Three Essays on the Economics of Climate Impacts on Agriculture

by

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Abstract

Global warming has been a hot issue lately all around world not only because it has been in increasing trend since 1980s but also affects many economic sectors as well as different aspect of human life. The three essays of this dissertation investigate the impacts of climate change on the agricultural sectors of the United States and the selected Asian countries using the pooled cross-section model and the panel analysis.

The first essay analyzes the impact of climate change on agricultural production in 13 Asian countries from 1998 and 2007. This study estimates a country-level fixed effect (FE) panel model for agricultural production using seasonal and annual climate variables as well as production input variables. According to Mendelsohn et al., (2000; 2004), high latitude countries that are currently cool will likely benefit from warming. However, regions those are already hot such as low latitude countries will be vulnerable to climate change. The results in this study show that higher summer temperatures and more precipitations increase agricultural production while higher fall temperature is harmful in South and Southeast Asia. On the other hand, higher annual temperature decreases agricultural production in Asian countries.

The second essay estimates the climate change effects on the U.S. agriculture using the pooled cross-section farm profit model mainly using the annual Agricultural Resource Management Survey (ARMS) data from USDA for the time period between 2000 and 2009 in the 48 contiguous States. For climate measure, growing season drought indices (the Palmer Drought Severity Index (PDSI) and Crop Moisture Index (CMI)) are applied to the analysis and both indices have a negative relationship with temperature. The estimates indicate that one unit increase in PDSI (CMI) leads to 5.5% (13.9%), 4% (9%), and 5% (14%) increase in farm profits for all farms, crop farms, and livestock farms.

In the third essay, I use a static labor supply model to estimate the impact of weather on the farmers' on-farm labor supply directly unlike the previous literature. The results suggest that there is an inverse U-shape relationship between temperature and farmers' labor supply. Farmers' labor supply is minimized between 50-70 degrees Fahrenheit. Consequently, it can be concluded that temperature is a substitute for labor until around 60 degrees. However, more labor is required after the temperature passes that threshold. Unlike temperature, the relationship between precipitation and labor supply is linear. The more precipitation a farm gets throughout the year, the more labor is supplied by the farmer. This is maybe because of the possibility that in my data set the observed precipitation may be already in the optimal range. The results show that precipitation and labor are complements.

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List of Abbreviations

AIC	Akaike Information Criterion
ARMS	Agricultural Resource Management Survey
CMI	Crop Moisture Index
FAO	Food and Agriculture Organization of United Nation
FE	Fixed Effect
GDP	Gross Domestic Product
IPCC	Intergovernmental Panel on Climate Change
LDCs	Less-Developed Countries
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
OLS	Ordinary Least Square
PDSI	Palmer Drought Severity Index
USDA	United States Department of Agriculture

Introduction

Global warming has been a hot issue lately all around the world since it affects many aspects. It might be the major concern to human being because warming will be directly related to food consumption and human health if it especially decreases agricultural production. Therefore, it is not surprising that global warming has been receiving a lot of people's attention. According to Oreskes (2004), 928 papers that have abstracts including "global climate change" were published in refereed scientific journals between 1993 and 2003. In fact, global warming has not been considered as a serious threat to human being in the past. This is because the average global temperature has been increased only by 0.5°C over the last hundred years.

Although global warming has been risen as a hot topic lately, its impacts also have been highly controversial among scientists, scholars, and policy makers. Intergovernmental Panel on Climate Change (IPCC) and the National Academy of Sciences have reported that most of observed warming is likely due to the results of human activities such as Greenhouse gas emission and warned that warming will be a serious threat in near future. On the other hand, policy-makers and media argued that climate change is highly uncertain (Oreskes, 2004).

However, NASA's Goddard Institute for Space Studies and the National Climatic Data Center reveal that warming has been in increasing trend since the 1980s. The National Oceanic and Atmospheric Administration (NOAA) also reports that seven of the eight warmest years on record have occurred since 2001 and the 10 warmest years have all occurred since 1995.

Previous studies also suggest that global warming has been in increasing trend since the1980s although the Earth's average surface temperature has increased by about 1.2 to 1.4°F in the last 100 years (Mendelsohn, 2007). Despite these facts, there still have been different forecasting and extensive debates over the concerns about the impacts of climate change. However, a broad consensus among climate scientists is that there would be drastic temperature increases and change in precipitation patterns due to greenhouse gas effect (Houghton *et al.*, 2001).

According to the latest report from NOAA, the recent warmth has been greatest over North America and Eurasia between 40 and 70°N although the warming has not been occurred in same fashion worldwide. That is, most of European countries and U.S. states except for the Southern states have been affected most by the recent warming. Therefore, climate change might be a major concern to humanity since it affects many economic sectors as well as different aspect of human life. Negative impacts of climate change on the agricultural sector will be especially dangerous since agriculture is directly related to food security and human health.

The main objective of this dissertation is to examine the impacts of climate change on the agricultural sector. The effect of climate change can be shown in agricultural output especially in crop production since it is directly affected by weather.

In Chapter 1, I estimate the impacts of weather variables on the agricultural production in selected Asian countries using the production function. The reason I decided to investigate the impacts of climate change in Asian countries is because about 60% of world population live in Asia and most of Asian countries still heavily rely on agriculture. Therefore, the impacts of climate change on the agricultural production will be very critical for food security in Asian countries.

In Chapter 2, I investigate the impacts of weather on the agricultural profits in the United States. As mentioned above, most parts of the U.S. have been affected most by the recent warming. In addition, the U.S. is the top exporter of major agricultural products such as corn, soybean, wheat, and pork according to FAOSTAT. Therefore, if weather negatively affects the U.S. agricultural production, it will cause a big problem not only in the U.S. economy but also in world food security. In previous studies, the production function and hedonic approach are two most widely used methods to estimate the climate impact on agriculture (Deschenes and Greenstone, 2007). However, both the production function and hedonic approach have weaknesses to properly estimate the effects of climate change as Deschenes and Greenstone (2007) address. Due to the weaknesses and disadvantages of the conventional estimations, they apply the profit function as a possible solution to properly estimate the impacts of climate change. In this analysis, I also apply the profit function for unbiased estimation.

In Chapter 3, the impact of weather on the farmers' on-farm labor supply is analyzed using a static labor supply model for the estimation. Weather conditions do have a crucial impact on the demand side of labor market in the agricultural sector, as well. One mechanism through which weather influences labor demand is through the farm profits. This is indirectly demonstrated by the previous research. Farmers or their family members tend to increase their labor supply in *off-farm* work under unfavorable weather conditions in order to maintain their consumption levels (Kochar 1999; Rose 2001; Cameron and Worswick 2003; Ito and Kurosaki 2009). That is, these researchers implicitly argue that when the weather conditions are not ideal for farm production, the farmer's family seek employment elsewhere, and reduces the amount of time they allocate on on-farm work.

In this paper, I test the same hypothesis in a more direct way by investigating the relationship between farm operator's *on-farm* labor supply and weather conditions. The research question in this paper is whether the farmers actually reduce the time spent on on-farm work. This is the first paper that investigates the relationship between weather conditions and individual's on-farm labor supply.

Chapter 1. The Impact of Climate Change on Agricultural Production in Asian Countries: Evidence from Panel Study

Abstract

Global warming has been an issue lately in many aspects because it has been in increasing trend since 1980s. Climate change might be a major concern to humanity since it affects many economic sectors as well as different aspects of human life. Negative impacts of climate change on agricultural sector will be especially dangerous since agriculture is directly related to food security and human life. This paper analyzes the impact of climate change on agricultural production in 13 Asian countries from 1998 and 2007. This study estimates a country-level fixed effect (FE) panel model for agricultural production using seasonal and annual climate variables as well as production input variables. The results show that higher summer temperatures and more precipitation increase agricultural production while higher fall temperature is harmful in South and Southeast Asia. On the other hand, higher annual temperature decreases agricultural production in Asian countries.

1. Introduction

According to previous studies, global warming has been an increasing trend since the1980s although the Earth's average surface temperature has increased by about 1.2 to 1.4°F in the last 100 years (Mendelsohn, 2007). Based on the National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA) data, the eight warmest years on record have all occurred since 1850 with the warmest year being 2005 since 1998. Global temperature continued to rise rapidly in the past decade. In addition, the global warming trend of 0.15-0.20°C per decade that began in the late 1970s has not decreased (Goddard Institute for Space Studies, GISS, 2010).

However, there is surprising absence of the impacts study on climate change (Mendelsohn, 2007). A broad consensus among climate scientists is that there would be drastic temperature increases and change in precipitation patterns. Therefore, climate change might be a major concern to humanity since it affects many economic sectors as well as different aspect of human life. Negative impacts of climate change on the agricultural sector will be especially dangerous since agriculture is directly related to food security and human health. This paper examines whether increase in temperature negatively affects the agricultural production in the Asian countries. If climate change negatively impacts agricultural production, it will cause big problem in world food security because the major agricultural product of the most Asian countries is paddy rice and it is an important dietary component more than half of the world’s human population.

2. Climate Change

A broad consensus among climate scientists is that there would be drastic temperature increases and change in precipitation patterns due to the greenhouse gas effect (Houghton *et al*., 2001). According to the estimation by the NASA's Goddard Institute for Space Studies and the National Climatic Data Center, global warming has been increasing since the1980s. Figure 1 presents the annual average global surface temperature anomalies degrees in Fahrenheit between 1901 and 2010.[1] Temperature has been rapidly increasing in last 25 years. Houghton et al. (2001) predicted that further emissions of greenhouse gases will cause temperatures to increase 1.5◦C to 5.8◦C and precipitation patterns to shift by 2100. Mendelsohn (2007) argues that future climate change may have very different effects from the past climate change since future climate changes are expected to be much larger.

As a result of these studies, global warming has become a significant issue lately. The impact of future climate change on several sectors such as agriculture, forestry, water, energy, ecosystem, and health has been subject to much controversy [Pearce et al. (1996); Watson et al. (1996); McCarthy et al. (2001)]. Specifically, authors have conflicting findings with respect to the impact of climate change on the sectors mentioned above. This paper aims at shedding light on part of this ambiguity by investigating the impact of rising temperature and changes in precipitation on agricultural production

3. Agriculture in Asia

Table 1 shows the list of countries included in the analysis with GDP share of agriculture and their major agricultural products in 2008. In Asia, agriculture is still a crucial part of

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[1] The unit of temperature is degrees in Fahrenheit in Figure.1 in order to show variation although degrees in Celsius are used as the unit of temperature variable in the analysis.

economy in most countries although many countries have become less dependent on agriculture in terms of the GDP share of agriculture especially in East Asian countries such as China, Japan, and South Korea due to the fast economic growth. According to the FAOSTAT, the share of agricultural output in GDP fell from 35% to 19% in East Asia from 1970 to 1991. The agricultural share of GDP also declined from 44% to 31% in South Asia although the decline rate is smaller than that of the East Asian countries. In rapidly growing economies in Southeast Asia such as Indonesia, Thailand, and Malaysia, by 1991 the share of agricultural output in GDP was less than half of its 1970 level. However, some countries such as Cambodia with 34% GDP share of agricultural output, Laos with 41%, Myanmar with 54%, and Nepal with 38% in 2008 still heavily rely on agriculture. Figure 2 shows the major agricultural products in Asia in 2008 with China and India being the 2 biggest agricultural producers in most products. As it is shown in both Table 1 and Figure 2, paddy rice is the most important agricultural product in Asia since it is the major product in almost all Asian countries and 9 out of top 10 world rice producers are Asian countries. The reason that mass rice production is limited to certain areas such as Asian countries is due to the fact that most of them have the ideal climate condition for rice production such as availability of water, suitable soil types, and high average temperatures especially for the growing season (USDA-ERS). That is, rice cultivation is well suited to regions or countries with high average temperatures and high rainfall. In addition, low labor cost is another factor since the cultivation is mostly labor intensive in many regions. This explains why Asian countries are major rice producers and rice is the most important crop in Asia. According to Mendelsohn et al., (2000; 2004), high latitude countries that are currently cool will likely benefit from warming; on the other hand, regions that are already hot such as low latitude countries will be vulnerable to climate change. Therefore, temperature change will negatively affect agricultural production in most Asian countries especially in the Southeastern region since most countries are located in the tropical region as presented in Table 2.

4. Climate Change Impacts on Asian Agriculture in Literature

There has been surprisingly little research of the climate change impacts on Asian agriculture although Asian countries will be vulnerable to the climate change as Mendelsohn et al. (2000; 2004) argue above. Moreover, following factors also contribute to the climate vulnerability. First, most Asian countries especially less developed countries (LDCs) still heavily depend on agriculture. In addition, China and India are one of the top producers in the world in corn, rice, and wheat while Thailand and Indonesia are top exporters to the world in rice and palm oil (FAOSTAT).[2] Therefore, a possible negative effect of climate change on the agricultural sector would be a big concern not only for the economy but also for domestic and world food security.

Most previous research mainly employs the simulation model to estimate the effect of climate change in Asian countries (see, for example, Matsui and Horie 1992; Horie et al. 1995b; Mathauda et al. 2000; Mendelsohn 2005; Basak 2009). The simulation method has been extensively used in climate impact research because of its advantage that climate variables such as temperature, precipitation, and CO_2 level can easily be controlled and yield outcomes under different controlled conditions. Although the impact of climate change varies by regions even within a country, it is commonly found that an increase in temperature negatively affect crop production in Asia. Mathauda et al. (2000) find that rice production in India is expected to decrease by about 3% to 8% if temperature increases by 1- 2°C. Basak (2009) also argue that rice

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[2] Although countries like China and India are prominently listed as top producers in many agricultural products they are not the top exporters. This should not be surprising because most productions are used internally for feeding their large population.

yield in Bangladesh will decrease by about 3 % to 14 % when the maximum temperature increases by 2°C. Mendelsohn (2005) estimates the impact of climate change on Southeast Asian agriculture for 2100. The results suggest that net revenues decline by about $60 billion to $200 billion per year which is equivalent to 11% and 39% loss in agricultural GDP if temperature increases by 3-4°C.

Mendelsohn and Dinar (1999) and Seo et al. (2005) employ the cross-sectional model (also called the Ricardian method) to estimate the climate change impact in addition to the simulation model. According to Mendelsohn and Dinar (1999), the Ricardian method has its advantage that the estimate accounts for farmers' adaptation in response to a change in climate. Although farmers' adaptation mitigates a negative impact of climate change, the agricultural production is predicted to be decreased in India (Mendelsohn and Dinar 1999) and Sri Lanka (Seo et al. 2005) due to the temperature increase.

