WPS4470

POLICY RESEARCH WORKING PAPER 4470

# Can China Continue Feeding Itself?

## The Impact of Climate Change on Agriculture

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The World Bank
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January 2008

## Abstract

Several studies addressing the supply and demand for food in China suggest that the nation can largely meet its needs in the coming decades. However, these studies do not consider the effects of climate change. This paper examines whether near future expected changes in climate are likely to alter this picture. The authors analyze the effect of temperature and precipitation on net crop revenues using a cross section consisting of both rainfed and irrigated farms. Based on survey data from 8,405 households across 28 provinces, the results of the Ricardian analysis demonstrate that global warming is likely to be harmful to China but the impacts are likely to be very different in each region. The mid latitude region of China may benefit from warming but the southern and northern regions are likely to be damaged by warming. More precipitation is beneficial to Chinese farmers except in the wet southeast. Irrigated and rainfed farmers have similar responses to precipitation but not to temperature. Warmer temperatures may benefit irrigated farms but they are likely to harm rainfed farms. Finally, seasonal effects vary and are offsetting. Although we were able to measure the direct effect of precipitation and temperature, we could not capture the effects of change in water flow which will be very important in China. Can China continue feeding itself if climate changes? Based on the empirical results, the likely gains realized by some farmers will nearly offset the losses that will occur to other farmers in China. If future climate scenarios lead to significant reductions in water, there may be large damages not addressed in this study.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to mainstream research on climate change and policy implications. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at jxwang.ccap@igsnrr.ac.cn, robert.mendelsohn@yale.edu, and adinar@worldbank.org.

Produced by the Research Support Team

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## The Impact of Climate Change on Agriculture

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"The authors would like to thank Jianming Cao, Cheng Cheng, Yumin Li and Hao Li for their assistance in data cleaning. The paper benefited from review comments by Hui Liu, Wolfram Schlenker and Apurva Sangi. We also thank the State Office of Agricultural Comprehensive Development in China (SOCAD) for their support - the writing of this paper took place in parallel with work carried in the context of the proposed Global Environmental Facility financed project "Adaptation to Climate Change" to be implemented by SOCAD. Additional support was provided by DECRG in the World Bank. The views expressed in this paper are those of the authors and should not be attributed to the World Bank."

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## I. Introduction

For quite some time, global food security issues have been in the center of a policy debate in the economic literature. One of the major aspects of this debate has been the role of China, a giant economy currently with a population of 1.30 billion, 20% of the world's population, and with expected population growth rate of 1.2-2.3 percent per year into the next decade (CIA 2007). China's share in the world's production of primary agricultural commodities is significant, mainly in grains, soybean, and cotton. In 2003, China's share was 15, 30, 17, 19, and 31 percent for wheat, rice, maize, soybean, and cotton, respectively (Winters and Yusuf, 2007:16). According to Census data (CNBS, 2001), shares of these crops in five of China's provinces (Hebei, Henan, Shandong, Anhui and Jiangsu), considered the bread basket of China, range between 70-80 percent of the area sown.

With projected increases in population and standard of living in China, feeding larger numbers of more affluent people could become a challenge if not accompanied by increased supply (Paarlberg (1997). Several studies provide grain production projections into the not so distant future, but variations in the estimates are quite wide. Fan and Agcaoili-Sombilla (1997) compare several studies with projections of grain production in China (Brown 1995; Rosegrant, Agcaoili-Sombilla, and Perez, 1995; Huang, Rozelle, and Rosegrant 1997; Tuan 1994; Mitchell and Ingco, 1993; and OECF, 1995). The reasons for the differences in projections among these studies are beyond the scope of this paper. However, one common feature of all these studies is that they do not take into account the potential effect of future climate change on agricultural production.

