (corn, soybeans, spring wheat and durum) to generate per acre gross returns under the weather change scenarios in order to provide evidence of the effects of precipitation and temperature on crop returns.

Results and Conclusions

This study has analyzed the impact of climate variability on major four crop yields in North Dakota. The results emphasize crop specific differences in the climate impacts on yields.

For corn and soybeans, the results of the regression models indicated that yields have been increasing at a decreasing rate over the study period. Precipitation and degree days are found to have the same effects on corn yield levels. Corn yields responds positively to precipitation during the growing season. However, greater rainfall has a negative effect on yields as measured by a quadratic term on precipitation.

The degree day results implied that corn responds positively to moderate temperature levels while higher temperature levels have negative effects on corn yields during the latter part of the growing season. Therefore, moderate levels of precipitation and temperature during the growing season positively affect corn yields, yet yields are reduced with higher levels of precipitation and temperatures.

For soybeans, precipitation during the growing season has a slight positive impact on soybean yields. Soybeans yields appear to be more significantly affected by temperatures or degree days during the growing season. The results seem to indicate that there is potential for further soybean yield enhancement should temperatures over the growing season continue to increase. Conversely, the results seem to indicate little yield effects from changes in precipitation levels in North Dakota during the growing season.

In contrast to results from corn and soybean yield models, durum and wheat yields have been increasing at a decreasing rate over the study periods. Durum results indicate that precipitation during the early season of May to June favors durum yields. However, excess precipitation during the period negatively affects yields. Degree days have a positive, though insignificant impact on durum yields. There is thus slight support for the positive effect of growing season temperatures on durum yields.

For wheat, the findings suggest that some rainfall positively affects wheat yields while too much rainfall negatively affects wheat yields. Furthermore, wheat yields appear to be positively affected by cooler temperatures during the first two months of the growing season, though the negative squared term indicates that there is a limit on the degree to which cooler temperatures positively affect yields.

The estimated elasticities of yields with respect to precipitation and degree days vary according to the crop. On average, the predicted corn yields would increase by 1.16% following a 10% increase in precipitation levels. In contrast, the predicted corn yields would decrease by 1.51% following a 10% decrease in precipitation levels. The average increase in predicted yields as a result of a 20% increase in precipitation level is 2.32%. On average, increasing precipitation levels with no change in average degree days have a positive impact on corn yields.

The impact of a 10% increase in degree days averaged over all counties is an increase in expected corn yields by 0.51%. In contrast, decreasing degree days by 10% would results in a 2.68% fall in expected corn yields over all counties. Conversely a 20% increase in degree days have a negative impact on expected corn yields. On average, the expected yields would decrease by 0.81% with a 20% increase in degree days. The mean impact of a 5% increase in both precipitation and degree days is a 1.10% increase in expected corn yields on average. On average, a 10% increase in both degree days and precipitation levels would results in 1.79% increase in predicted corn yields.

The percentage change in soybean yields as a result of climate change is similar to corn results. On average, the predicted yields would increase by 1.77% with a 10% change in precipitation levels. Decreasing precipitation levels by 10% would decrease the predicted yields by 1.65% over all counties. The average increased in predicted yields as a result of a 20% increase in precipitation level is 3.65%.

Increasing degree days have a positive impact on soybeans yields. The impact of a 10% increase in degree days averaged over all counties is an increased in soybean's yields by 4.56%. In contrast, decreasing degree days levels by 10% result in a 6.05% fall in predicted yields. Similarly, the impact of a 20% increase in degree days averaged over all counties is an increased in soybean's yields by 7.33%. Increasing both precipitation and degree days levels results in an increase in soybean's yields. The long run effect for a 5% and a 5% increase in precipitation and degree days are 3.37% and 6.32% respectively.

For durum, increasing precipitation results in a decrease in predicted yields. On average, increasing precipitation levels by 10% result in a 0.09% decrease in expected yields over all counties. Also, decreasing precipitation levels by 10% results in a 0.15% decrease in expected yields over all counties. By comparison, increasing precipitation levels by 20% results in a 0.43% decrease in expect yields over all counties. Overall, increasing precipitation levels with constant degree days have a negative impact on durum's yields.