5. Data & Methodology

The empirical analysis utilizes cross-sectional time series (panel) data that is based on 13 Asian countries for the time period between 1998 and 2007. Due to the unavailability of the data for a few countries, some observations are missing. Therefore, the data set is unbalanced. The sample of countries include China, India, Indonesia, Thailand, Philippines, Japan, Pakistan, South Korea, Nepal, Sri Lanka, Laos, Malaysia, and Myanmar.

Temperature is in Celsius and *Precipitation* is in millimeters. These climate variables are obtained from the NOAA Satellite and Information Service, National Environmental Satellite, Data, and Information Services (NESDIS). Variables Winter Temp (Rain), Spring Temp (Rain), Summer Temp (Rain) and Fall Temp (Rain) are the temperatures (precipitation) in the corresponding season.

The economic variables include production, labor, irrigation, machinery, and fertilizer. These variables are obtained from the Food and Agriculture Organization of United Nation Statistics Division (FAOSTAT). Production is the net agricultural production in a country. It is constructed using 1999-2001 average international commodity prices. Therefore the changes in this variable are due to the change in production. Labor is economically active population in agriculture. Irrigation measures the total area equipped for irrigation in 1000 Ha. Machinery denotes the number of machinery in use in agricultural production. Fertilizer is the consumption of fertilizer in agriculture. It is measured in 1000 tons. The summary of the descriptions is provided in Table 3.

5.1. Conceptual model

In order to empirically estimate the impact of climate change, most previous research employs either the production function or hedonic approach (Deschenes and Greenstone, 2007). The hedonic approach is also called the Ricardian method. It directly measures the effect of weather on land values and has been predominant in the previous literature (Mendelsohn, Nordhaus, and Shaw 1994, 1996; Mendelsohn and Dinar 1999; Schlenker, Wolfram, Hanemann, and Fisher 2005; Mendelsohn 2007). However, the disadvantage of hedonic approach is that the land value may not reflect the discounted value of land rents. Schlenker et al. (2005) also argue that the hedonic approach will be inappropriate if there are endogenous price changes since agricultural prices are assumed to be constant in the model. The production function approach also has been widely used to estimate the effect of climate change in prior research (Kalirajan 1990; Nordhaus 1991; Cline 1992; Howarth and Norgaard 1992; Turvey 2001). However, it has the weakness that farmer's adaptation s in response to climate change are constrained in the estimation. In spite of its weakness, the production function is the most appropriate method in this analysis because we use aggregated country-level dataset due to the limited availability of dataset. Finding land-value data or its good proxy for all sample countries to employ hedonic approach is also very difficult.

Following Turvey (2001)[3], the Cobb-Douglas production function is employed and it takes the following form:

where Y represents the net agricultural production. Calculation of the outcome variable involves weighting the production quantities of each commodity by 1999-2001 average international commodity prices and adding them up for each year. The unit of production is “international dollars” rather than production quantity or local currency.[4] The international commodity prices are used because of two reasons. First, it avoids the complexities associated with the use of exchange rates for obtaining aggregates. Secondly, it facilitates international comparative analysis of productivity at the national level. A is an intercept multiplier.

L represents the total number of economically active population in agriculture. M stands for the total number of machines in use in agriculture. I and F denote country averages of the total area equipped for irrigation in 1000 Ha and the total consumption of fertilizer in agriculture in 1000 tons, respectively.

C is the vector of climate variables. As mentioned in the introduction, the most important measures of climate are temperature and precipitation. For temperature and precipitation, mean temperature and rainfall of winter season (December, January, and February), spring season

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[3] Turvey (2001) only includes rainfall and heat as input variables in the log-linear Cobb-Douglas production function.

[4] FAO explains that the international prices, expressed in “international dollars” in data, are derived using a Geary-Khamis formula for the agricultural sector. This method assigns a single price to each commodity. For example, one metric ton of wheat has the same price regardless of the country where it was produced.

(March, April, and May), summer season (June, July, and August), and fall season (September, October, and November) are included in the regressions.

The list of countries and their geographical and climatic zones are presented in Table 2. Table 3 shows definitions of the variables used in the model.

5.2. Econometric Model

Following Turvey (2001), the climate variables enter in levels into the regression.[5] It is easier to interpret the coefficients of climate variables rather than seeing the effects in percentage change (elasticity). However, the economic inputs in the production function are in the natural logarithm because estimating elasticity is more conventional way to analyze the traditional production inputs. Therefore, the agricultural production model used in the analysis is outlined below:

$$=$$

After taking natural logarithms of both sides, the fixed effect (FE) panel model becomes:

$$=$$

where C_1 is the vector of climate variables and C_2 is the vector of squared climate variables. Inclusion of both the linear and quadratic terms permits capturing the possible non-linear relationship between the agricultural production and climate variables. L, I, M, and F represent labor, irrigation, machinery, and fertilizer respectively. μ is the error term. Hereinafter, this empirical specification will be referred to as Model 1.

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[5] The climate variables are also estimated in levels in the hedonic approach (the Ricardian method). For example in Mendelsohn et al. (1994).

Another version of the specification mentioned above is used in the empirical analysis. Specifically, the natural logarithm of the dependent variable is regressed on the natural logarithms of all control variables including the climate variables (Model 2). This model is a modified translog production function where only substitutability of labor and capital is assumed. In other words, interaction and square terms of labor and machinery variables are included in Model 2. Put differently, since weather inputs as well as irrigation and fertilizer are less likely to be substitutes/complements with capital and labor, interactions of these variables with capital and labor are not included in Model 2.

In essence, Model 1 is the simple version, whereas the translog is more sophisticated and theoretically plausible.

6. Results

Tables 5A and 5B show the regression results of fixed effect panel analysis for models 1 and 2, respectively.[6] Model 1 (Table 5A) analyzes the impact of seasonal climate variables and production input variables on agricultural production in Southeastern Asian countries. I first perform a specification test using Akaike Information Criterion (AIC) for four different versions of Model 1. Specifically, column 1 of Table 5A presents results of the model in which all climate variables and their squared terms as well as the production inputs are included. Results in columns 2-4 demonstrate a restricted version of the model in column 1. In Column 2 only the main effects of the climate variables are included. Column 3 (column 4) includes only

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[6] For Model 1 (column 1 of Table 5A), Hausman test rejects the null hypothesis that the random effect model is appropriate (chi2 (15) = 84.70 and Prob>chi2 = 0.000) and thus the fixed effect model is used. Modified Wald test is also performed in order to test the existence of heteroskedasticity. The test rejects the null hypothesis that variance is homoskedastic with the following result: chi2 (10) = 152.45 and Prob>chi2= 0.0000. Also, the Wooldridge test rejects the null hypothesis that there is no first-order autocorrelation (F (1, 9) = 6.171 and Prob>F= 0.0348). Due to the presence of heteroskedasticity and autocorrelation, robust standard errors are used in the fixed effect model.

temperature (only precipitation) variables. According to the AIC, the model in the first column (that includes all variables) is better than the others. Consequently, I will focus on the model in column 1 in my analysis.

In Model 1 (column 1 of Table 5A), China, Japan, and Korea are not included because they are located in the temperate region while other countries included in the model are located in tropical region in Asia.[7] A quadratic term of each climate variable is included in order to capture the possible non-linear relationship. The regression results show that the coefficients of summer and fall temperatures as well as the summer precipitation are significant at 10% level with a positive sign. Square terms of these significant variables are also significant at 10% with a negative sign. The coefficients of other climate variables are insignificant. Marginal impacts and elasticities of seasonal climate variables in Tables 6 and 7are obtained from the estimates of Model 1. The annual elasticity of climate variables is calculated with estimates of Model 2.

The coefficients of all production input variables indicate the elasticities since both production and input variables are in natural logarithms. As expected, most input variables are significant in the model. Irrigation is significant at 1% and has a positive impact on production. The fact that irrigation's effect on production is the greatest among all the factors of production implies that providing sufficient water is crucial for agricultural, especially rice, production in tropical Asian countries. In Asian countries, rice is mostly cultivated in flooded fields which require sufficient water all the time. The results show that agricultural production increases by about 0.9% when irrigation equipped area increases by 1%, holding other variables constant. This is almost a one-to-one correspondence.

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[7] Major distinctive characteristics of tropical Asian countries are year-around warm weather and two monsoon seasons: Southwest monsoons (from June through September) and Northeast monsoons (from December to early March). These two factors enable crop cultivation more than twice a year in most tropical Asian countries. Monsoons are especially important in South Asian agriculture since most crops are heavily dependent on rainfall and most countries have insufficient irrigation system.

Machinery is positive and significant at 10% level. When machinery is increased by 1%, production increases by about 0.1%. Fertilizer is also positive and significant at 5% level. A 1% increase in fertilizer use will lead to an increase in production by 0.2%. Although agriculture is very labor intensive in most Asian countries, labor is insignificant in the model. This result could be explained by the already saturated labor structure in Asian countries. Specifically, there may be already sufficient labor in agricultural sector, since agricultural population is very high and labor cost is very low in most developing Asian countries. This is consistent with the findings of Pender and Gebremedhin (2008) who found that the impact of human labor is quantitatively small and statistically insignificant in crop production in Ethiopia suggesting that additional labor yields little positive impact on crop production because of labor surplus. Cornia (1985) also found that a labor input on crop production is insignificant especially in the South and Southeast Asia because the marginal product of labor under the surplus conditions is very low.

Model 2 (Table 5B) differs from Model 1 (Table 5A) in four ways.[8] First, instead of seasonal climate variables, annual averages are used which captures the overall climate change effects on agricultural production regardless of the season. Secondly, all control variables are in natural logarithms. In addition, Model 2 is a modified translog production function that has squared terms and the interactions of the labor and capital. This is because in this modified translog production function only substitutability of labor and capital is assumed. In other words,

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[8] For the model 2 (Column 1 of Table 5B), Hausman test also rejects the null hypothesis that random effect model is appropriate; chi2 (8) = 51.61 and Prob>chi2 = 0.000. Therefore, the test suggests using fixed Effect (FE) model over random effect (RE) model. Modified Wald test is done in order to test the existence of heteroskedasticity. The test rejects the null hypothesis that variance is homoskedastic with the following result; chi2 (13) = 3780.58 and Prob>chi2= 0.0000. For testing autocorrelation, Wooldridge test rejects the null hypothesis that there is no first-order autocorrelation with following result; F (1, 12) = 13.533 and Prob>F= 0.0032. As for the model1, robust standard errors are used in the fixed effect model due to the presence of heteroskedasticity and autocorrelation.

interaction and square terms of labor and machinery variables are included in Model 2. Since weather inputs as well as irrigation and fertilizer are less likely to be substitutes/complements with capital and labor, interactions of these variables with capital and labor are not included in Model 2. Finally, linear country trends are included in the regressions as control variables. In this model, temperature is expected to have a negative impact on agricultural production. Precipitation is expected to have a positive impact since agriculture in most countries heavily relies on rainfall because of insufficient irrigation.

Similar to the analysis of model 1, AIC is utilized to select the best specification. Four different versions of model 2 are run. Column 1 of Table 5B shows results of the model in which all climate variables, their squared terms as well as the production inputs are included. Results in columns 2-4 provide restricted versions of the specification in column 1. In Column 2 only the main effects of the climate variables are included. Column 3 (column 4) includes only temperature (only precipitation) variables. For model 2 (Table 5B), the specification in the first column (that includes all variables) is better than the others according to the AIC. As a result, I will focus on the model in column 1 of Table 5B.Annual temperature and its squared term are significant at 10% and 5% levels, respectively. This suggests that temperature has a positive impact on production and this positive impact is decreasing as temperature increases. Rainfall does not significantly influence production at conventional levels.

The sum of the coefficients on the factors of production variables is -0.242 (1.629).[9] It can be concluded that the agricultural production function exhibits decreasing returns to scale. For example, doubling the amount of inputs increases the production less than a proportional amount. The coefficients on machinery and its squared term are highly significant. The

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[9] Climate variables are not included in the returns to scale calculation. This is because climate variables are considered to be a part of the technology parameter in the production function.

coefficients of capital indicate that there are diminishing returns to capital in agricultural production. On the other hand, the impact of labor on production is not statistically different than zero. As mentioned earlier in the results of model 1, insignificant impact of labor in the analysis can be explained by labor abundance in Asian countries (Pender and Gebremedhin, 2008; Cornia, 1985). The interaction of labor and machinery is insignificant, and therefore, capital and labor are not substitutable inputs in agricultural production in Asia. Among the remaining inputs, the irrigation-equipped area is positively and significantly associated with agricultural production. This result shows that irrigation plays a crucial role in Asian agriculture regardless of climate zone. Fertilizer-usage becomes insignificant in Model 2, although it was a significant determinant in Model 1 where China, Japan, and South Korea are not included (Model 2 includes China, Japan, South Korea).

6.1. Marginal Impact Analysis

The expected marginal effect of climate variables on agricultural production evaluated at the mean are calculated using following equation for model 1;

$$\frac{\quad}{\quad} =$$

where are linear term coefficients and are quadratic term coefficients for temperature and precipitation variables. and) are sample means of temperature and precipitation variables. The elasticities of the climate variables are calculated according to

$$\frac{\quad}{\quad} =$$

Table 6 presents the results of these calculations. An increase in temperature and precipitation during the summer season raises agricultural production in tropical Asian countries.

However, marginal effect of temperature during the fall season influences agricultural production negatively.

In Table 7, the elasticities of climate variables in the models 1 and 2 are displayed. The results indicate that an increase in temperature and precipitation during the summer increase agricultural production in tropical Asian countries. When the summer temperature and precipitation are increased by 1%, production increases by 1.031% and 0.002%, respectively. However, increasing temperature during the fall season reduces production. If temperature is increased by 1% in the fall, production is reduced by 0.892%. The last column of Table 7 shows elasticities of annual climate variables. Warmer temperature significantly decreases agricultural production in Asia. When annual mean temperature increases by 1%, average agricultural production decreases by 0.253%. The mean agricultural production is I$ 13,072,221,000, and the mean annual temperature is 22.982°C. Consequently, a one degree Celsius increase in annual mean temperature decreases agricultural production by about I$ 130 million in Asian countries. On the other hand, changes in rainfall do not significantly influence output, possibly due to the nature of rice production.

The analysis in this paper focuses on the production effects of climate variables. However, using the demand elasticities reported in the literature, the price effects of the climate variables can also be simulated. I assume that there is only an indirect effect of climate variables on price through production. Specifically, I use the equation below to simulate the influence of a change in climate variables on price:

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where P, Q and T stand for price, quantity and temperature, respectively. and are the sample means. denotes own price elasticity of demand.