As scientific evidence becomes more convincing that rising greenhouse gases will warm the planet (IPCC 2007), it has become ever more important to understand the impacts of global warming. The impacts to the agriculture sector from climate change are among the largest and best documented. Agronomic studies suggest that crop yields may fall if the same crops are grown in the same places under various climate change scenarios (Reilly et al. 1996, McCarthy et al 2001). Studies applying the Ricardian Approach in Africa (Kurukulasuriya et al 2006) and South America (Seo and Mendelsohn 2007) suggest that warming will reduce farm net revenues. However, no single country is more important than China in terms of the number of people at risk and the impact on the world economy that may result from future climate change. Will China continue to be able to feed itself as the climate warms?

Many agronomic modeling studies have assessed the impacts of climate change on several grain crops (e.g., rice, maize, wheat) in various regions of China. The general findings of these studies are that crop yields will fall in China like those in other developing countries (e.g., Matthews and Wassmann, 2003; Parry et al., 2004; Tao et al., 2006; Wu et al., 2006; Xiong et al., 2007; Yao et al., 2007). These and other crop modeling studies have the same caveat in that they assume the same crops are grown in the same places as climate changes. Further, crop modeling studies in China do not include any economic values attached to the estimated yield reductions. And, there are no agro-economic models (such as Adams et al., 1995) that convert crop modeling results into economic outcomes for China.

The only economic study in China to date of the effect of warming on agriculture is a Ricardian analysis (Liu et al. 2004). Curiously, this study finds that warming will increase average farm net revenue, not reduce it. However, this Ricardian study is based on county level data with severe data limitations. Therefore, it is difficult to weigh the results of this study in comparison to the results of the host of crop studies that suggest that warming is harmful. Thus, there is not sufficient evidence to determine whether China can continue feeding itself given global warming.

To answer this question, this paper reports the results of a new study that measures the sensitivity of Chinese agriculture to warming, employing farm level data. Like the Liu et al., (2004) study, the analysis in this paper relies on the Ricardian method (Mendelsohn, et al., MNS 1994). The analysis is conducted on 8,405 farms sampled across 28 provinces. The data include information on each farm's economic operations, locational data, and other farm characteristics. Net revenue per hectare is regressed on climate and a number of other exogenous control variables. Matching the location to climate data (rainfall and temperature) and soils, it is possible to examine the effect of climate on net revenue controlling for many other factors.

The available data allow us to measure econometrically the direct effects of temperature and precipitation on crop net revenues. Unfortunately, the amount of irrigation water a farmer uses is not available in the dataset. Although we know whether each farm is irrigated or not, we do not know water availability or cost. If future climate scenarios reduce available water supplies, this is likely to have an important harmful effect on China's agriculture that this study does not take into account. The analysis does not capture the indirect effect of climate change on crop net revenues through the supply of irrigation water and should be addressed in future studies.

The paper is organized as follows. We briefly review the methodology of the Ricardian method in the next section. Section III discusses the available data and the construction of the data set. In the Section IV, we present the estimation results and simulation of national and regional impacts for marginal changes in climate. The paper concludes with a summary of the key results, a discussion of policy relevance, and suggestions for future research.

## II. METHODOLOGY

The Ricardian approach (MNS 1994) is the primary method that we use in the analysis in this paper. The Ricardian model assumes that each farmer wishes to maximize income subject to the exogenous conditions of their farm. Specifically, the farmer chooses the crop and inputs for each unit of land that maximizes:

$$Max \quad \pi = \sum_i P_{q_i} Q_i(X_i, L_i, K_i, IR_i, C, W, S) - \sum_i P_x X_i - \sum_i P_L L_i - \sum_i P_K K_i - \sum_i P_{IR} IR_i \qquad (1)$$

where π is net annual income, $P_{qi}$ is the market price of crop *i*, $Q_i$ is a production function for crop *i*, $X_i$ is a vector of annual inputs such as seeds, fertilizer, and pesticides for each crop *i*, $L_i$ is a vector of labor (hired and household) for each crop *i*, $K_i$ is a vector of capital such as tractors and harvesting equipment for each crop *i*, *C* is a vector of climate variables, $IR_i$ is a vector of irrigation choices for each crop *i*, *W* is available water for irrigation, *S* is a vector of soil characteristics, $P_x$ is a vector of prices for the annual inputs, $P_L$ is a vector of prices for each type of labor, $P_K$ is the rental price of capital, and $P_{IR}$ is the annual cost of each type of irrigation system.