On the other hand, increasing degree days while holding precipitation levels constant results in a positive impact in expected durum yields. On average, the impact of a 10% increase in degree days is a 0.52% increase in expected yields over all counties. In contrast, decreasing degree days levels by 10% have a negative impact in expected durum yields. On average, the impact of a 10% decrease in degree days is a 0.71% decrease in expected yields over all counties. Similarly, the average increase in durum yields with a 20% increase in degree days is 0.86% over all counties. Increasing both precipitation and degree days levels have a positive impact on durum yields on average. By comparison, the average yields would increase by a 0.27% when both precipitation and degree day are increased by 5% while the average durum yields would increase by 0.43% when both precipitation and degree days levels are increased by 10%.

For wheat increasing precipitation levels have a positive impact on predicted wheat yields. On average, the expected wheat yields would increased by a 2.17% over all counties with a 10% increase in precipitation level. Decreasing precipitation levels have a negative impact in expected wheat yields. The average elasticity when precipitation level is increased by 20% is 3.76% over all counties.

However, increasing degree days has a negative impact on predicted wheat yields. The average impact of a 10% increase in degree days is a 4.89% decrease in expected wheat yields over all counties. In contrast, decreasing degree days by 10% have a positive impact on expected yields. The average decrease in expected yields when degree days are increased by 20% is 3.37% over all counties. Overall, increasing both precipitation and degree days have a positive impact on predicted average wheat yields on.

The average impact of a 5% increase in both precipitation and degree days is a 0.32% increase in expected wheat yields in all counties. Similarly, the mean impact of a 10% increase in both precipitation and degree days levels is a 0.49% increase in expected yields.

The effects of climate change on gross returns are consistent with the yield elasticities. Increasing precipitation levels have a significant impact on expected corn gross revenues. The expected corn revenues per acre would increase by 1.35% with 10% increase in precipitation level and 2.58% with 20% increase in precipitation levels. However, increasing degree days have a negative impact on expected corn gross revenues. The expected corn gross revenues per acre would decrease by 0.50% and 3.14% with ten percent and 20% increase in precipitation levels. Increasing both precipitation and degree day levels by 5% and 10% have a positive impact on expected corn gross revenues. The mean increase in expected gross revenues per acre when both precipitation and degree days are increased is 0.70% and 0.84%, respectively.

Similar to corn, increasing precipitation levels have a positive impact on the expected soybean gross revenues. The effect of 10% and 20% increase in precipitation levels is a 1.99% and 4.12% increase in expected soybean gross revenues per acre, respectively. In contrast to corn, increasing degree days have a positive impact on expected soybean revenues. The expected soybean gross revenues per acre would increase by 4.60% with 10% increase in degree days and by 7.47% with 20% in degree days. Expected soybean gross revenues per acre would increase by 3.49% when both temperature and degree days levels are increase by 5%. With 10%increase in both precipitation and degree days levels, the expected soybean gross revenues per acre would increase by 6.59%.

For wheat, increasing precipitation levels by 10% and 20% would result in a positive impact on expected gross revenues per acre. The expected wheat gross revenues per acre for wheat would increase by 0.01% and 1.57%, respectively. However, increasing degree days by 10% and 20% have a negative impact on expected wheat revenues. The expected wheat gross revenues would fall by 1.30% and 2.60% respectively. With 5% and 20% increase in both precipitation and degree day's levels, the expected wheat gross revenues per acre would decrease by 0.03% and 0.22%, respectively.

For durum, increasing precipitation levels by 10% and 20% result in a fall in expected gross revenues per acre of 0.03% and 0.24%, respectively. When degree days are increased by 10% and 20%, the expected durum gross revenues per acre would increase by 0.24% and 0.25%, respectively. Also, increasing both precipitation and degree days levels by 5% and 10% result in an increase in expected durum gross revenues by 0.15% and 0.21% respectively.

Implications

The above analysis shows the magnitude and direction of climate change impact on North Dakota agriculture. Most of the results show that climate change is detrimental to crop yields. The analysis also shows that more rainfalls and higher temperature levels have a negative impact of crop yields. The expected gross revenues would also be affected by the negative crop yields and farmers cropping decision patterns would also be affected. Therefore, more research is needed.