The production measure used in this paper is an aggregation of all agricultural products. However, I use data on rice because of two reasons. First, the price elasticity of demand of such an aggregated production measure is not available. Secondly, the most dominant agricultural product in Asia is rice and therefore, I expect that the price elasticity of demand is mainly driven by that of rice. I use the demand elasticities in Huang and David (1993) who report that the average price elasticity of demand for rice is -0.7 in the countries that are included in this analysis. The average price of rice per ton is about $458, and the average annual temperature is 23 degrees Celsius. Using these statistics and the equation above, the impact of temperature on price is estimated to be $6.51. This is significant at 5% level.

Using the estimated effect of temperature on price and quantity, predictions about its influence on revenue (value of production, production volume) can be made. Specifically, the equation below can be used to project the effect of temperature on revenue:

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where R stands for revenue. As mentioned above, this equation assumes that temperature affects price only through its impact on quantity. The back of the envelope calculation indicates that the effect of temperature on price is about $80 million.

7. Conclusion

This paper analyzes the impact of climate change on the agricultural production using fixed effect country-level panel analysis in Asian countries from 1998 and 2007. According to my best knowledge, this is the first paper that employs panel data analyses in Asian countries instead of simulation techniques. The results show that an increase in temperature and precipitation during the summer increases agricultural production in tropical Asian countries while increasing temperature during the fall season reduces production. This result conflicts the conventional wisdom. Specifically, in summer months (generally growing season), when it is highly warm, an increase in the temperature should be harmful to most crops. In addition, in fall months (generally harvest season), a warmer temperature is beneficial for agricultural production. However, my results indicate that 30 and 18 degrees Celsius are the optimal temperatures for agricultural production in summer and fall seasons, respectively. The mean of the summer and fall temperatures are 27 and 25 degrees Celsius. Therefore, an increase (decrease) in (fall) summer temperature from the base line of 27 (25) degrees Celsius is beneficial to the crops.

The results that utilize annual climate variables suggest that an increase in annual temperature significantly decreases agricultural production in Asia. Rainfall's impact on agricultural production is statistically not different from zero. These results are consistent with the findings of the previous papers that employ simulation techniques (Iglesias et al., 1996; Matthhews et al., 1997).

As many studies indicate, the Asian agriculture will be very vulnerable to climate change. Since the Asian countries are major world rice producers and consumers, climate change might be a major concern to their economies and well-being. Therefore, adaptation to climate change will be necessary such as developing new varieties that are more tolerant to higher temperature.

The results presented in this paper are economically significant and alarming. If the average temperature continues to increase as it has been since 1980, the average annual temperature will be about 108 degrees Fahrenheit in 2030 (with a growth rate of 1.5% per year). This increase in annual temperature corresponds to about 35% increase in annual temperature in 2030 from the 2010 annual temperature. According to the estimates reported in this paper, I project that such an increase in the annual temperature will lead to about 9% loss of agricultural production.

Table 1
The list of Countries and Agricultural Commodities

Country	GDP Share of Agriculture in 2008 (%)	Major Products by Rank in 2008
China	11.7	Rice, Pork, Vegetables, Wheat, Eggs, Chicken, Beef, Cotton
India	16.6	Rice, Milk, Wheat, Sugar, Vegetables, Cotton, Potatoes
Indonesia	12.4	Rice, Palm Oil, Chicken, Coconuts, Rubber, Maize, Cassava
Japan	1.5	Rice, Eggs, Milk, Chicken, Pork, Beef, Vegetables
Laos	41.2	Rice, Vegetable, Tobacco, Maize, Beef, Pork, Coffee
Malaysia	8.6	Palm Oil, Chicken, Palm Kernels, Rubber, Rice, Eggs, Pork
Myanmar	53.9	Rice, Chicken, Beans, Vegetables, Sesame Seed, Pork
Nepal	38.0	Rice, Milk, Vegetables, Potatoes, Wheat, Maize, Ginger
Pakistan	19.6	Milk, Wheat, Cotton, Rice, Beef, Sugar, Chicken, Cottonseed
Philippines	14.1	Rice, Pork, Coconuts, Bananas, Chicken, Sugar, Eggs, Fruits
South Korea	3.2	Rice, Pork, Vegetables, Milk, Chicken, Beef, Eggs, Cabbages
Sri Lanka	16.3	Rice, Tea, Coconuts, Chicken, Plantains, Pepper, Rubber
Thailand	10.8	Rice, Cassava, Rubber, Sugar, Chicken, Pork, Beef, Mangoes

Sources: Food and Agriculture Organization of United Nation Statistics Division (FAOSTAT), CIA- The World Factbook

Table 2
Geographical and Climate Zones of Countries

Country	Geographical Region	Climate Zone
China	Eastern	Extremely Diverse tropical in south to subarctic in north
India	Southern	Varies from tropical monsoon in south to temperate in north
Indonesia	South-Eastern	tropical; hot, humid; more moderate in highlands
Japan	Eastern	varies from tropical in south to cool temperate in north
Laos	South-Eastern	tropical monsoon; rainy season (May to November); dry season (December to April)
Malaysia	South-Eastern	tropical; annual southwest (April to October) and northeast (October to February) monsoons
Myanmar	South-Eastern	Tropical; southwest (June to September) and northeast (December to April) monsoons
Nepal	Southern	varies from cool summers and severe winters in north to subtropical summers and mild winters in south
Pakistan	Southern	mostly hot, dry desert; temperate in northwest; arctic in north
Philippines	South-Eastern	tropical marine; northeast monsoon (November to April); southwest monsoon (May to October)
South Korea	Eastern	temperate, with rainfall heavier in summer than winter
Sri Lanka	Southern	tropical monsoon; northeast monsoon (December to March); southwest monsoon (June to October)
Thailand	South-Eastern	tropical; rainy, warm, cloudy southwest monsoon (mid-May to September); dry, cool northeast monsoon (November to mid-March)

Source: Climate-zone.com

Table 3
Variable Definitions

Production	Net agricultural production (base: 1999-2001 average international commodity prices)
Labor	Total number of economically active population in agriculture
Irrigation	The total area equipped for irrigation in 1000 Ha
Machinery	Total number of machinery in use in agriculture
Fertilizer	Total consumption of fertilizer in agriculture (unit: 1000 ton)
Winter Temp	Mean temperature of December, January, and February (unit: degrees in Celsius)
Spring Temp	Mean temperature of March, April, and May (unit: degrees in Celsius)
Summer Temp	Mean temperature of June, July, and August (unit: degrees in Celsius)
Fall Temp	Mean temperature of September, October, and November (unit: degrees in Celsius)
Winter Rain	Mean precipitation of December, January, and February (unit: mm)
Spring Rain	Mean precipitation of March, April, and May (unit: mm)
Summer Rain	Mean precipitation of June, July, and August (unit: mm)
Fall Rain	Mean precipitation of September, October, and November (unit: mm)
Annual Temp	Annual mean temperature (unit: degrees in Celsius)
Annual Rain	Annual mean precipitation (unit: mm)
*Temp*Rain*	Interaction variable of annual mean temperature and precipitation

Table 4
Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Production	92	9830497	4.242	616614.9	170000000
Winter Temp	92	22.612	5.208	11.1	27.689
Spring Temp	92	27.115	2.451	19.133	30.492
Summer Temp	92	27.860	1.755	23.8	31.875
Fall Temp	92	25.899	2.286	16.133	28.311
Winter Precip	92	107.854	114.020	0	475.945
Spring Precip	92	123.264	64.597	6.567	280.419
Summer Precip	92	223.358	134.300	27.771	690.983
Fall Precip	92	187.502	87.649	16.917	398.901
Irrigation	92	2583.757	5.496	189.995	63831.37
Labor	92	13266.54	4.267	1662.371	258590.2
Machinery	92	53530.13	9.403	1069.557	3150274
Fertilizer	92	695.061	8.559	4.563	22561.5
Production	122	13072221	4.840	616614.9	355000000
Annual Temp	122	22.982	5.512	13.012	28.703
Annual Precip	122	144.238	67.354	16.249	286.688
Temp*Precip	122	3494.224	2017.392	219.435	7694.334
Irrigation	122	3053.366	5.755	189.995	63831.37
Labor	122	13226.8	6.025	1526.908	498819.7
Machinery	122	103156.2	10.095	1069.557	3150274
Fertilizer	122	1046.284	8.802	4.563	52944.53

Table 5A
Regression Analysis Results
Dependent Variable: Net Agricultural Production (1,000 I$)

	(1)	(2)	(3)	(4)
	All variables	Only Linear Terms	Only Temperature variables	Only Precipitation variables
Winter Temp	0.073	0.018	0.062	
	(0.052)	(0.014)	(0.045)	
Spring Temp	0.216	-0.027	0.147	
	(0.148)	(0.021)	(0.116)	
Summer Temp	0.737*	0.015	0.687	
	(0.382)	(0.020)	(0.390)	
Fall Temp	0.138*	-0.027	0.098	
	(0.070)	(0.019)	(0.063)	
Winter Prec	0.000	0.000		0.001
	(0.001)	(0.000)		(0.001)
Spring Prec	0.001	-0.000		0.000
	(0.001)	(0.000)		(0.001)
Summer Prec	0.001*	-0.000		0.001
	(0.000)	(0.000)		(0.000)
Fall Prec	0.000	-0.000		0.000
	(0.000)	(0.000)		(0.001)
Winter Temp Sq	-0.001		-0.001	
	(0.001)		(0.001)	
Spring Temp Sq	-0.005		-0.003	
	(0.003)		(0.002)	
Summer Temp Sq	-0.012*		-0.011	
	(0.006)		(0.006)	
Fall Temp Sq	-0.004*		-0.003	
	(0.002)		(0.002)	
Winter Prec Sq	-0.000			-0.000
	(0.000)			(0.000)
Spring Prec Sq	-0.000			-0.000
	(0.000)			(0.000)
Summer Prec Sq	-0.000*			-0.000
	(0.000)			(0.000)
Fall Prec Sq	-0.000			-0.000
	(0.000)			(0.000)
Log Irrigation	0.904***	0.869***	0.900***	0.777***
	(0.146)	(0.119)	(0.144)	(0.110)

Table 5A Concluded

	(1)	(2)	(3)	(4)
	All variables	Only Linear Terms	Only Temperature variables	Only Precipitation variables
Log Labor	0.023	0.354	0.198	0.433
	(0.410)	(0.363)	(0.387)	(0.348)
Log Machinery	0.121*	0.118**	0.095**	0.165*
	(0.057)	(0.037)	(0.032)	(0.075)
Log Fertilizer	0.158**	0.083*	0.107*	0.091
	(0.066)	(0.045)	(0.058)	(0.051)
Constant	-9.247	4.734	-7.824	3.379
	(5.923)	(2.640)	(5.251)	(2.264)
N	92	92	92	92
R-sq	0.758	0.665	0.703	0.659
Adj. R-sq	0.689	0.614	0.658	0.608
AIC	-266.910	-237.164	-248.354	-235.617
No of countries	10	10	10	10

*** significant at 1% ** significant at 5% *significant at 10%

Table 5B
Regression Analysis Results
Dependent Variable: Net Agricultural Production (1,000 I$)

	(1)	(2)	(3)	(4)
	All variables	Only Main Effects	Only Temperature variables	Only Precipitation variables
Log Annual Temp	1.941*	-0.210**	1.860**	
	(0.940)	(0.091)	(0.797)	
Log Annual Prec	-0.295	-0.020		-0.083
	(0.196)	(0.020)		(0.069)
Log Annual Temp Sq	-0.423**		-0.342**	
	(0.142)		(0.137)	
Log Prec*Log Temp	0.090			
	(0.065)			
Log Annual Prec Sq	0.001			0.008
	(0.012)			(0.011)
Log Irrigation	0.403**	0.409**	0.395**	0.415**
	(0.148)	(0.160)	(0.149)	(0.157)
Log Labor	-1.240	-1.888	-1.096	-1.166
	(1.725)	(1.702)	(1.535)	(1.603)
Log Machinery	0.584***	0.583**	0.579**	0.625**
	(0.177)	(0.218)	(0.203)	(0.225)
Log Fertilizer	0.011	0.013	0.011	0.014
	(0.016)	(0.016)	(0.017)	(0.017)
Log Labor Sq	0.059	0.092	0.053	0.061
	(0.097)	(0.098)	(0.089)	(0.093)
Log Labor * Log Mach	-0.007	-0.001	-0.007	-0.003
	(0.022)	(0.022)	(0.025)	(0.023)
Log Machinery Sq	-0.017**	-0.020**	-0.017**	-0.020**
	(0.007)	(0.007)	(0.007)	(0.007)
Constant	-23.315	-15.388	-24.751	-23.240
	(16.448)	(15.328)	(14.818)	(14.812)
N	122	122	122	122
R-sq	0.956	0.953	0.953	0.952
Adj. R-sq	0.944	0.942	0.943	0.941
AIC	-582.883	-581.006	-582.052	-578.944
No of countries	13	13	13	13

*** significant at 1%   ** significant at 5%   *significant at 10%

Table 6
Marginal Impacts of Climate Variables on Agricultural Production (1000I$)

Seasons	Winter	Spring	Summer	Fall
Temperature	0.187	-0.548	1.031*	-0.892*
Precipitation	0.006	-0.001	0.002*	-0.003

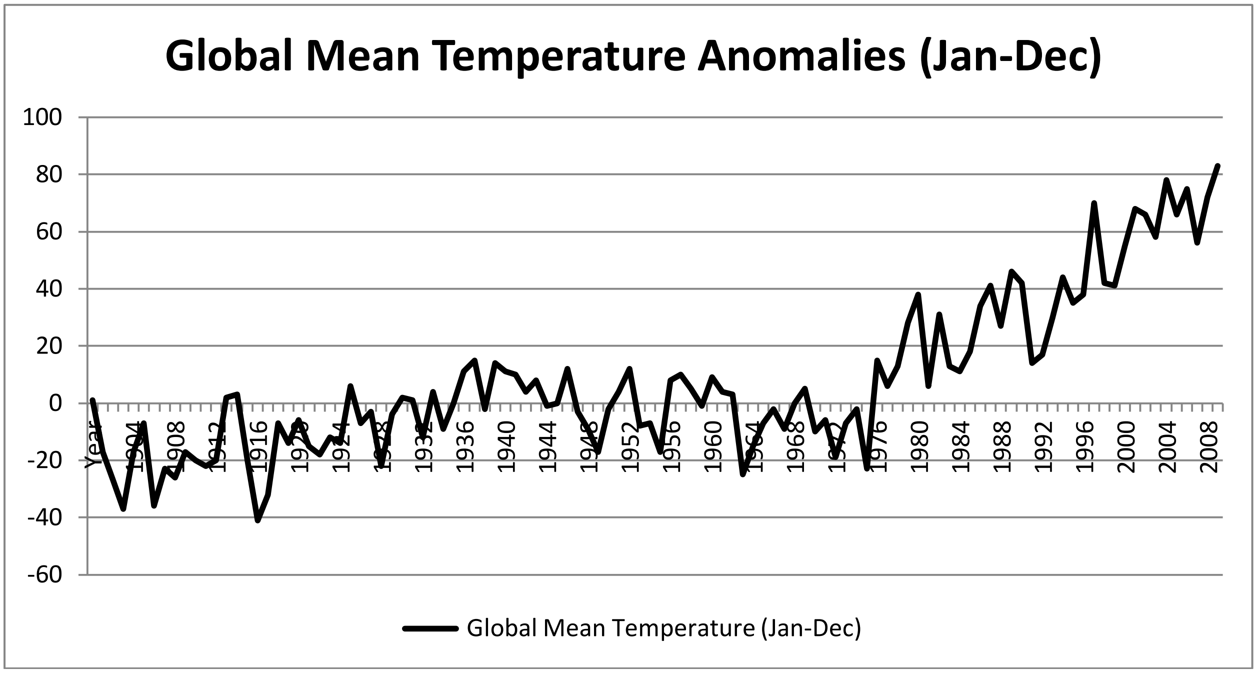
*** significant at 1%   ** significant at 5%   *significant at 10%