If the farmer chooses the crop that provides the highest net income and chooses each endogenous input in order to maximize net income, the resulting chosen net income will be a function of just the exogenous variables:

$$\pi^* = f(P_q, C, W, S, P_X, P_L, P_K, P_{IR}) \qquad (2)$$

With perfect competition for land, free entry and exit will ensure that excess profits are driven to zero. Land rents will consequently be equal to net income per hectare (Ricardo 1817; MNS, 1994).

The Ricardian function is intended to be a locus of the most profitable crops with respect to each exogenous variable such as temperature. The net income function does not include less profitable alternatives. It consequently does not look like the response function for any single crop but rather as a flatter function across all choices. Figure 1 depicts a theoretical set of crop specific net income functions with respect to temperature as well as the overarching Ricardian function. For example, at cool temperatures, farmers would choose to grow wheat (*Triticum aestivum* L.). As temperatures rise, farmers would no longer want to grow wheat because it would become less profitable. They instead would shift to maize (*Zea mays* L.). As temperatures increase further, they might want to shift to fruit (*Panicum miliaceum*) or vegetables which are more heat tolerant. The Ricardian function, Equation (2), captures the locus of maximum profits for each temperature or precipitation level. It is estimated across crops and across inputs, revealing the net effect of changing the exogenous variable. Because farmers are assumed to make adaptations that are profitable, the method automatically captures the adaptation inherent in the market (MNS, 1994).

The Ricardian model was developed to explain the variation in land value per hectare of cropland over climate zones (MNS, 1994). In repeated studies in the United States, Brazil, Sri Lanka and South America, the land value per hectare of cropland has been found to be sensitive to seasonal precipitation and temperature (Mendelsohn and Dinar 1999; 2003; Seo et al. 2005; Seo and Mendelsohn 2007). Similar results have also been found for crop net revenue in India, Africa, South America, and Israel (Mendelsohn and Dinar 1999; Kurukulasuirya et al 2006; Seo and Mendelsohn 2007; Fleischer et al. 2007). Because the response is nonlinear, a quadratic functional form has been used in every Ricardian study.

There have been a number of criticisms of the Ricardian approach since it was first developed. There was initially a concern about irrigation (Cline 1996; Schlenker et al 2005). This study and other analyses (Mendelsohn and Dinar 2003; Kurukulasuriya and Mendelsohn 2006; Mendelsohn and Seo 2007) address this concern by examining the differences in the response to warming between irrigated and rainfed land. A related concern is the importance of water.  Some studies have controlled for water supply (Mendelsohn and Dinar 2003 and Fleisher and Mendelsohn 2007).  However, water data is not available in this study.  This is important since climate change may reduce (or increase) the amount of water that is available to farmers and this effect is not captured in this analysis.  Given China's clear dependence on irrigation water, this is an important omission.

There have also been concerns about the role of price changes (Quiggin and Horowitz 1999).  The Ricardian model does not take into account price changes and thus will overestimate welfare effects.  Although changes in local supply might be dramatic, prices of food crops tend to be determined by global markets.  With the expansion of crop production in some parts of the world and the contraction in others, the changes in the price of crops from global warming is expected to be small (Reilly et al. 1994).  Finally, there is a concern that the Ricardian analysis does not take into account the cost of transition (Kelly et al 2005).  Although we expect transition costs to be relatively small, the Ricardian method does not measure them.