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APPENDIX

Regression Analysis Results for Corn

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The TSCSREG Procedure

Dependent Variable: Yield Yield

Model Description

Estimation Method	FixOne
Number of Cross Sections	19
Time Series Length	57

Fit Statistics

SSE	222696.9273	DFE	1048
MSE	212.4971	Root MSE	14.5773
R-Square	0.8078		

F Test for No Fixed Effects

Num DF	Den DF	F Value	Pr > F
18	1048	6.77	<.0001

Parameter Estimates

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|	Label
CS1	1	-1.23232	2.7634	-0.45	0.6557	Cross Sectional Effect 1
CS2	1	-8.18287	2.7793	-2.94	0.0033	Cross Sectional Effect 2
CS3	1	4.77079	2.7702	1.72	0.0853	Cross Sectional Effect 3
CS4	1	0.84829	2.8058	0.30	0.7625	Cross Sectional Effect 4
CS5	1	-3.09679	2.7646	-1.12	0.2629	Cross Sectional Effect 5
CS6	1	2.787291	2.7570	1.01	0.3123	Cross Sectional Effect 6
CS7	1	0.289933	2.7460	0.11	0.9159	Cross Sectional Effect 7
CS8	1	8.56943	2.7562	3.11	0.0019	Cross Sectional Effect 8
CS9	1	0.112705	2.7409	0.04	0.9672	Cross Sectional Effect 9

CS10	1	-4.70786	2.7554	-1.71	0.0878	Cross Sectional Effect 10
CS11	1	-9.27669	2.7737	-3.34	0.0009	Cross Sectional Effect 11
CS12	1	-9.08492	2.8121	-3.23	0.0013	Cross Sectional Effect 12
CS13	1	-6.89546	2.8036	-2.46	0.0141	Cross Sectional Effect 13
CS14	1	6.169382	2.7624	2.23	0.0257	Cross Sectional Effect 14
CS15	1	10.2851	2.8187	3.65	0.0003	Cross Sectional Effect 15
CS16	1	2.484922	2.7817	0.89	0.3719	Cross Sectional Effect 16
CS17	1	-4.24488	2.7523	-1.54	0.1233	Cross Sectional Effect 17
CS18	1	5.647205	2.7598	2.05	0.0410	Cross Sectional Effect 18
Intercept	1	-105.002	21.4987	-4.88	<.0001	Intercept
L1yield	1	0.18082	0.0249	7.25	<.0001	
Time	1	0.934763	0.1128	8.29	<.0001	Time
Time2	1	0.007746	0.00209	3.70	0.0002	Time2
L1prec1	1	-0.09854	0.9098	-0.11	0.9138	
Prec2	1	-0.25716	1.1349	-0.23	0.8208	Prec2
Prec3	1	1.695132	0.7151	2.37	0.0179	Prec3
Prec4	1	1.810735	0.6827	2.65	0.0081	Prec4
L1prec1sq	1	0.157762	0.1184	1.33	0.1829	
prec2sq	1	0.127734	0.1372	0.93	0.3521	
prec3sq	1	-0.08179	0.0495	-1.65	0.0985	
prec4sq	1	-0.09189	0.0415	-2.21	0.0271	
DD1	1	0.011601	0.0200	0.58	0.5620	DD1
DD2	1	0.126488	0.0281	4.50	<.0001	DD2
dd1sq	1	-2.36E-6	0.000012	-0.19	0.8497	
dd2sq	1	-0.00004	9.582E-6	-4.32	<.0001	

The TSCSREG Procedure

Dependent Variable: Yield Yield

Model Description

Estimation Method	RanOne
Number of Cross Sections	19
Time Series Length	57

Fit Statistics

SSE	226379.9898	DFE	1066
MSE	212.3640	Root MSE	14.5727
R-Square	0.7931		

Variance Component Estimates

Variance Component for Cross Sections	30.56745
Variance Component for Error	212.4971