Table 7
Elasticities of Climate Variables on Agricultural Production (1000I$)

Seasons	Winter	Spring	Summer	Fall	Annual
Temperature	0.262	-0.923	1.784*	-1.434*	-0.253**
Precipitation	0.040	-0.010	0.028*	-0.036	-0.012

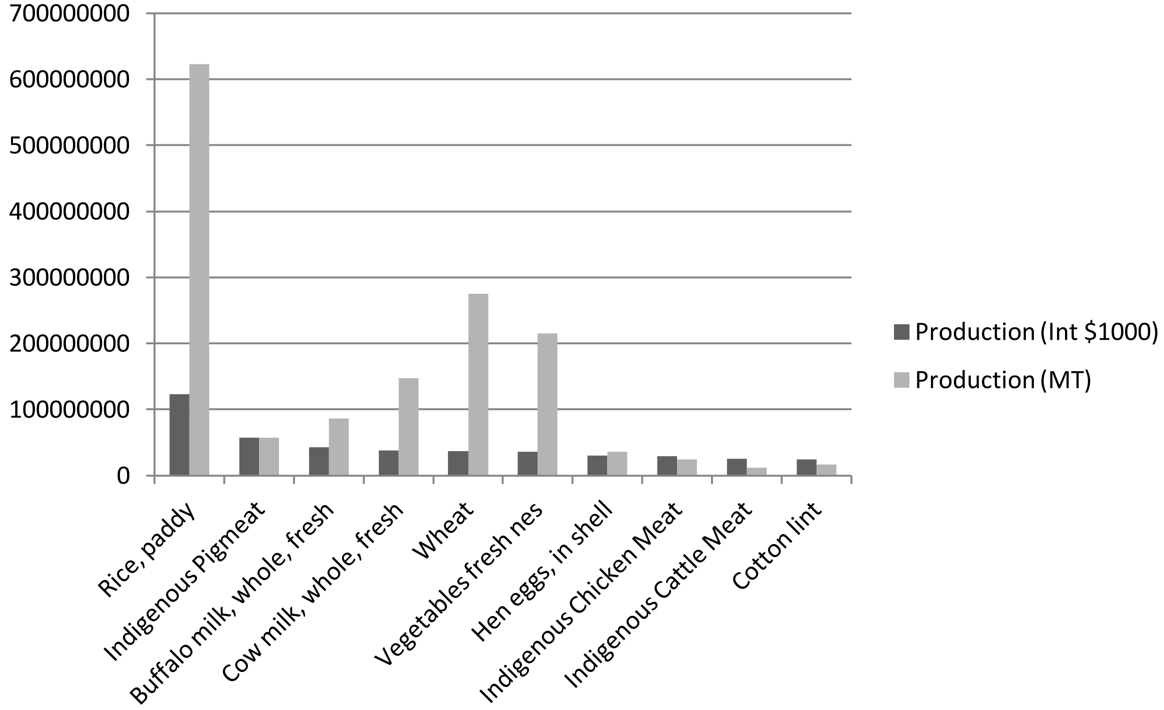
*** significant at 1%   ** significant at 5%   *significant at 10%

Figure 1
Annual Average Global Surface Temperature Anomalies 1901-2010
(Degrees in One Hundredths of a Celsius)



Data source: Goddard Institute for Space Studies, National Aeronautics and Space Administration (NASA)

Figure 2
Major Agricultural Products in Asia in 2008



Source: FAOSTAT

Chapter 2. The Impacts of Climate Change on Agricultural Farm Profits in the United States

Abstract

Global warming has been an issue lately in many aspects because it has been in increasing trend since 1980s. This paper estimates the climate change effects on the U.S. agriculture using the pooled cross-section farm profit model. The data are mainly based on the annual Agricultural Resource Management Survey (ARMS) from USDA for the time period between 2000 and 2009 in the 48 contiguous States. For climate measure, growing season drought indices (the Palmer Drought Severity Index (PDSI) and Crop Moisture Index (CMI)) are applied to the analysis and both indices have a negative relationship with temperature. The estimates indicate that one unit increase in PDSI (CMI) leads to 5.5% (13.9%), 4% (9%), and 5% (14%) increase in farm profits for all farms, crop farms, and livestock farms. This paper provides several contributions to the literature. First, the data set is very rare and unique national survey that provides an individual farm level observation. Therefore, it gives more detailed farm structure and financial information for the analysis compared to other studies. Second, drought indices (PDSI and CMI) are used for estimating the impact of weather on farm profits while temperature, precipitation, and growing degree-days are typical weather variables in literatures.

1. Introduction

Global warming has been a hot issue lately all around the world since it affects many aspects. It might be the major concern to human being because warming will be directly related to food consumption and human health if it especially decreases agricultural production. It is not surprising that global warming has been receiving a lot of people's attention. According to Oreskes (2004), 928 papers that have abstracts including "global climate change" were published in refereed scientific journals between 1993 and 2003. This is very surprising since Houghton et al. (2001) argued that there is surprising absence of impact studies on climate change effects partially due to the slight temperature increase on average over the globe which has warmed only by 0.5°C over the last hundred years. Mendelsohn (2007) also addresses the absence of research in past climate change impact on global agriculture over the last 40 years.

The impacts of global warming also have been highly controversial among scientists, scholars, and policy makers. Intergovernmental Panel on Climate Change (IPCC) and the National Academy of Sciences have reported that most of observed warming is likely due to the results of human activities such as Greenhouse gas emission while policy-makers and media argued that climate change is highly uncertain (Oreskes, 2004).

However, according to the estimation by the NASA's Goddard Institute for Space Studies and the National Climatic Data Center, warming has been in increasing trend since the 1980s. The National Oceanic and Atmospheric Administration (NOAA) also reports that seven of the eight warmest years on record have occurred since 2001 and the 10 warmest years have all occurred since 1995. Previous studies also suggest that global warming has been in increasing trend since the1980s although the Earth's average surface temperature has increased by about 1.2 to 1.4°F in the last 100 years (Mendelsohn, 2007). There have been different forecasting and extensive debates over the concerns about the impacts of climate change. However, a broad consensus among climate scientists is that there would be drastic temperature increases and change in precipitation patterns due to greenhouse gas effect (Houghton *et al.*, 2001).

According to the NOAA's report, the recent warmth has been greatest over North America and Eurasia between 40 and 70°N although the warming has not been occurred in same fashion worldwide. That is, most of European countries and U.S. states except for the Southern states have been affected most by the recent warming.

Therefore, climate change might be a major concern to humanity since it affects many economic sectors as well as different aspect of human life. Negative impacts of climate change on the agricultural sector will be especially dangerous since agriculture is directly related to food security and human health. Many believe that agricultural production will be affected most by temperature and precipitation since they are directly related to the production (Deschenes and Greenstone, 2007). This paper mainly examines the economic impacts of climate change on the agricultural profits in the United States.

If weather negatively impacts the U.S. agricultural production, it will cause a big problem in world food security because the U.S. is the top exporter of major agricultural products such as corn, soybean, wheat, and pork (FAOSTAT).

2. The Impacts of Climate Change on the U.S. Agriculture

There have been debates on potential climate change and its impacts. The impacts of climate change on the U.S. agricultural sector also have been an issue lately. While negative impacts of climate change on U.S. agriculture are found in most previous research, some argue that warming will be beneficial.

Schlenker et al. (2005) find that climate change effect (under warming scenario) will lead to an annual loss of about $5 to $5.3 billion in agricultural profits in dry-land non-urban counties. Kelly et al. (2005) also conclude that warmer weather will be harmful to agriculture. In the results of the estimation, climate change will decrease agricultural profits and its adjustment costs. Huang and Khanna (2010) estimate the future climate change impact on U.S. crop yields using the county level panel analysis. They find that increase in temperature significantly reduces the yields of corn, soybeans, and wheat while precipitation has positive relationship with the crop yields.

However, Deschenes and Greenstone (2007) argue that climate change will increase annual agricultural profits by $1.3 billion in 2002 dollars that is equivalent to about 4% increase in profits. Mendelsohn and Massetti (2011) also suggest that warming will be beneficial to farms in relatively cool location. For example, farms in the northern part of the U.S. will get benefit from warming although warming will be harmful to the farms in the western U.S.

In previous studies, the production function and hedonic approach are two most widely used methods to estimate the climate impact on agriculture (Deschenes and Greenstone, 2007).[10] Deschenes and Greenstone (2007) argue that both the production function and hedonic approach have weaknesses to properly estimate the effects of climate change. For the method using the production function, the estimates do not account for farmer's adaptations therefore the impacts of climate change are likely biased. The disadvantage of hedonic approach is that the land value may not reflect the discounted value of land rents. Schlenker et al. (2005) also point the potential disadvantage of hedonic approach. In its analysis, agricultural prices are assumed to be constant and it will be inappropriate if there are endogenous price changes however.

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[10] Hedonic approach is sometimes called the Ricardian analysis since it attempts to measure the impact of climate on the agricultural land value instead of production quantity or yields (see, Mendelsohn, R., W. Nordhaus and D. Shaw (1994) and Schlenker, Wolfram, W. Michael Hanemann, and Anthony C. Fisher (2005)).

3. Data and Methodology

3.1. Conceptual model

Following the standard theory on profit maximizing firm, the profits of the firm are formulated as a function of input and output prices. In addition, some technology parameters enter into the profit function. Specifically, the profit function takes the following form:

where π represents farm profits. P stands for input prices and output prices of agricultural production. C represents drought indices that are the Palmer Drought Severity Index (PDSI) and Crop Moisture Index (CMI). F is a set of individual farm structure such as total acres operated, farm type (crop farm/ livestock farm), and farm ownership (family farm/ non-family farm). O denotes the characteristics of a primary farm operator including age, gender, and education. The variables C, F, and O are technology shifters.

3.2.Econometric Model

The empirical counterpart of the conceptual profit function outlined above is described below and the model is also partially following Deschenes and Greenstone (2007).[11]

where represents the profits of an individual farm i in county c at year t. The equation includes a set of indicators for counties and years, and . is the growing-season humidity indicator. Specifically, PDSI and CMI are included in the regressions. The indices are the

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[11] Deschenes and Greenstone (2007) argue that the production function and the cross-section hedonic approach are likely misspecified and biased. They estimate agricultural profits and call the model "new approach" in the paper. The main differences of the profit function used in this paper from Deschenes and Greenstone (2007) are that prices (input and output prices) are controlled and drought indices are used as a weather variable instead of growing season degree-days.

average of a growing season in county level and weekly-level data are used for the calculation of the growing season. The growing season is defined as the period between the first week of June and the last week of September in the analysis. In fact, a growing season varies by crops and regions. However, except for winter wheat, the period from June to September covers the growing season for most major crops such as corn, cotton, and soybean (USDA-NASS, 1997).

represents the input price and output price indices. Both input and out prices indices consist of categories of agricultural production inputs and outputs. Regressions in the analysis are run for three different samples, namely all farms together, and crop farms, and livestock farms separately. For the estimation with the sample of all farms, the output price index for “all farm products” category is used. For the regressions with the sample of crop farms and livestock farms, the output price indices for “all crops” and “livestock and products” are chosen, respectively. Input price index reflects costs of several categories of factors of production, such as feed, seeds, fertilizer, chemicals, fuels, farm machinery, building material, farm services, and labor. The average of these factor price indices is used in the analysis. is a vector of farm and its operator’s characteristics. More specifically, includes indicators for whether the farm is a professionally-owned business (non-family owned) and whether the farm mainly produces crops rather than livestock products. In addition, the land area of the farm and the farm operator’s age, gender, and education level are included. The standard errors are clustered at the county level in order to correct for the possible correlation in unobservable characteristics of the farms located in the same county.

3.3. Data

The empirical analysis utilizes pooled cross-sectional data that is mainly based on the annual Agricultural Resource Management Survey (ARMS)-Phase III from USDA for the time period between 2000 and 2009 in the 48 contiguous States. Due to the fact that ARMS is the only national survey that provides individual farm-level observations, it gives detailed farm structure and financial information for the analysis. The outcome variable is the farm profits. Net farm income (computed as total farm revenues net of total production costs) is used for farm profits.[12] These data are obtained from Agricultural Resource Management Survey (ARMS).

Variables of interest are drought indices. Climate data of drought indices, temperature, and precipitation are obtained from National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center. For draught indices, the Palmer Drought Severity Index (PDSI) and Crop Moisture Index (CMI) are chosen. This is because, among major drought indices, the PDSI and CMI are the most widely used ones by government agencies and researchers in the United States. According to National Drought Mitigation Center, many U.S. government agencies and states rely on PDSI for evaluating drought relief programs. Therefore, PDSI is one of the most reliable measurements for drought condition. NOAA explains that total weekly precipitation, average temperature, climate division constants such as water capacity of the soil and others, and previous history of indices are included in the calculation of both PDSI and CMI for 350 climate divisions in the U.S. and Puerto Rico. Since both temperature and precipitation are included in the calculation of indices, the drought indices can be a good measurement for evaluating the effect of climate change in various fields. Table 1 shows the classifications of PDSI and CMI indices that represent the degrees of dryness/ wetness. Both PDSI and CMI indices are correlated with temperature and precipitation. The time series graphs of PDSI, CMI, temperature and precipitation are illustrated in Figures 3 and 4. There is a positive relationship between precipitation and drought indices and a negative one with temperature. To quantify these

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[12] In the farm income statement, the total revenue consists of following categories: Cash receipts from crops and livestock, direct government payments, Farm-related income, Non-money income, and Value of inventory adjustment according to USDA.

correlations, I run regressions of PDI and CMI on temperature and precipitation. The results are provided in Table 9. A one degree Fahrenheit (inch) increase in temperature (precipitation) reduces (inches) PDSI and CMI by 0.065 and 0.038 (3.733 and 1.999), respectively.