## III. DATA AND MODEL SPECIFICATIONS

The climate data (monthly temperature and precipitation) were gathered from the National Meteorological Information Center in China.   The data are based on actual measurements in 753 national meteorological stations that are located throughout China.  The temperature and precipitation data were collected from 1951 to 2001. We rely on the mean values of these variables (climate normals) over this time period for each month.

Because we cannot include every month in the analysis because of the high correlation from month to month, we average the monthly climate data into four seasons.  Winter is the averaged of December to February, spring is the average of March to May, summer is the average of June to August, and fall is the average of September to November.

Socio-economic data come from China's National Bureau of Statistics (CNBS).  The data were collected by a highly trained, professional enumeration staff in 2001 as part of the annual, nation-wide Household Income and Expenditure Survey (HIES).  The data cover 45,700 farm households in 4365 villages, 533 counties and 31 provinces.

During the survey enumerators from CNBS collected a rich set of information at both the village and household level.  The data provide us with a measure for the dependent variable, net crop revenue for each household. Net crop revenue here is the gross crop revenue (or total sales for each crop) less all expenditures for production, including expenditures on seed, fertilizer, irrigation, pesticide, machinery, plastic sheeting, hired labor and custom services. All of the output that was consumed by each household was given a value based on a price of the output as if it was sold on the market. Neither family labor nor a household's rent for contracted land is counted as an expenditure. Therefore, net revenue is a measure of returns to land and family labor. Based on the total cultivated land of each household, we can calculate net crop revenue per hectare.

The data set also includes a number of other household and village characteristics. These variables are important from a theoretical point of view since they can give us measures of fixed factors which belong in Ricardian regressions. Using the data, we are able to construct variables that measure the education level of members of the farm household, each family's land area, a number of indicators about the topographical environment of each village (e.g., if it is located on a plain or in a mountainous region), each household's irrigation status (measured as the share of area that is irrigated in the village) and the ease of access to markets (e.g., the presence of paved roads between the village and key services; the distance to each township's government). Such variables are used as control variables in the regressions. Descriptive statistics of the key variables are in Table 1. The Table provides key data about the entire sample as well as two important subsamples: farms that rely on irrigation and farms that do not (rainfed).

In addition to information about climate and socio-economic conditions, the characteristics of a region's soils are also important determinants of net crop revenue. To account for soils, we downloaded a soil map from FAO's website. There are three major soil types—clay, sand and loam soils. The final set of variables for our analysis was created by generating a variable measuring the share of cultivated area with each type of soil. These soil variables are used directly in the regression. We also include county elevation data into the regression to control the influence of elevation on net crop revenue.

In order to proceed with our analysis of the effect of climate on agriculture, we need to match the climate data with the socio-economic data of each farmer. Although there are 752 counties with meteorological stations and 533 counties in which CNBS collected HIES data, there are only 124 counties in which there are both meteorological stations and CNBS samples.

In order to ensure that we have a relatively good match between the crop revenue (and other socio-economic) data and climate information, we restrict our sample to only those households in counties with meteorological stations. In total, this means that our final sample has 8405 households in 915 villages, in 124 counties in 28 provinces.[1]

**Model Specifications**

In order to capture the expected nonlinear relationship between net revenue and climate, we specify the following model to examine the impacts of climate change on agriculture in China:

$$V = b_0 + b_1 \cdot T + b_2 \cdot T^2 + b_3 \cdot P + b_4 \cdot P^2 + \sum_j d_j \cdot Z_j + e \tag{3}$$

where the dependent variable, *V*, is net crop revenue per hectare (as defined above). The variables *T* and *P* represent vectors of temperature and precipitation (four seasons). In addition, we include *Z*, a vector of county-, village- and household-level socio-economic and other control variables. Included in *Z* are our measures of soil type (Z1), elevation of the county (Z2), terrain (Z3=1 if the village is located on a plain and 0 if the village is in a mountain), the share a village's cultivated area that is irrigated (Z4), the conditions of a village's road (Z5=1 if there is a road that connects the village to the outside world and 0 if there is not) and a variable measuring the distance between the village and township government (Z6). There are also a series of household-level variables in Z, including the average education level of the laborers in the family (Z7), a household's land area (Z8) and whether or not a household belongs to a production cooperation (Z9=1 if yes and 0 if no). The symbols $b_k$ and $d_j$ are vectors of the coefficients to be estimated, and *e* is an error term.