Hausman Test for
Random Effects

DF m Value Pr > m

15	16.56	0.3461

Parameter Estimates

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|	Label
Intercept	1	-107.803	21.3843	-5.04	<.0001	Intercept
L1yield	1	0.195223	0.0247	7.91	<.0001	
Time	1	0.932097	0.1127	8.27	<.0001	Time
Time2	1	0.007332	0.00209	3.51	0.0005	Time2
L1prec1	1	0.124076	0.9067	0.14	0.8912	
Prec2	1	-0.06136	1.1325	-0.05	0.9568	Prec2
Prec3	1	1.716508	0.7144	2.40	0.0164	Prec3
Prec4	1	1.90117	0.6812	2.79	0.0054	Prec4
L1prec1sq	1	0.136369	0.1181	1.15	0.2485	
prec2sq	1	0.111514	0.1370	0.81	0.4158	
prec3sq	1	-0.08092	0.0494	-1.64	0.1019	
prec4sq	1	-0.0945	0.0415	-2.28	0.0229	
DD1	1	0.01512	0.0200	0.76	0.4487	DD1
DD2	1	0.124746	0.0281	4.44	<.0001	DD2
dd1sq	1	-3.86E-6	0.000012	-0.31	0.7560	
dd2sq	1	-0.00004	9.558E-6	-4.25	<.0001	

Regression Analysis Results for Soybeans

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The TSCSREG Procedure

Dependent Variable: Yield Yield

Model Description

Estimation Method	FixOne
Number of Cross Sections	10
Time Series Length	30

Fit Statistics

SSE	6577.9456	DFE	274
MSE	24.0071	Root MSE	4.8997
R-Square	0.5360		

F Test for No Fixed Effects

Num DF	Den DF	F Value	Pr > F
9	274	2.99	0.0020

Parameter Estimates

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|	Label
CS1	1	2.660257	1.3553	1.96	0.0507	Cross Sectional Effect 1
CS2	1	3.823102	1.3785	2.77	0.0059	Cross Sectional Effect 2
CS3	1	-0.81551	1.3289	-0.61	0.5400	Cross Sectional Effect 3
CS4	1	0.259481	1.3248	0.20	0.8449	Cross Sectional Effect 4

CS5	1	1.971402	1.3184	1.50	0.1360	Cross Sectional Effect 5
CS6	1	3.437593	1.3329	2.58	0.0104	Cross Sectional Effect 6
CS7	1	1.415161	1.3527	1.05	0.2964	Cross Sectional Effect 7
CS8	1	3.385707	1.3484	2.51	0.0126	Cross Sectional Effect 8
CS9	1	3.002905	1.3279	2.26	0.0245	Cross Sectional Effect 9
Intercept	1	-33.8978	12.9233	-2.62	0.0092	Intercept
L1yield	1	0.020076	0.0556	0.36	0.7181	
Time	1	0.126425	0.1382	0.91	0.3611	Time
Time2	1	0.008794	0.00480	1.83	0.0680	Time2
L1prec1	1	-0.29902	0.5138	-0.58	0.5611	
Prec2	1	0.011027	0.6747	0.02	0.9870	Prec2
Prec3	1	0.210739	0.5064	0.42	0.6776	Prec3
Prec4	1	0.160937	0.5607	0.29	0.7743	Prec4
L1prec1sq	1	0.085689	0.0586	1.46	0.1447	
prec2sq	1	0.101277	0.0748	1.35	0.1767	
prec3sq	1	0.000937	0.0330	0.03	0.9773	
prec4sq	1	0.006805	0.0324	0.21	0.8337	
DD1	1	0.036557	0.0120	3.05	0.0025	DD1
DD2	1	0.041106	0.0158	2.60	0.0099	DD2
dd1sq	1	-0.00002	7.165E-6	-2.94	0.0035	
dd2sq	1	-0.00001	5.335E-6	-2.27	0.0238	

The TSCSREG Procedure

Dependent Variable: Yield Yield

Model Description

Estimation Method	RanOne
Number of Cross Sections	10
Time Series Length	30

Fit Statistics

SSE	6792.0557	DFE	283
MSE	24.0002	Root MSE	4.8990
R-Square	0.4996		

Variance Component Estimates

Variance Component for Cross Sections	1.795218
Variance Component for Error	24.0071