Input and output prices data are obtained from Monthly Agricultural Prices Summary from USDA-National Agricultural Statistics Services (USDA-NASS). The data are in fact indices of agriculture prices and weighted 1990-1992 average equals 100. Each index of input prices represents categories of all production inputs that are feed, livestock and poultry, seeds, fertilizer, chemicals, fuels, supplies and repairs, autos and trucks, farm machinery, building material, farm services, rents, interests, taxes, and wage rates. Since these indices are highly correlated to each other, an average input price index is used in the analysis.[13]

The remaining control variables for farm structures and operator characteristics that are used in the analysis are obtained from the annual Agricultural Resource Management Survey (ARMS). The set of control variables include the land area of the farm in acres (*Acres*), indicators for whether the farm mainly produces crops and whether the farm is a non-family business. In addition, farm operator’s characteristics are included among covariates. The operator characteristics considered are age and gender of the primary farm operator and an indicator for whether the operator has obtained a college degree.

The definitions of the variables used in the estimation are presented in Table 10. Table 11 provides the summary statistics of the variables.

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[13] Kelly, Kolstad, and Mitchell (2005) also use an aggregate input price index for their agricultural profit analysis using a sample of 5 U.S. states including Illinois, Iowa, Kansas, Missouri, and Nebraska. They also use the same price indices data from USDA-NASS as I use in my analysis.

4. Estimation and Analysis

Figures 5 and 6 illustrate the relationship between drought indices and average farm profits over time for PDSI and CMI, respectively. PDSI and farm profits follow similar trends over the sample period (2000-2009) considered in this paper. That is, as the average PDSI increases, farm profits tend to increase as well. As illustrated in Figure 6, although weak, a positive relationship is observed between CMI and profits over time. The analyses below quantifies the relationship between the drought indices PDSI and CMI and profits conditioning on several control variables as described in the Data section.

In general, farms are divided in two categories: crop farms and livestock farms. Consequently, three different samples are used in the estimation: all farms combined, and crop and livestock farms separately. PDSI is used as a measure of weather variable in the regressions. As an alternative measure, CMI is included instead of PDSI. These two measures are highly correlated (over 0.8). CMI differs from PDSI such that the former is a measure of short term moisture conditions in soil; whereas PDSI is more relevant for long term measurements.

The regression results pertaining to the whole sample is reported in Table 12A. Columns 1 and 2 include PDSI and CMI as measures of moisture, respectively. All the remaining control variables are identical. The regressions include indicators for counties and years. Except for the indicators, all variables are in natural logarithms. The standard errors are clustered at the county level.

Note that some of the variables including the variables of interest and the dependent variable has negative observations. In order not to lose any observations, I transformed the variables by adding 0.1 + the minimum of the variable before taking the natural logarithms. For example, the minimum value for the profits in the data set is -47,600,000. To make the transformation mentioned above, I added 47,600,000.1 to each farm's profits before taking the logarithms. Similarly, -8.482 (-8.382-0.1) is added to each observation's PDSI variable. As a result, the coefficient estimates are small in the tables below.

In Table 12A, PDSI has a positive effect on the farm profit and its coefficient is statistically significant at 1%. The coefficient is 0.0002. This number implies that for each one percent increase in PDSI index (about 8.424×0.01=0.084), the farm profits increases by about 0.0002% or approximately about $100 (47600000+131270+.1=4,773,270.1; 4,773,270.1×0.0002%=$95). To put this estimate into context, consider moving a farm from extreme drought (PDSI=-4) to normal moisture (PDSI=0). Such a change (about 50 times of one percent of the outcome variable) will improve farm profits by about $4,500.

Both output and input price indices have expected signs and they are statistically significant at conventional levels. The estimated elasticity of profits with respect to input and output prices at the mean of the data are –0.001 (-$47) and 0.0006 ($25), respectively. Total operated land area of a farm has a statistically significant influence on the farm profits. However, the magnitude is very small. The indicator for livestock farm identifies the difference in profits between a crop farm and a live stock farm. The coefficient of livestock farm indicates that on average livestock farms earn $110 less in profits compared to a crop farm. Similarly, the coefficient on the non-family farm indicates that non-family farms earn about $750 more compared to the farms that are owned and operated by families. This difference could be observed because of the possibility that non-family owned farms are managed professionally and they use more advanced technologies compared to the family owned businesses.

The coefficients on the farm operator's characteristics have expected signs. That is, the farms that are run by a primary operator who has at least a college degree make an additional $50 profits compared to their counterparts which are managed by a primary operator with lower educational attainment. Farms with female primary operators earn smaller profits than farms with male primary operators. There is a negative linear relationship between primary operator's age and farm profits. Specifically, compared to the primary operator of an average farm who is 55 years old, an operator who is 54 years old contribute $1,587 more to their farm's profits for example. In column 2 of Table 12A the results of the same model is presented, except CMI is used as a measure of weather effect instead of PDSI. The results are similar to those obtained from the regression with PDSI. CMI has a positive impact on farm profit and it is significant at 1%. Specifically, a one unit increase in CMI leads to $18,300 increase in profits. In other words, farm profits will be increased by about 13.9% for each unit increase in CMI. This change corresponds to increasing the level of index from “Slightly Dry” to “Favorably Moist”.

The coefficients of control variables are similar to those obtained in the first column of Table 12A. The estimates of elasticity of profits with respect to input and output prices are -1.93 and 3.61, respectively. Land area of a farm does not have a significant impact on the farm profits. On average crop farms earn about $14,704 more profits compared to a livestock farm. A non-family operated farm make about $347,000 more in profits than the family owned and operated farms. The coefficients on the farm operator's characteristics are almost identical to those obtained from the regression that includes PDSI. Farms with a male operator who has at least a college degree make an additional $82,224 due to gender and $32,241 due to education of the operator.

Results pertaining to the regressions that are run for separate samples of crop and livestock farms are presented in Table 12B. The first (last) two columns show the results of the crop (livestock) farm sample. In columns 1 and 3, the regressions include PDSI. PDSI is replaced by CMI in columns 2 and 4. Output price reflects the relevant outputs produced in crop and livestock farms. That is, the national output price index of crops is used as a control variable in columns 1 and 2 (crop farms regressions). In livestock regressions, the national output price index of livestock products is used. All regressions include indicators for counties and years. The standard errors are clustered at the county level.

For an average crop farm, a one unit increase in PDSI and CMI increases profits by about $5,900 and $15,000, respectively (columns 1 and 2 of Table 12B). These coefficients translate into an increase in profits of 4% for PDSI and 9% for CMI. From the Table 9, I find that one unit change in PDSI (CMI) is a result of about 15°F (26°F) in temperature change. That is, the profits for an average crop farm increases by about $393 ($577) if temperature increases by 1°F. The coefficients of PDSI and CMI are significant at the 1% level. The magnitude of the impact is greater in livestock farms. A one unit increase in PDSI improves farm profits by about $8,000 (column 3 of Table 12B). That is an increase in profits of about 5%. When CMI rises by one unit, the profits increase by $23,000 or by 14% (column 4 of Table 12B).

The coefficients of the control variables reported in Table 12B are mostly similar to those obtained from the regressions run on the whole sample of farms (Table 12A). Specifically, farms with operators who are male, who have more education, and who are younger earn greater profits. In addition, non-family operated farms profits are about $240,000 and $ 376,000 greater than family operated farms for crop farms and livestock farms, respectively. Although land area is a significant determinant of crop farm profits, it does not affect profits of an average livestock farm. As expected by the economic theory, output prices are positively associated with profits and input prices have a negative influence. However, for crop farms, prices are not statistically significant at conventional levels.

In order to put these results into perspective (Tables 12A and 12B), the impact of changing the drought index level on profits is simulated. Specifically, I calculated the change in an average farm's profits when it is hypothetically moved from one state to another. The selected results are provided in Table 13. In these simulations, I considered the case of extremes such that a farm is hypothetically moved from the state with a very low level of index to another state with high level of index. For example, if an average farm in Wyoming (lowest PDI: -3.54) is moved to New Hampshire (highest PDI: 2.50), then its profits will rise by about 33%. I also present the impact of a one standard deviation increase in an index on farm profits in Table 13. For example, if a drought index of an average farm was a one standard deviation higher (2.5 units increase in PDSI), then its profits would have been 14% greater. As observed in Table 6, the effect of a bigger index is higher for livestock farms compared to crop farms. A one standard deviation increase in PDSI increase crop farm profits by about 9%, whereas an increase in the level of an index of same magnitude increases profits of a livestock farm by more than 20%. It follows that profits for crop farm and livestock farm increase by about \$5874 and \$8090 respectively if temperature increases by 15°F.

Table 14 shows the impact of weather condition on the farm profit per acre in the selected regions. In this estimation, Southeast, Mid-west, and Pacific regions sub-samples are used. Southeast region includes Alabama, Georgia, and Mississippi. Although Florida and South Carolina are also fit into this region geographically, they are not included in the estimation due to the different agricultural conditions such as weather, soil condition, and major agricultural products. Illinois, Indiana, Iowa, Missouri, Minnesota, and Ohio represent Mid-west region and these states are also known as the corn-belt states. Pacific region includes California, Oregon, and Washington. Instead of using the whole sample within the region, the estimation is conditioned with the 10th percentile of the profit from crop farm and the 10th percentile of the growing season CMI in order to see the pure impact of weather condition on the farm profit.[14] The result shows that CMI has the greatest positive impact in the Southeast region and it is significant with 1%. When the drought condition improves by 1 unit in the growing season, the profit from a crop farm increases by about $930 per acre holding others constant. CMI also has a positive impact in the pacific region with 1% significance although the magnitude is smaller than that of the Southeast region. A crop farm makes about $500 more per acre if the drought condition improves by 1 unit. On the other hand, CMI does not have any significant impact in the Midwest region. According to USDA and United States Environmental Protection Agency (EPA), the Midwest region has some of the best soil and weather condition for growing crops in addition to the one of the most advanced agricultural system in the United States. These facts may explain that CMI does not play a crucial role for the farm profit in the Midwest. Mendelsohn and Massetti (2011) also argue that warming is especially harmful for the Southern states and the western part of the United States.

Both input and output prices are significant at the 1% level and have the expected signs in the Southeast region. However, they are insignificant in the Midwest and the Pacific regions.

Table 15 presents the impact of drought indices on the yield of five major field crops: corn, cotton, hay, soybean, and wheat.[15] The output variables are measured in dollars per acre. The results show that soil humidity (measured by the drought indices CMI and PDSI) is positively associated with the production of all crops except wheat. Specifically, a one percent increase in soil humidity increases production of hay, corn, cotton and soybean by about 0.2-

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[14] Although not reported, the other quantiles of the farm profit under the same CMI level are also estimated and the results are consistent throughout the different distribution. However, the results indicate that the impact of CMI gets smaller in the higher quantile of the farm profit.

[15] Profit data of individual crop is not available in ARMS. Other data are also insufficient to calculate profit.

0.4%. This result is not sensitive to functional form employed. For example, as presented in Table 16, using level of production instead of using production per acre of land produces coefficients similar to those in Table 15. Similarly, using a translog function changes neither the size nor the sign of the coefficients. The effect of soil humidity on wheat production is statistically insignificant in both Tables 15 and 16. This result could be observed because wheat is not the one of the field crops that favors increased soil humidity as a favorable growing condition. Similar finding can be found in Huang and Khanna (2010) that the marginal impact of precipitation with respect to wheat yield is -0.004. They also argue that deviation in monthly temperature is beneficial for wheat while it is generally harmful for corn and soybean yields.

The control variables employed in the production function estimation represented in Table 15 are the major inputs of production: labor, equipment and buildings. The signs of these variables are generally consistent with the economic theory. Increase in amounts of inputs, holding other things constant, increases production of individual crops. Farms which use one percent of more labor, and agricultural equipment produce about 0.01%, and 0.04%, respectively. The effect of buildings on production is statistically insignificant.

The coefficients of the drought index variables displayed in Table 15 that employed production function estimation are greater in magnitude than those presented in Tables 12A and 12B from profit function analysis. This could be because of the possibility that farmers may adapt to changes in weather conditions. For example, farmers may alter their input mix, fertilizer utilization for example, or they may start producing other crops which are more suitable for the new weather conditions. Alternatively, farmers may change the land use for other activities such as manufacturing or housing which are not much related to weather conditions (Deschenes and Greenstone, 2007). The profits of a farm would reflect such adaptation activities, whereas production of specific crops would not. Specifically, consider this hypothetical case: weather conditions that are suitable for, say, corn production is likely to result in greater yield (production) of corn and high profits for the farm at the same time. However, under the bad weather conditions for corn, farmers may plant a different crop, say, wheat. In this case, production of corn will decrease but the farm can still sustain its profits from alternative wheat production. Consequently, in a least squares estimation (as in this paper), the coefficient of the weather conditions in the production function will be greater than that in the profit function.

5. Conclusion

This paper estimates the climate change effects on U.S. agriculture using the pooled cross-section farm profit model. The data are mainly based on the annual Agricultural Resource Management Survey (ARMS) from USDA for the time period between 2000 and 2009 in the 48 contiguous States. This paper provides several contributions to the literature. First, the ARMS data used in the analysis are very rich and unique resource due to the fact that it is the only national survey providing an individual farm-level observation. Therefore, it gives more detailed farm structure and financial information for the analysis compared to other studies. Another uniqueness of this analysis is that drought indices (PDSI and CMI) are used for estimating the impact of weather on farm profits while including temperature, precipitation, and growing degree-days are typical weather variables in literatures.

The result shows that warming is harmful to U.S. agriculture based on the analysis with three different samples (all farms together, crop farms only, and livestock farms only). In all farms sample, for each unit increase in PDSI (CMI), the farm profits increases by about $7240 ($18,300). This corresponds to about a 5.5% (13.9%) increase from the mean profits ($131,270).

For an average crop farm, a one unit increase in PDSI and CMI increases profits by about $5,900 and $15,000, respectively. These are equivalent to an increase in profits of 4% for PDSI and 9% for CMI. The magnitude of the impact is greater in livestock farms. A one unit increase in PDSI improves farm profits by about $8,000. That is an increase in profits of about 5%. When CMI rises by one unit, the profits increase by $23,000 or by 14%.