In order to assess the robustness of the model, we try a number of alternative specifications of equation 3. For example, we also try using the log of net revenue as the dependent variable. We test whether precipitation and temperature are independent by adding

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[1] We have tried various approaches (such as linear and non-linear regression; GIS methods) to extrapolate the climate data from the location of the meteorological stations in the counties with weather data across the landscape of counties and villages in adjacent counties (or those counties without weather data). However, our results suggest that such extrapolation methods introduce substantial amounts of data measurement error into the analysis. In order to avoid such measurement error in the climate variables, we have chosen to drop all farm households that are in counties that do not have climate data (i.e., that do not belong to a county with a meteorological stations). In addition, we dropped those households which did not cultivate any crops (characterized with total cropping sown areas of zero).

climate interaction terms. We break the sample between irrigated and rainfed villages and estimate separate regressions for each subsample (Schlenker *et al.* 2005). As in Schlenker et al. (2005), we assume in this analysis that the choice of irrigation is exogenous.

Based on this model, the change in land value from a marginal change in temperature or precipitation evaluated at a particular vector of seasonal temperatures *T* or precipitation *P* is:

$$\begin{aligned}\frac{\partial V_i}{\partial T} &= b_1 + 2 \cdot b_2 \cdot T \\ \frac{\partial V_i}{\partial P} &= b_3 + 2 \cdot b_4 \cdot P\end{aligned} \tag{4}$$

With four seasons, one can calculate the marginal impact of each season. While seasonal effects might be of some interest, the more relevant expression for studying global warming is the overall change in annual climate. The annual marginal effect can be calculated as the sum of the seasonal marginal effects.

## IV. RESULTS

### China's Climate

In general, China's climate is best described as monsoonal (Ren 2007). There are clear temperature and precipitation differences across China that vary by region and by season. The average annual temperature in China is 10.9℃ (Figure 1).[2] From the south to the north, temperature declines steadily. For example, in the southern areas of China the average annual temperature is as high as 20-24 ℃. In the middle part of the country (in the Yangtze River Basin) the average annual temperature is 12-20 ℃. Further north, beginning in the Yellow River Basin and moving to the far north of the country, the average annual temperature is only 4-12 ℃. As typical of temperate regions, the temperature in China also differs significantly by season (Figure 2).

There are even greater seasonal and regional differences in precipitation. Average annual precipitation rates in China as a whole are near world average at about 820 mm (Figure 3). In

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[2] Temperature here means the Surface Air Temperature (SAT).

the south, however, annual precipitation ranges from 1000 to 1500 mm. In the north, in the Huaihe River and Yellow River Basins, annual precipitation is only 600-1000 mm. It is only 500-600 mm in the rest of northern China. Generally, it is also quite dry in Western China.

The seasonal patterns of precipitation also vary by region. In the north, more than 70 percent of each year's precipitation is concentrated in the summer. Precipitation during the winter months is very low, less than 5 percent of the annual total (Ren, 2007). In contrast, in the south, precipitation is mainly concentrated in the spring as well as the summer. These regional differences in climate may be reflected in our results, where climate change has different effects on regions with different present climates.

Recent evidence indicates that global temperatures have been rising since 1750 and especially since 1950 (IPCC 2007). There is supporting evidence in China as well of temperature increases between 1950 and the present (Ren, 2007). Of much greater concern are projections that temperatures will rise even more quickly into the future (IPCC 2007). It is not yet clear how large these temperature changes will be, but climate research consistently predicts warming (IPCC 2007). The exact amount of warming across China is therefore not known, but scientists are confident warming will occur here. The climate models also all predict an increase in global precipitation but how these changes are distributed across different regions is not yet known. Individual locations across China may get more or less rainfall. The change in precipitation patterns is more uncertain than the change in temperature for China.