Hausman Test for Random Effects

DF	m Value	Pr > m
15	8.79	0.8881

Parameter Estimates

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|	Label

Intercept	1	-32.4527	12.8086	-2.53	0.0118	Intercept
L1yield	1	0.044102	0.0547	0.81	0.4207	
Time	1	0.139096	0.1380	1.01	0.3143	Time
Time2	1	0.007974	0.00479	1.67	0.0969	Time2
L1prec1	1	-0.28346	0.5117	-0.55	0.5801	
Prec2	1	0.050632	0.6713	0.08	0.9399	Prec2
Prec3	1	0.160069	0.5037	0.32	0.7509	Prec3
Prec4	1	0.208733	0.5587	0.37	0.7090	Prec4
L1prec1sq	1	0.085803	0.0584	1.47	0.1426	
prec2sq	1	0.095016	0.0745	1.28	0.2033	
prec3sq	1	0.00448	0.0328	0.14	0.8914	
prec4sq	1	0.004003	0.0323	0.12	0.9014	
DD1	1	0.035447	0.0119	2.97	0.0032	DD1
DD2	1	0.041835	0.0157	2.66	0.0083	DD2
dd1sq	1	-0.00002	7.147E-6	-2.91	0.0039	
dd2sq	1	-0.00001	5.3E-6	-2.34	0.0199	

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The TSCSREG Procedure

Dependent Variable: Yield Yield

Model Description

Estimation Method	FixOne
Number of Cross Sections	35
Time Series Length	56

Fit Statistics

SSE	84005.2276	DFE	1901
MSE	44.1900	Root MSE	6.6476
R-Square	0.4927		

F Test for No Fixed Effects

Num DF	Den DF	F Value	Pr > F
34	1901	5.30	<.0001

Parameter Estimates

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|	Label
CS1	1	1.321026	1.2817	1.03	0.3028	Cross Sectional Effect 1
CS2	1	1.419826	1.2805	1.11	0.2677	Cross Sectional Effect 2
CS3	1	0.741384	1.2957	0.57	0.5672	Cross Sectional Effect 3
CS4	1	-1.56025	1.2627	-1.24	0.2167	Cross Sectional Effect 4
CS5	1	3.682643	1.3007	2.83	0.0047	Cross Sectional Effect 5
CS6	1	0.610306	1.2686	0.48	0.6305	Cross Sectional Effect 6
CS7	1	-0.5583	1.2768	-0.44	0.6620	Cross Sectional Effect 7
CS8	1	1.667658	1.2760	1.31	0.1914	Cross Sectional