As many studies indicate, warming will be very vulnerable to agriculture in most part of the world. Since the U.S. is the top exporter of major agricultural products such as maize, soybean, wheat, and pig meat, climate change might be a major concern to global economy and peoples’ well-being. Therefore, adaptation to climate change will be necessary such as altering production inputs, changing land-use, or developing new varieties that are more tolerant to higher temperature/ less precipitation.

Table 8
Drought Index Classifications

Palmer Drought Severity Index (PDSI)	Crop Moisture Index (CMI)
-4.0 or less (Extreme Drought)	-3.0 or less (Severely Dry)
-3.0 to -3.9 (Severe Drought)	-2.0 to -2.9 (Excessively Dry)
-2.0 to -2.9 (Moderate Drought)	-1.0 to -1.9 (Abnormally Dry)
-1.9 to 1.9 (Near Normal)	-0.9 to 0.9 (Slightly Dry/ Favorably Moist)
2.0 to 2.9 (Usual Moist Spell)	1.0 to 1.9 (Abnormally Moist)
3.0 to 3.9 (Very Moist Spell)	2.0 to 2.9 (Wet)
4.0 or above (Extremely Moist)	3.0 and above (Excessively Wet)

Source: NOAA-Climate Prediction Center

Table 9
The Impact of Temperature and Precipitation on Drought Index

PDSI	Coef.	Std.Err.
Temperature	-0.065***	0.001
Precipitation	3.733***	0.014

CMI	Coef.	Std.Err.
Temperature	-0.038***	0.0002
Precipitation	1.999***	0.004

Notes: *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

Table 10
Variable Definitions

Profit	Net farm income (unit: dollars)
PDSI	Palmer Drought Severity Index for growing season (June-September)
CMI	Crop Moisture Index for growing season (June-September)
Input Price	Input price index of agricultural production (base: 1990-1992 = 100)
Output Price	Output price index of agricultural production (base: 1990-1992 = 100)
Output Price Crop	Output price index of crop production (base: 1990-1992 = 100)
Output Price Livestock	Output price index of livestock production (base: 1990-1992 = 100)
Acres	Acres operated
Crop Farm	=1 if the farm mainly produces crops
Non-family Farm	=1 if the farm is non-family farm.
Operator at least college	=1 if the operator has at least graduated from college.
Operator Age	Age of the primary operator
Operator female	=1 if the primary operator is female

Table 11
Summary Statistics

Whole Sample

Variable	Obs	Mean	Std. Dev.	Min	Max
Profit	146,031	131,270	925,105	-47,600,000	81,000,000
PDSI	146,031	-0.058	2.507	-8.382	9.790
CMI	146,031	-0.110	0.935	-3.298	3.670
Output Price	146,031	122.577	14.885	98.000	149.000
Input Price	146,031	155.897	25.525	120.571	198.000
Acres	146,031	1,323	7,456	0	***
Crop Farm	146,031	0.524	0.499	0.000	1.000
Non-family Farm	146,031	0.053	0.225	0.000	1.000
Operator at least college	146,031	0.223	0.416	0.000	1.000
Operator age	146,031	55.460	12.422	16.000	***
Operator female	146,031	0.052	0.222	0.000	1.000

Crop Farm Sample

Variable	Obs	Mean	Std. Dev.	Min	Max
Profit	76,488	162,704	892,409	-16,500,000	81,000,000
PDSI	76,488	-0.100	2.511	-8.382	9.790
CMI	76,488	-0.149	0.913	-3.298	3.670
Output Price - Crops	76,488	130.096	21.407	106.000	169.000
Input Price	76,488	156.431	25.662	120.571	198.000
Acres	76,488	1,210	2,184	1	***
Crop Farm	76,488	1.000	0.000	1.000	1.000
Non-family Farm	76,488	0.063	0.243	0.000	1.000
Operator at least college	76,488	0.256	0.436	0.000	1.000
Operator age	76,488	55.467	12.323	17.000	***
Operator female	76,488	0.044	0.204	0.000	1.000

Table 11 Concluded

Livestock Farm Sample					
Variable	Obs	Mean	Std. Dev.	Min	Max
Profit	69,543	96,697	958,599	-47,600,000	71,200,000
PDSI	69,543	-0.012	2.502	-8.382	9.790
CMI	69,543	-0.067	0.957	-3.298	3.670
Output Price - Livestock	69,543	116.371	11.293	91.000	130.000
Input Price	69,543	155.310	25.359	120.571	198.000
Acres	69,543	1,448	10,558	0	***
Crop Farm	69,543	0.000	0.000	0.000	0.000
Non-family Farm	69,543	0.043	0.203	0.000	1.000
Operator at least college	69,543	0.186	0.389	0.000	1.000
Operator age	69,543	55.452	12.531	16.000	***
Operator female	69,543	0.061	0.240	0.000	1.000

Notes: *** implies that the statistic is censored by the USDA.

Table 12A
The Regression Result on Farm Profits with the Sample of All Farms

	(1)	(2)
PDSI	.0002017***	
	(.0000459)	
CMI		.0002106***
		(.0000336)
Output Price	.0013539***	.0014935***
	(.0004329)	(.0004372)
Input Price	-.0006952**	-.0007752**
	(.0003354)	(.0003382)
Acres	6.70e-08***	6.70e-08***
	(2.17e-08)	(2.17e-08)
Livestock Farm	-.0002308***	-.000231***
	(.0000297)	(.0000297)
Non-family Farm	.0015749***	.0015759***
	(.0002436)	(.0002436)
Operator at least college	.000127***	.0001259***
	(.0000292)	(.0000291)
Operator age	-5.13e-06***	-5.16e-06***
	(6.44e-07)	(6.45e-07)
Operator female	-.0003982***	-.0003987***
	(.0000281)	(.0000281)
Constant	17.67655***	17.67647***
	(.000513)	(.0005133)
N	146031	146031
R^2	0.007	0.007

Notes: The outcome variable is the natural logarithm of profits of the farm reported in their income statement. Descriptions of other variables are in Table 1 and summary statistics are presented in Table 2. All control variables are in natural logarithms. All regressions include indicators for counties and year dummies. The standard errors are clustered at the county level and they are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

Table 12B
The Regression Result on Farm Profits with the Sample of Crop and Livestock Farms

	Crop Farms		Livestock Farms	
	(1)	(2)	(3)	(4)
PDSI	.0002785***		.0001615**	
	(.0000721)		(.0000685)	
CMI		.0003342***		.0001475***
		(.0000608)		(.0000437)
Output Price	.0013684	.0016056*	.0008428*	.0009175**
	(.0008728)	(.0008713)	(.0004321)	(.0004436)
Input Price	-.0001467	-.0003344	-.0005727**	-.0005902**
	(.0008045)	(.0007966)	(.0002602)	(.0002726)
Acres	1.14e-06***	1.14e-06***	2.98e-09	3.00e-09
	(1.20e-07)	(1.20e-07)	(1.48e-08)	(1.48e-08)
Non-family Farm	.0012133***	.0012152***	.0018221***	.0018229***
	(.0002254)	(.0002254)	(.0005219)	(.0005219)
Operator at least college	.0001143***	.0001123**	.0000794*	.0000785*
	(.0000436)	(.0000437)	(.000044)	(.000044)
Operator age	-5.05e-06***	-5.03e-06***	-7.67e-07	-8.04e-07
	(1.23e-06)	(1.23e-06)	(8.45e-07)	(8.46e-07)
Operator female	-.0002475***	-.0002498***	-.0002602***	-.0002603***
	(.0000555)	(.0000553)	(.0000308)	(.0000309)
Constant	17.67311***	17.67309***	17.67798***	17.67788***
	(.000584)	(.0005829)	(.0008206)	(.0008331)
N	76488	76488	69543	69543
R-sq	0.080	0.080	0.006	0.006

Notes: The outcome variable is the natural logarithm of profits of the farm reported in their income statement. Descriptions of other variables are in Table 1 and summary statistics are presented in Table 2. All control variables are in natural logarithms. First (Last) two columns are regressions run on the crop (livestock) farms. All regressions include indicators for counties and year dummies. The standard errors are clustered at the county level and they are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

Table 13
The Impact of Changes in Drought Index on Farm Profits

		Change	% Change in Profits	Std. Err.
All Farms	PDSI	WY(-3.54) → NH(2.50)	33%	7%
		One Standard Deviation	14%	3%
	CMI	CA(-1.22) → ME(0.69)	27%	5%
		One Standard Deviation	13%	3%
Crop Farms	PDSI	NV(-4.10) → VT(2.33)	23%	8%
		One Standard Deviation	9%	3%
	CMI	UT(-1.29) → CT(0.75)	19%	7%
		One Standard Deviation	8%	3%
Livestock Farms	PDSI	ID(-3.02) → MA(2.05)	42%	12%
		One Standard Deviation	21%	6%
	CMI	AZ(-1.00) → ME(0.75)	41%	9%

Table 14
The Impact of Drought Index on Farm Profits per Acre by Selected Regions
Dependent Variable: Profit per acre

	Southeast	Midwest	Pacific
CMI_gs	926.841***	-27.356	485.956***
	(232.514)	(79.382)	(155.246)
Output Price	142.314***	-9.358	45.630
	(36.726)	(11.476)	(47.351)
Input Price	-93.189***	9.190	-46.403
	(32.325)	(8.945)	(34.121)
Constant	13964.290***	487.458	458.170
	(1972.893)	(526.378)	(1152.392)
N	5687	15768	5040
R-squared	0.034	0.0005	0.0007
F-stat	19.67***	2.63***	3.26***

Notes: All regressions include indicators for counties and year dummies. The standard errors are clustered at the county level and they are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

Table 15
The Impact of Drought Index Changes on Crop Production per Acre

	HAY		CORN		COTTON		SOYBEAN		WHEAT	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
PDSI	.2998***		.1583***		.2641***		.3086***		.0580	
	(.0360)		(.0363)		(.0803)		(.0241)		(.0374)	
CMI		.3218***		.2117***		.2172***		.4092***		.0046
		(.0361)		(.0379)		(.0600)		(.0241)		(.0339)
Labor	.0222***	.0219***	.0114***	.0114***	.0201	.0206	.0062**	.0064**	.0109**	.0110**
	(.0058)	(.0058)	(.0027)	(.0027)	(.0134)	(.0136)	(.0026)	(.0025)	(.0046)	(.0046)
Equipment	.0760***	.0769***	.0438***	.0438***	.0347*	.0330*	.0252***	.0246***	.0400***	.0400***
	(.0102)	(.0102)	(.0059)	(.0059)	(.0182)	(.0182)	(.0048)	(.0047)	(.0082)	(.0082)
Buildings	.0009	.0006	.0154***	.0153***	.0163	.01608	.0144***	.0144***	-.0045	-.0045
	(.0110)	(.0111)	(.0050)	(.0050)	(.0119)	(.0118)	(.0048)	(.0047)	(.0076)	(.0076)
Constant	-.4119***	-.1756*	3.9582***	4.0359***	5.3121***	5.6307***	2.6563***	2.8143***	3.3123***	3.4241***
	(.1081)	(.0899)	(.0789)	(.0622)	(.2349)	(.17059)	(.0698)	(.0528)	(.1023)	(.0764)
N	36,964	36,964	27,781	27,781	5,243	5,243	24,422	24,422	17,715	17,715
R-sq	0.418	0.419	0.563	0.565	0.578	0.579	0.489	0.503	0.577	0.576

Notes: The outcome variable is the natural logarithm of production of the crop listed at the top of the columns. Descriptions of other variables are in Table 1 and summary statistics are presented in Table 2. All control variables are in natural logarithms. All regressions include indicators for counties and year dummies. The standard errors are clustered at the county level and they are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

Table 16
The Impact of Drought Index Changes on Crop Yield per Acre

	HAY		CORN		COTTON		SOYBEAN		WHEAT	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
PDSI	.2022**		.2170***		.2770***		.3180***		.0568	
	(.0934)		(.0383)		(.0863)		(.0268)		(.0409)	
CMI		.2407*		.2724***		.2232***		.4011***		.0215
		(.1291)		(.0397)		(.0633)		(.0274)		(.0372)
Labor	-.0105	-.0104	-.0170***	-.0169***	.0165	.0171	.0016	.0019	.0079	.0080*
	(.0143)	(.0142)	(.0049)	(.0049)	(.0148)	(.0150)	(.0034)	(.0033)	(.0048)	(.0048)
Equipment	.0622***	.0627***	.0569***	.0569***	.0278	.0260	.0271***	.0264***	.0340***	.0340***
	(.0232)	(.0232)	(.0089)	(.0089)	(.0214)	(.0215)	(.0059)	(.0058)	(.0088)	(.0088)
Buildings	-.0349	-.0355	.0107	.0106	.0183	.0180	.0198***	.0196***	-.0022	-.0023
	(.0268)	(.0269)	(.0065)	(.0066)	(.0124)	(.0123)	(.0058)	(.0057)	(.0084)	(.0084)
Constant	4.1260***	4.2562***	4.3969***	4.5261***	4.4129***	4.7517***	4.0648***	4.2547***	4.3248***	4.4164***
	(.2659)	(.2265)	(.0974)	(.0853)	(.2570)	(.1978)	(.0821)	(.0649)	(.1105)	(.0832)
N	12,454	12,454	22,288	22,288	5,239	5,239	23,267	23,267	16,981	16,981
R-sq	0.585	0.585	0.506	0.507	0.650	0.650	0.607	0.614	0.621	0.621

Notes: The outcome variable is the natural logarithm of the crop yield listed at the top of the columns. Descriptions of other variables are in Table 1 and summary statistics are presented in Table 2. All control variables are in natural logarithms. All regressions include indicators for counties and year dummies. The standard errors are clustered at the county level and they are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

Table 17
The Impact of Drought Index Changes on Crop Yield per Acre (Alternative Specifications)

Quantity Produced per Acre

	Acres on right hand side		Translog		Translog and Acres on right hand side	
	PDSI	CMI	PDSI	CMI	PDSI	CMI
HAY	.2991***	.3214***	.3013***	.3249***	.3006***	.3259***
CORN	.1585***	.2123***	.1594***	.2122***	.1615***	.2151***
COTTON	.2606***	.2144***	.2646***	.2193***	.2616***	.2171***
SOYBEAN	.3083***	.4087***	.3087***	.4095***	.3081***	.4092***
WHEAT	.0552	.0030	.0599	.0064	.0550	.0019

Yield per Acre

	Acres on right hand side		Translog		Translog and Acres on right hand side	
	PDSI	CMI	PDSI	CMI	PDSI	CMI
HAY	.2022**	.2407*	.2017**	.2361*	.1952**	.2481**
CORN	.2170***	.2724***	.2158***	.2728***	.2174***	.2734***
COTTON	.2770***	.2232***	.2760***	.2241***	.2697***	.2212***
SOYBEAN	.3180***	.4011***	.3183***	.4009***	.3179***	.4009***
WHEAT	.0568	.0215	.0587	.0229	.0524	.0192