						Effect 8
CS9	1	6.488195	1.2907	5.03	<.0001	Cross Sectional Effect 9
CS10	1	3.072645	1.2848	2.39	0.0169	Cross Sectional Effect 10
CS11	1	1.718647	1.2775	1.35	0.1787	Cross Sectional Effect 11
CS12	1	-1.76086	1.2696	-1.39	0.1656	Cross Sectional Effect 12
CS13	1	1.561311	1.2801	1.22	0.2228	Cross Sectional Effect 13
CS14	1	-1.53899	1.2696	-1.21	0.2256	Cross Sectional Effect 14
CS15	1	0.650567	1.2705	0.51	0.6087	Cross Sectional Effect 15
CS16	1	-2.77187	1.2722	-2.18	0.0295	Cross Sectional Effect 16
CS17	1	1.507845	1.2690	1.19	0.2349	Cross Sectional Effect 17
CS18	1	1.00148	1.2693	0.79	0.4302	Cross Sectional Effect 18
CS19	1	-3.03851	1.2649	-2.40	0.0164	Cross Sectional Effect 19
CS20	1	0.725828	1.2877	0.56	0.5730	Cross Sectional Effect 20
CS21	1	2.54333	1.2847	1.98	0.0479	Cross Sectional Effect 21
CS22	1	7.446843	1.2873	5.78	<.0001	Cross Sectional Effect 22
CS23	1	0.435398	1.2687	0.34	0.7315	Cross Sectional Effect 23
CS24	1	1.62728	1.2724	1.28	0.2011	Cross Sectional Effect 24
CS25	1	2.144232	1.2791	1.68	0.0938	Cross Sectional Effect 25
CS26	1	1.414897	1.3037	1.09	0.2779	Cross Sectional Effect 26
CS27	1	-0.62844	1.2699	-0.49	0.6208	Cross Sectional Effect 27
CS28	1	-0.16896	1.2714	-0.13	0.8943	Cross Sectional Effect 28
CS29	1	-0.07004	1.2756	-0.05	0.9562	Cross Sectional Effect 29
CS30	1	1.424127	1.2782	1.11	0.2654	Cross Sectional Effect 30
CS31	1	1.750387	1.2932	1.35	0.1760	Cross Sectional Effect 31
CS32	1	4.735976	1.2826	3.69	0.0002	Cross Sectional Effect 32
CS33	1	2.78158	1.2651	2.20	0.0280	Cross Sectional Effect 33
CS34	1	1.523636	1.2663	1.20	0.2290	Cross Sectional Effect 34
Intercept	1	-0.42583	5.5602	-0.08	0.9390	Intercept
L1yield	1	0.193726	0.0202	9.60	<.0001	
Time	1	0.837853	0.0415	20.19	<.0001	Time
Time2	1	-0.01013	0.000697	-14.52	<.0001	Time2
L1prec1	1	-1.04276	0.3475	-3.00	0.0027	
Prec2	1	-0.25456	0.4110	-0.62	0.5357	Prec2
Prec3	1	0.583003	0.2605	2.24	0.0253	Prec3
Prec4	1	0.266456	0.2410	1.11	0.2690	Prec4
L1prec1sq	1	0.058232	0.0523	1.11	0.2657	
prec2sq	1	-0.03025	0.0545	-0.56	0.5787	
prec3sq	1	-0.03308	0.0194	-1.71	0.0883	
prec4sq	1	-0.01673	0.0151	-1.11	0.2666	
DD1	1	0.012017	0.00574	2.09	0.0365	DD1
DD2	1	0.004523	0.00756	0.60	0.5496	DD2
dd1sq	1	-0.00001	3.836E-6	-3.84	0.0001	
dd2sq	1	-5.94E-7	2.752E-6	-0.22	0.8292	

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The TSCSREG Procedure

Dependent Variable: Yield Yield

Model Description

Estimation Method	RanOne
Number of Cross Sections	35
Time Series Length	56

Fit Statistics

SSE	85468.2853	DFE	1935
MSE	44.1697	Root MSE	6.6460
R-Square	0.4498		

Variance Component Estimates

Variance Component for Cross Sections	4.098495
Variance Component for Error	44.19002

Hausman Test for Random Effects

DF	m Value	Pr > m
15	32.24	0.0060

Parameter Estimates

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|	Label
Intercept	1	0.301537	5.4576	0.06	0.9559	Intercept
L1yield	1	0.208104	0.0200	10.40	<.0001	
Time	1	0.826544	0.0414	19.96	<.0001	Time
Time2	1	-0.01	0.000697	-14.35	<.0001	Time2
L1prec1	1	-0.97525	0.3460	-2.82	0.0049	
Prec2	1	-0.25881	0.4097	-0.63	0.5276	Prec2
Prec3	1	0.555198	0.2597	2.14	0.0326	Prec3
Prec4	1	0.315139	0.2404	1.31	0.1900	Prec4
L1prec1sq	1	0.052108	0.0521	1.00	0.3178	
prec2sq	1	-0.02864	0.0544	-0.53	0.5984	
prec3sq	1	-0.0315	0.0194	-1.63	0.1038	
prec4sq	1	-0.01902	0.0150	-1.27	0.2056	
DD1	1	0.011732	0.00571	2.05	0.0400	DD1
DD2	1	0.005079	0.00752	0.68	0.4997	DD2
dd1sq	1	-0.00001	3.823E-6	-3.77	0.0002	
dd2sq	1	-9.28E-7	2.741E-6	-0.34	0.73	

Regression Analysis Results for Wheat

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The TSCSREG Procedure

Dependent Variable: Yield Yield

Model Description

Estimation Method	FixOne
Number of Cross Sections	53
Time Series Length	57

Fit Statistics

SSE	91580.5762	DFE	2952
MSE	31.0232	Root MSE	5.5699
R-Square	0.6616		

F Test for No Fixed Effects

Num DF	Den DF	F Value	Pr > F
52	2952	18.27	<.0001

Parameter Estimates

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|	Label
CS1	1	-3.27111	1.0542	-3.10	0.0019	Cross Sectional Effect 1
CS2	1	4.581633	1.0558	4.34	<.0001	Cross Sectional Effect 2
CS3	1	0.319924	1.0536	0.30	0.7614	Cross Sectional Effect 3
CS4	1	-3.23996	1.0493	-3.09	0.0020	Cross Sectional Effect 4
CS5	1	1.450955	1.0560	1.37	0.1695	Cross Sectional Effect 5
CS6	1	-3.05709	1.0472	-2.92	0.0035	Cross Sectional Effect 6
CS7	1	-0.00617	1.0538	-0.01	0.9953	Cross Sectional Effect 7
CS8	1	-1.45247	1.0467	-1.39	0.1654	Cross Sectional Effect 8
CS9	1	9.992068	1.0743	9.30	<.0001	Cross Sectional Effect 9
CS10	1	3.700302	1.0720	3.45	0.0006	Cross Sectional Effect 10
CS11	1	2.929297	1.0725	2.73	0.0063	Cross Sectional Effect 11
CS12	1	-0.00056	1.0464	-0.00	0.9996	Cross Sectional Effect 12
CS13	1	-1.64959	1.0474	-1.57	0.1154	Cross Sectional Effect 13
CS14	1	0.297264	1.0538	0.28	0.7779	Cross Sectional Effect 14
CS15	1	-2.51002	1.0515	-2.39	0.0170	Cross Sectional Effect 15
CS16	1	2.444768	1.0542	2.32	0.0205	Cross Sectional Effect 16
CS17	1	-0.96893	1.0447	-0.93	0.3538	Cross Sectional Effect 17
CS18	1	9.229001	1.0691	8.63	<.0001	Cross Sectional Effect 18
CS19	1	-4.55783	1.0555	-4.32	<.0001	Cross Sectional Effect 19
CS20	1	4.522548	1.0598	4.27	<.0001	Cross Sectional Effect 20
CS21	1	-0.01852	1.0475	-0.02	0.9859	Cross Sectional

						Effect 21
CS22	1	-2.94325	1.0515	-2.80	0.0052	Cross Sectional Effect 22
CS23	1	3.387799	1.0544	3.21	0.0013	Cross Sectional Effect 23
CS24	1	-2.53672	1.0508	-2.41	0.0158	Cross Sectional Effect 24
CS25	1	-0.35082	1.0521	-0.33	0.7388	Cross Sectional Effect 25
CS26	1	-3.8718	1.0523	-3.68	0.0002	Cross Sectional Effect 26
CS27	1	1.04252	1.0496	0.99	0.3207	Cross Sectional Effect 27
CS28	1	1.506283	1.0502	1.43	0.1516	Cross Sectional Effect 28
CS29	1	-0.32854	1.0467	-0.31	0.7536	Cross Sectional Effect 29
CS30	1	-1.61967	1.0476	-1.55	0.1222	Cross Sectional Effect 30
CS31	1	-1.97763	1.0626	-1.86	0.0628	Cross Sectional Effect 31
CS32	1	3.273067	1.0602	3.09	0.0020	Cross Sectional Effect 32
CS33	1	-1.29169	1.0491	-1.23	0.2183	Cross Sectional Effect 33
CS34	1	7.814194	1.0634	7.35	<.0001	Cross Sectional Effect 34
CS35	1	0.011989	1.0501	0.01	0.9909	Cross Sectional Effect 35
CS36	1	3.27753	1.0529	3.11	0.0019	Cross Sectional Effect 36
CS37	1	5.296035	1.0641	4.98	<.0001	Cross Sectional Effect 37
CS38	1	0.940658	1.0658	0.88	0.3776	Cross Sectional Effect 38
CS39	1	9.135779	1.0824	8.44	<.0001	Cross Sectional Effect 39
CS40	1	0.098621	1.0706	0.09	0.9266	Cross Sectional Effect 40
CS41	1	5.334159	1.0707	4.98	<.0001	Cross Sectional Effect 41
CS42	1	-0.02346	1.0505	-0.02	0.9822	Cross Sectional Effect 42
CS43	1	-3.23003	1.0603	-3.05	0.0023	Cross Sectional Effect 43
CS44	1	-0.35301	1.0480	-0.34	0.7363	Cross Sectional Effect 44
CS45	1	-0.93609	1.0468	-0.89	0.3713	Cross Sectional Effect 45
CS46	1	6.989957	1.0583	6.60	<.0001	Cross Sectional Effect 46
CS47	1	3.686072	1.0562	3.49	0.0005	Cross Sectional Effect 47
CS48	1	3.102678	1.0652	2.91	0.0036	Cross Sectional Effect 48
CS49	1	10.59691	1.0749	9.86	<.0001	Cross Sectional Effect 49
CS50	1	9.773249	1.0675	9.16	<.0001	Cross Sectional Effect 50
CS51	1	3.046319	1.0486	2.91	0.0037	Cross Sectional Effect 51
CS52	1	3.030605	1.0491	2.89	0.0039	Cross Sectional Effect 52
Intercept	1	19.9142	3.7576	5.30	<.0001	Intercept
L1yield	1	0.15999	0.0156	10.29	<.0001	
Time	1	0.655387	0.0263	24.88	<.0001	Time
Time2	1	-0.00623	0.000440	-14.15	<.0001	Time2
L1prec1	1	0.277468	0.2075	1.34	0.1813	
Prec2	1	1.13054	0.2648	4.27	<.0001	Prec2