Notes: Each cell refers to the outcome variable is the natural logarithm of the crop yield listed at the top of the columns. Descriptions of other variables are in Table 1 and summary statistics are presented in Table 2. All control variables are in natural logarithms. All regressions include indicators for counties and year dummies. The standard errors are clustered at the county level and they are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

Figure 3
Average PDSI, CMI and Temperature

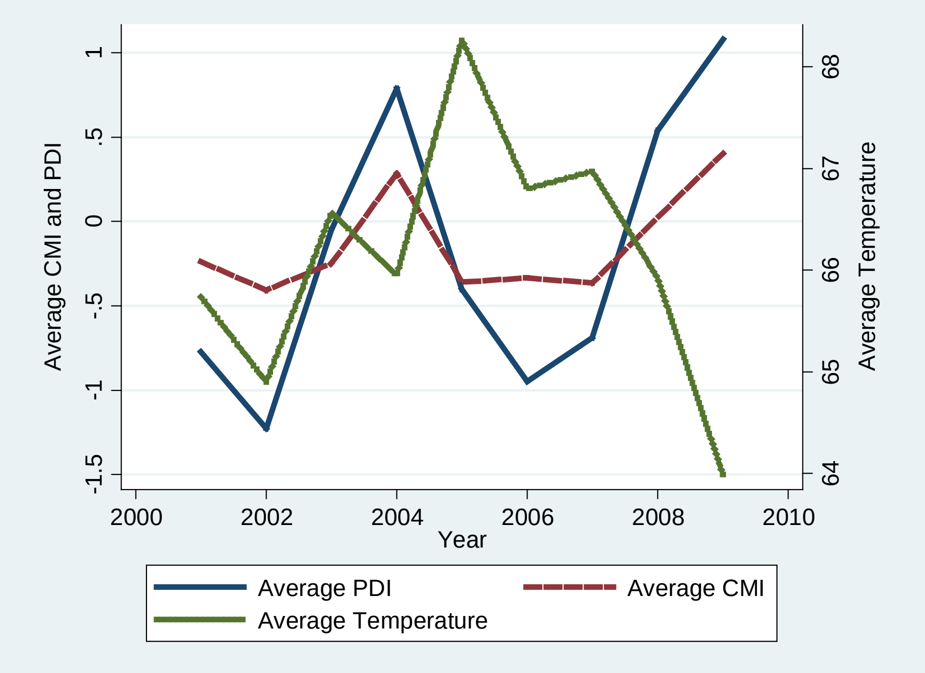


Figure 4
Average PDSI, CMI and Precipitation

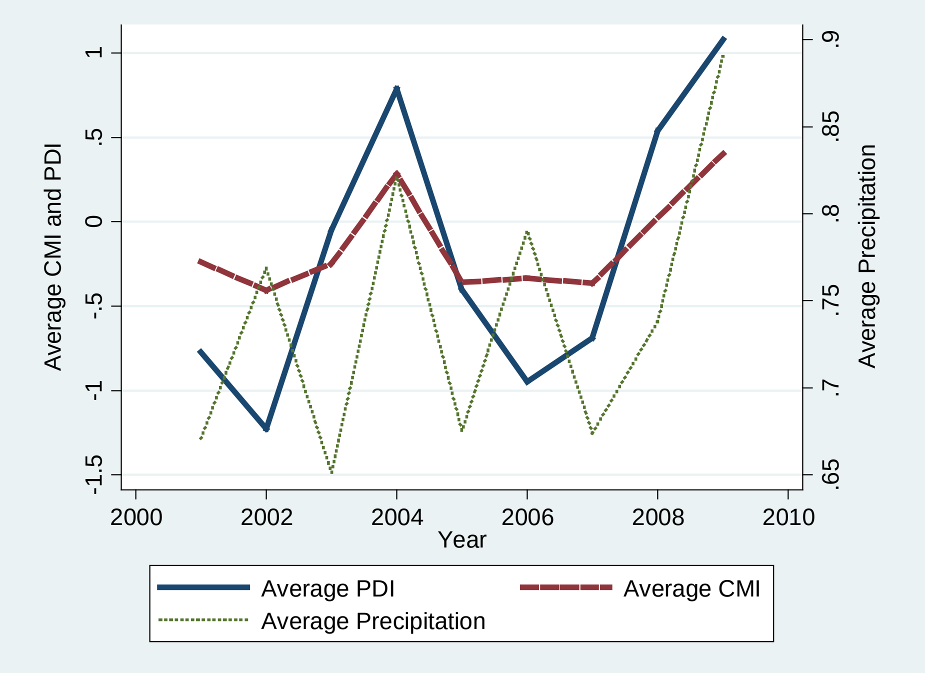


Figure 5
Average PDSI and Farm Profits

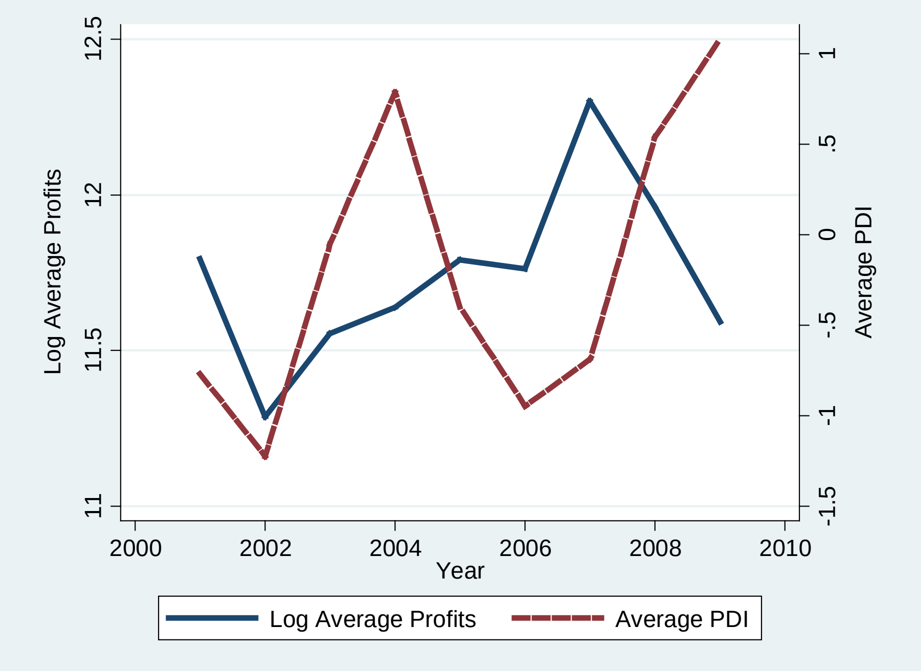
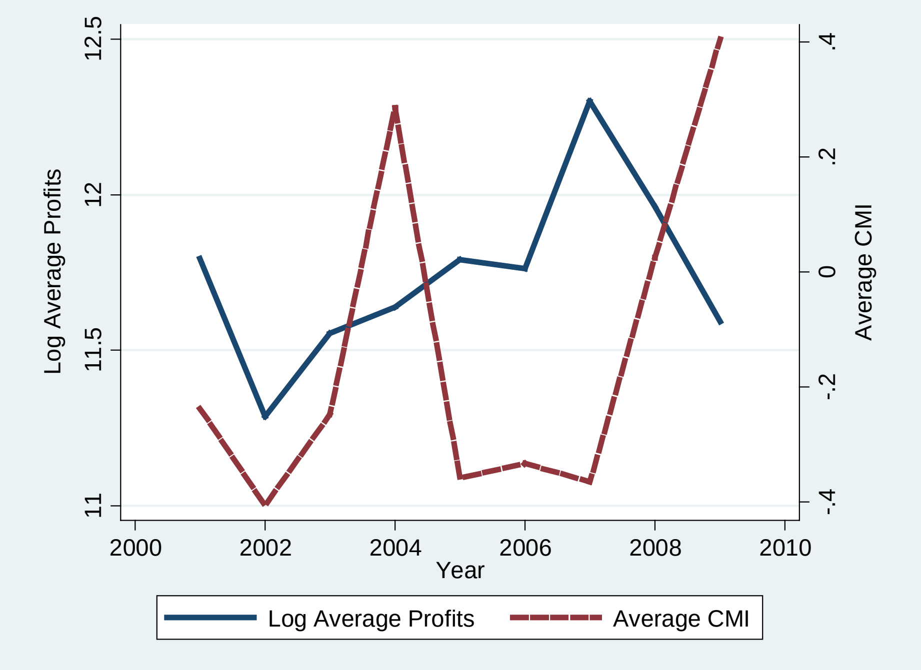


Figure 6
Average CMI and Farm Profits



Chapter 3. Does Weather Affect the Farmers’ On-farm Labor Supply?

Abstract

In this paper, I use a static labor supply model to estimate the impact of weather on the farmers’ on-farm labor supply directly unlike the previous literature. The results suggest that there is an inverse U-shape relationship between temperature and farmers’ labor supply. Farmers’ labor supply is minimized between 50-70 degrees Fahrenheit. Consequently, it can be concluded that temperature is a substitute for labor until around 60 degrees. However, more labor is required after the temperature passes that threshold. Unlike temperature, the relationship between precipitation and labor supply is linear. The more precipitation a farm gets throughout the year, the more labor is supplied by the farmer. This is maybe because of the possibility that in my data set the observed precipitation may be already in the optimal range. The results show that precipitation and labor are complements.

1. Introduction

Weather affects people's job performance and work-load directly and indirectly although its effects vary by type of work and individual. Weather conditions are especially more directly related to people whose working places are mainly outdoor settings such as people working in agriculture, construction, leisure/sports business, manufacturing, and transportation industries.

For example, Zivin and Neidell (2010) argue that unfavorable weather conditions, namely higher temperature, can cause change in time allocation on work by altering the marginal productivity of labor or the marginal cost of supplying labor. More specifically, if the temperature increases, workers' performance decreases. Therefore, marginal product of labor diminishes. In addition, the hot weather may result in unpleasant or unhealthy work environment, making work more costly.

Weather conditions do have a crucial impact on the demand side of labor market in the agricultural sector, as well. One mechanism through which weather influences labor demand is through the farm profits. This is indirectly demonstrated by the previous research. Farmers or their family members tend to increase their labor supply in *off-farm* work under unfavorable weather conditions in order to maintain their consumption levels (Kochar 1999; Rose 2001; Cameron and Worswick 2003; Ito and Kurosaki 2009). That is, these researchers implicitly argue that when the weather conditions are not ideal for farm production, the farmer's family seek employment elsewhere, and reduces the amount of time they allocate on on-farm work.

In this paper, I test the same hypothesis in a more direct way by investigating the relationship between farm operator's *on-farm* labor supply and weather conditions. The research question in this paper is whether the farmers actually reduce the time spent on on-farm work. This is the first paper that investigates the relationship between weather conditions and individual's on-farm labor supply. The closest to my work is that of Zivin and Neidell (2010) who looks at the impact of weather conditions on overall labor supply, not specifically in the agricultural sector.

The secondary question in this paper is whether on-farm labor supply and favorable weather conditions are substitutes or complements. There are arguments for both. For example, there is a positive relationship between favorable weather conditions and the operator's income from farm through production function. More specifically, the more favorable weather conditions are, the more farm output will be produced. As a result, the operator will have to work more in the farm.[16] If this hypothesis holds, then operator's labor and favorable weather conditions are complements. That is, the operator works more in the farm when weather conditions become better, other things are equal. On the other hand, operator's labor and favorable weather conditions can be substitutes. For example, if the weather conditions are severely bad, such as in the case that it rains heavily and the farm area is flooded, the operator has to work more to prevent the crops from going bad. This second mechanism suggests that operator's labor and favorable weather conditions are substitutes.

In this paper, I use a static labor supply model in which the farm operator maximizes utility subject to time and budget constraints. Budget constraint dictates that operator's consumption is equal to his or her earnings which are composed of his on and off-farm incomes. Temperature variables enter into the model through production function. Total output is a function of weather, and so is the hours worked by the farm operator. More details are provided in the Conceptual Model section.

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[16] If the weather conditions are good, then for example, there will be more, say, tomatoes produced. More output will require more labor on the operator's side.

2. Data and Methodology

2.1. Conceptual model

The purpose of this paper is to measure the impacts of weather variables on on-farm labor supply decision, while controlling for prices, farm characteristics, and individual characteristics additionally. For the analysis the static labor supply model (Household model) is used following by Ahearn et al. (2006). The farm operator maximizes utility depicted by the equation (1) subject to budget and time constraints (2-4).

(1)

where C stands for individual's consumption and L represents leisure. The price of consumption good is normalized to one.

It is assumed that there are three activities the farm operator can allocate their time to: farm work, off-farm work and leisure. These options are reflected in the time constraint below:

(2)

L, F and J stand for leisure, farm work and off farm work.

The budget constraint imposes that the total consumption of the operator equals their earnings.

(3)

The two sources of operator's earnings are earnings from the farm and off-farm. w defines the operator's wages from off farm work. p and Q are the price and total farm output.

The variable "Hours worked by the Operator" enters the budget constraint through production function shown below:

(4)

X is the inputs of production; HC is the human capital of the operator and Weather represents the weather conditions described by temperature and precipitation.

Since all farm operators work positive hours at the farm (by definition), I ignore the decision to work and focus on the interior solution (equation 5).

(5)

F* stand for the optimal time allocated to the farm work by the operator. represents all the exogenous variables of the model, such as X, HC, and w.

2.2. Econometric Model

The empirical counterpart of the equation (5) is described below:

(6)

where represents the hours worked by the operator of the individual farm *i* in county *c* at year *t*. The equation includes a set of indicators for counties and years, and . stands for climate variables, their squares and their interaction. Specifically, temperature and precipitation are included in the regressions. The indices are the average of the temperature and precipitation of the county throughout the year. represents the input price and output price indices. Both input and out prices indices consist of categories of agricultural production inputs and outputs. The output price index for “all farm products” category is used. Input price index reflects costs of several categories of factors of production, such as feed, seeds, fertilizer, chemicals, fuels, farm machinery, building material, farm services, and labor. The average of these factor price indices is used in the analysis. is a vector of farm and its operator’s characteristics. More specifically, includes an indicator for whether the farm is a professionally-owned business or non-family owned business. In addition, the land area of the farm and the farm operator’s age, gender, and education level are included. The standard errors are clustered at the county level in order to correct for the possible correlation in unobservable characteristics of the farms located in the same county.