Prec3	1	1.804103	0.1674	10.78	<.0001	Prec3
Prec4	1	0.376567	0.1596	2.36	0.0183	Prec4
L1prec1sq	1	-0.07146	0.0289	-2.48	0.0133	
prec2sq	1	-0.15601	0.0344	-4.53	<.0001	
prec3sq	1	-0.09932	0.0121	-8.19	<.0001	
prec4sq	1	-0.03629	0.0101	-3.59	0.0003	
DD1	1	0.015574	0.00380	4.10	<.0001	DD1
DD2	1	-0.03005	0.00489	-6.14	<.0001	DD2
dd1sq	1	-0.00002	2.478E-6	-6.65	<.0001	
dd2sq	1	9.049E-6	1.732E-6	5.22	<.0001	

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The TSCSREG Procedure

Dependent Variable: Yield Yield

Model Description

Estimation Method	RanOne
Number of Cross Sections	53
Time Series Length	57

Fit Statistics

SSE	93164.7916	DFE	3004
MSE	31.0136	Root MSE	5.5690
R-Square	0.5715		

Variance Component Estimates

Variance Component for Cross Sections	14.51853
Variance Component for Error	31.02323

Hausman Test for Random Effects

DF	m Value	Pr > m
15	49.85	<.0001

Parameter Estimates

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|	Label
Intercept	1	20.34758	3.7139	5.48	<.0001	Intercept
L1yield	1	0.171931	0.0155	11.12	<.0001	
Time	1	0.648429	0.0263	24.64	<.0001	Time
Time2	1	-0.00619	0.000440	-14.06	<.0001	Time2
L1prec1	1	0.311669	0.2073	1.50	0.1328	
Prec2	1	1.15569	0.2646	4.37	<.0001	Prec2
Prec3	1	1.807367	0.1673	10.80	<.0001	Prec3
Prec4	1	0.400859	0.1594	2.51	0.0120	Prec4
L1prec1sq	1	-0.07474	0.0288	-2.59	0.0096	
prec2sq	1	-0.15757	0.0344	-4.58	<.0001	
prec3sq	1	-0.09922	0.0121	-8.18	<.0001	
prec4sq	1	-0.03681	0.0101	-3.64	0.0003	
DD1	1	0.016121	0.00379	4.25	<.0001	DD1

DD2	1	-0.0296	0.00488	-6.06	<.0001	DD2
dd1sq	1	-0.00002	2.475E-6	-6.74	<.0001	
dd2sq	1	8.935E-6	1.729E-6	5.17	<.0001	