2.3. Data

The empirical analysis utilizes pooled cross-sectional data that is mainly based on the annual Agricultural Resource Management Survey (ARMS)-Phase III from U.S. Department of Agriculture (USDA)-Economic Research Service for the time period between 2000 and 2009 in the 48 contiguous States. Due to the fact that ARMS is the only national survey that provides individual farm-level observations, it gives detailed farm structure and financial information for the analysis. The outcome variable is the operator’s labor supply. These data are obtained from Agricultural Resource Management Survey (ARMS).

Variables of interest are weather variables that are temperature and precipitation. Weather data are obtained from National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center.

Input and output prices data are obtained from Monthly Agricultural Prices Summary from USDA-National Agricultural Statistics Services (USDA-NASS). The data are in fact indices of agriculture prices and weighted 1990-1992 average equals 100. Each index of input prices represents categories of all production inputs that are feed, livestock and poultry, seeds, fertilizer, chemicals, fuels, supplies and repairs, autos and trucks, farm machinery, building material, farm services, rents, interests, taxes, and wage rates. Since these indices are highly correlated to each other, an average input price index is used in the analysis.[17]

The remaining control variables for farm structures and operator characteristics that are used in the analysis are obtained from the annual Agricultural Resource Management Survey (ARMS). The set of control variables include the land area of the farm in acres (*Acres*), indicators for whether the farm mainly produces crops and whether the farm is a non-family business. In addition, farm operator's characteristics are included among covariates. The operator characteristics considered are age and gender of the farm operator and an indicator for whether the operator has obtained a college degree.

The definitions of the variables used in the estimation are presented in Table 18. Table 19 provides the summary statistics of the variables.

3. Results

Table 20 provides the results of estimating equation (5) using OLS. In column 1, only the weather variables that are temperature and precipitation are included as the control variables. The regression in column 2 additionally controls for farm characteristics and prices. In column 3, I control for operator characteristics, as well. The model in the third column has the most extensive set of control variables. All models include year dummies. Standard errors are clustered at the county level.

The coefficients of the temperature variables are identical in all regressions. The relationship between temperature and operator's labor supply is inverse U-shaped which is maximized at around 83 degrees Fahrenheit. This is consistent with the literature in that the optimal weather temperature for crops to grow and develop is between 64 to 77 degrees

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[17] Kelly, Kolstad, and Mitchell (2005) also use an aggregate input price index for their agricultural profit analysis using a sample of 5 U.S. states including Illinois, Iowa, Kansas, Missouri, and Nebraska. They also use the same price indices data from USDA-NASS as I use in my analysis.

Fahrenheit (Schlenker and Roberts, 2008). When the temperature is about the optimal, crops grow well. However, when weather condition is ideal for crops, weeds also grow fast and other problems arise such as pests and diseases (Hatfield, 2012). Therefore, the operator will not only have to deal with crops but also these factors that affect negatively on crop growth. Since the output becomes much larger under good weather condition, the operator has to spend more time on the farm. Precipitation is linearly related the operator's labor supply. If the precipitation per day increases by one inch, then operator works about 1,500 additional hours per year. Although, this seems like a too large of an increase, the sample mean of precipitation is 0.7 inches per day. The implied elasticity of labor supply with respect to precipitation is about 0.5. Similar to the temperature, it could be the case that more rain helps the growth of crops, and with more crops the operator has more to deal with.

Interaction variable between temperature and precipitation has a negative effect and is a significant at 1%. For example, in regression (3) its coefficient is -28.3. That is, the impact of temperature on labor supply decreases by about 28 hours for each inch increase in precipitation.

The coefficients of the control variables are of the expected signs. The more the operator is paid, the more hours they work. A one percent increase in the salaries of the operator leads them to work about 0.02 percent more from an average of 2,200 hours per year. An increase in the off-farm income of the operator is associated with a decrease in the hours worked in the farm. In this context, off-farm income can be viewed as non-labor income in the static labor supply model. The operator's working hours on the farm rises with the amount of land processed. The coefficients of the price variables are insignificant. More educated operators work less than their less educated counterparts. This could be because, the operators with a higher education have greater opportunity cost of working in the farm, and therefore, they could be pursuing other jobs outside the farm. Specifically, operators who have college degree or more works about 300 hours per year less compared to those whose highest grade completed is less than high school. Older and female operators work less compared to younger males.

Table 21 shows the regression results of the impact of weather on on-farm labor supply using the sub-samples of male and female primary operators. The analysis is also restricted to crop farms only in order to see the relationship between weather condition and the labor supply of a crop farm since crops are mostly more sensitive to weather condition compared to livestock. Among the primary operators working on the crop farms, the majority is a male operator as it is shown in Table 21. With the male primary operator sample, both temperature and its square term are significant at the 1% and 5%, respectively. The signs indicate that the relationship between temperature and the male operator's on-farm labor supply is inverse U-shaped which is maximized at around 85 degrees Fahrenheit. Precipitation is also positively associated with the labor supply and significant at the 1% level. However, the squared term of precipitation is insignificant and it implies the linear relationship between the precipitation and labor supply therefore. The effects of all other control variables are similar to the model with the whole crop farm sample shown in Table 20. The main difference in the model with the female sample from the one with the male sample is that temperature does not affect on the labor supply although the sample is very small compared to the male counterpart. The impact of education is also different from the result with the male sample. Education does not play a role in the labor supply while the more educated operators tend to work less among the male operators.

Table 22 provides the impact of weather on on-farm labor supply by the selected regions. The analysis is estimated by 4 different regions. The Southeast region includes Alabama, Georgia, Mississippi, Louisiana, and South Carolina. The Midwest region includes Illinois, Indiana, Iowa, Minnesota, Missouri, Ohio, and Wisconsin. The West region is represented by Arizona, California, and Nevada. Finally, the Northeast region includes Connecticut, Delaware, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. In the hot places such as the Southeast and the West regions, the relationship between temperature and operator's labor supply shows the U-shape which are minimized at around 67 and 70 degrees Fahrenheit. However, temperature is insignificant in the West region. On the other hand, in the cool places such as the Midwest and Northeast regions, it shows the inverse U-shaped relationship between temperature and operator's labor supply with the maximum point at about 48 and 76 degrees Fahrenheit.

4. Summary and Conclusion

In this paper, I use a static labor supply model to estimate the impact of weather on the farmers' on-farm labor supply directly unlike the previous literature. Specifically, the previous literature has analyzed the same question indirectly by testing whether weather changes farmers' off-farm labor supply. The majority of these papers (that are cited in the Introduction section) find that when the weather conditions are unfavorable, the farmers and their families seek employment outside of the farm. This implicitly suggests that farmers reduce the amount of time they allocate on the on-farm work. Secondly, I investigate whether favorable weather conditions and farmer's labor supply are substitutes or complements.

I use the ARMS (Agricultural Resource Management Survey) data to empirically test the questions posed above. My results suggest an inverse U-shape relationship between temperature and farmers' labor supply. Farmers' labor supply is maximized around 80 degrees Fahrenheit. Consequently, it can be concluded that temperature is a complement for labor until around 80 degrees. However, less labor is required after the temperature passes that threshold. Unlike temperature, the relationship between precipitation and labor supply is linear. The more precipitation a farm gets throughout the year, the more labor is supplied by the farmer. This could be explained that the observed precipitation may be already in the optimal range in my data set. The results show that precipitation and labor are complements.

Table 18
Variable Definitions

Hours Worked	Annual on-farm working hours (unit in hour)
Temperature	Annual average of the temperature (degree in Fahrenheits)
Temperature Sq	Square term of the temperature
Precipitation	Daily average of precipitation in a county (unit in inches)
Precipitation Sq	Square term of the precipitation
*Temp*Precip*	Output price index of crop production (base: 1990-1992 = 100)
Input Price	Input price index of agricultural production (base: 1990-1992 = 100)
Output Prices	Output price index of agricultural production (base: 1990-1992 = 100)
Op.On-farm Income	Operator's income from farm work
Op.Off-farm Income	Operator's income from off-farm work
Acres	Acres operated
Non-family Farm	=1 if the farm is non-family farm.
Operator Education	Operator's highest degree attained. =1 if less than high school, =2 if high school or GED, =3 if some college, =4 if associates degree, =5 if college degree or more.
Operator Age	Age of the primary operator
Operator female	=1 if the primary operator is female

Table 19
Summary Statistics

Variable	Obs.	Mean	Std. Dev	Min	Max
Hours worked	124,615	2236.617	1289.482	0	7000
Temperature	124,615	54.745	7.686	35.360	76.612
Precipitation	124,615	0.718	0.294	0.030	2.122
Op. Farm income	124,615	3469.763	18819.960	0	***
Op. Off-farm income	124,615	30652.570	68645.040	0	***
Acres	124,615	1338.933	7653.524	0	***
Input Prices	124,615	154.782	26.159	120.571	198
Output Prices	124,615	122.569	18.762	91	169
Farm Type	124,615	1.475	0.499	1	2
Operator’s education	124,615	2.662	0.961	1	5
Operator age	124,615	55.256	12.450	14	***
Operator gender	124,615	1.054	0.226	1	2

Maximum values of some variables are censored by USDA.

Table 20
The Impact of Weather on the Primary Operators' On-Farm Labor Supply (whole crop farm sample)

	(1)		(2)		(3)	
Variables	Coef.	Robust S.E.	Coef.	Robust S.E.	Coef.	Robust S.E.
Temperature	40.497**	21.096	48.183***	19.017	49.981***	17.711
Temperature Sq	-0.382**	0.198	-0.301*	0.179	-0.302*	0.166
Precipitation	-234.250	363.817	1684.759***	361.998	1557.980***	341.144
Precipitation Sq	157.182	131.647	-108.773	115.584	-59.055	118.501
Temp * Precip	-5.403	7.388	-28.570***	6.604	-28.297***	6.383
Salary from farm work			0.012***	0.001	0.011***	0.001
Off-farm Income			-0.002***	0.000	-0.002***	0.000
Acres			0.451***	0.029	0.423***	0.028
Input Price			-0.230	2.318	1.773	2.254
Output Price			0.684	2.964	-1.092	2.866
Op-Education						
High School					-136.055***	40.427
Some college					-33.501	43.116
Associates degree					-163.407***	43.737
College or more					-277.506***	63.644
Op-Age					-13.121***	0.820
Op-Female					-472.729***	37.035
Constant	529.225	578.902	-596.572	525.639	-4.818	452.247
Observations	65924		65924		65924	
R^2	0.011		0.169		0.212	
F-stat	9.97***		51.50***		53.57***	

Note: The dependent variable is the *Annual Hours Worked by the Farm Operator*. All regressions include county fixed effects and year dummies. The descriptions and summary statistics of the variables are in Table 1 and 2, respectively. Standard errors are clustered at the county level. *, **, ***

Table 21
The Impact of Weather on Male and Female Operators' On-Farm Labor Supply

	Male		Female	
Variables	Coef.	Robust S.E.	Coef.	Robust S.E.
Temperature	51.021***	18.271	64.294	54.498
Temperature Sq	-0.336**	0.171	-0.256	0.515
Precipitation	1416.965***	357.684	2084.642**	840.589
Precipitation Sq	-131.591	122.730	655.319**	267.506
Temp * Precip	-24.337***	6.721	-53.676***	17.473
Salary from farm work	0.011***	0.001	0.023***	0.004
Off-farm Income	-0.002***	0.0002	-0.0007***	0.0002
Acres	0.424***	0.028	0.221***	0.061
Input Price	0.898	2.382	10.842*	6.041
Output Price	0.115	3.027	-13.082*	7.674
Op-Education				
High School	-131.349***	42.373	-129.953	116.320
Some college	-14.983	45.540	-145.602	110.367
Associates degree	-170.854***	46.109	-88.327	117.802
College or more	-266.786***	67.205	-364.307	223.131
Op-Age	-12.720***	0.887	-16.202***	2.105
Constant	488.114**	256.312	-639.947	1474.683
Observations	63037		2887	
R^2	0.199		0.110	

Note: The dependent variable is the *Annual Hours Worked by the Farm Operator.* All regressions include county fixed effects and year dummies. The descriptions and summary statistics of the variables are in Table 1 and 2, respectively. Standard errors are clustered at the county level. *, **, ***

Table 22
The Impact of Weather on On-Farm Labor Supply by Selected Regions

	Southeast		Midwest		Pacific		Northeast	
Variables	Coef.	Robust S.E.	Coef.	Robust S.E.	Coef.	Robust S.E.	Coef.	Robust S.E.
Temperature	-1840.006***	585.156	470.572***	75.985	-167.249	121.299	378.743***	169.174
Temperature Sq	13.988***	4.381	-4.859***	0.989	1.215	0.904	-2.625	1.842
Precipitation	-8759.392***	3380.02	-1128.087	1664.025	-4827.339	5113.993	7526.706	5161.671
Precipitation Sq	532.483	607.407	-169.242	832.812	861.197	726.211	-1494.421	2170.742
Temp * Precip	108.701**	48.651	23.336	50.754	64.701	85.213	-103.014	76.994
Salary from farm work	0.013***	0.002	0.007***	0.002	0.011***	0.001	0.011***	0.002
Off-farm Income	-0.002***	0.0005	-0.002***	0.0004	-0.001***	0.0004	-0.002	0.001
Acres	0.537***	0.049	0.904***	0.055	0.185***	0.062	0.819***	0.134
Input Price	2.305	9.857	-1.236	3.097	6.960	6.818	1.820	13.169
Output Price	-2.656	12.324	4.524	3.838	-6.180	9.166	-5.117	16.932
Op-Education								
High School	-185.799	139.723	-139.126*	73.200	18.329	171.157	-36.728	204.824
Some college	-121.394	149.070	-26.749	76.437	-19.206	180.039	51.928	184.656
Associates degree	-352.292**	141.036	-193.514**	78.912	-3.411	170.055	27.083	196.521
College or more	-350.036*	190.526	-183.663	133.537	-180.008	213.802	-460.194	314.558
Op-Age	-14.235***	3.387	-9.607***	1.356	-5.737***	2.446	-10.091***	3.989
Op-Female	-420.286***	100.106	-490.875***	49.029	-241.651	147.623	-176.097	170.440
Constant	63769.61	19673.34	-11216.78***	2367.296	5431.518***	991.484	-1971.672	2351.887
Observations	5321		21267		5218		1388	
R^2	0.303		0.299		0.116		0.129	

Table 23
Marginal Impacts of Weather Variables on On-farm Labor Supply by Selected Regions (crop farm sample)

Regions	Southeast	Midwest	West	Northeast
Temperature	73.049***	9.387*	6.675	34.447***
Precipitation	-675.271***	-232.388*	-196.525	-121.509

*** significant at 1%   ** significant at 5%   *significant at 10%

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