### Relationship between Net Crop Revenue and Climate

On average, in 2001 the crop net revenue in China was 10,146 Yuan per ha (1353 USD) (Table 1). The reliance on irrigation and the availability of ample rain in certain regions of China has led to relatively high net revenues compared to other countries (even developed countries such as the US) (Rozelle et al., 2007). The high levels of per hectare output in China offset the somewhat lower real prices. These net crop revenues differ by region. In general, net crop revenue in the south is higher than in the north and net revenues are higher in the east than in the west.

Just as significantly, if not more, net crop revenues also vary between villages that are irrigated and those that are rainfed (Table 1). The average net crop revenue in irrigated villages was 12319 Yuan per hectare (1643 USD), a rate that is more than 20 percent higher than average.

In contrast, average net revenues in rainfed villages were only 7464 Yuan per hectare (995 USD), more than 25 percent lower than average.

Simple statistics indicate that there is possibly some relationship between climate and net crop revenue. In Table 2, we group farms by net revenue. Farms with higher net revenues tend to have higher temperatures and more rain. For example, the twenty percent of farms with the lowest net revenues had annual temperatures of 8.2$^{o}$C and annual precipitation of 595mm. In contrast, the twenty percent of farms with the highest net revenue had temperatures of 15.8$^{o}$C and precipitation of 1152 mm. This positive association between net revenue, precipitation, and temperature applies to both rainfed and irrigated farms.

Table 2, of course, does not control for many factors that might vary from farm to farm. In order to do a more complete analysis, we must control for these factors. It is also important to do a more thorough job of exploring the role of seasonal variation in climate. We therefore turn to the Ricardian regressions to do a more thorough analysis of how climate and other factors affect net revenues.

## Ricardian Regression Analysis

In Table 3, we explore a regression model of net revenue per hectare on climate, soils, and a number of farm variables. We examine this regression for three samples: all farms, farms that are irrigated, and farms that are rainfed (no irrigation). Note that there are 8405 farms in the full sample, there are 2750 irrigated farms, and there are 2119 rainfed farms. There are approximately 3500 farms in villages with a mix of rainfed and irrigated farms where we cannot determine whether the farm is irrigated or not. The goodness of fit measures (adjusted $R^2$) for all of the models range from 0.17 to 0.26, a level that is relatively high for cross sectional household data[3].

The analysis of all farms shown in the first column in Table 3 reveals that many of the control variables are highly significant. Clay and silt soils increase net revenues per hectare (compared to sand). It is advantageous for a farmer to be on a plain, have access to a road, and participate in a production association. It is disadvantageous for a farm to be a larger size or

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[3] The adjusted $R^2$ of our estimation results are also similar to that in other countries, for example, in the research of Africa (Kurukulasuriya and Mendelson, 2006), the adjusted $R^2$ is 0.35; for Brazil and India, it is 0.40 and 0.56 separately (Mendelson, et.al., 2007).

higher elevation. Other factors such as whether the village has more irrigated land, laborers with lower education, or is closer to the township government do not matter[4].

Perhaps most important are the results for the climate variables. At least one climate variables is significant in every season except for fall temperature and summer precipitation. Many of the coefficients of the squared terms are significant implying that climate effects are nonlinear. However, the quadratic nature of the climate variables makes them difficult to interpret. In Table 4, we calculate the marginal impact of climate using both the linear and squared coefficients of each variable. The first column of Table 4 presents the annual marginal temperature and precipitation effects, calculated at the sample mean, for the entire sample. The results suggest that higher annual temperatures slightly reduce net revenues per hectare in China 10 USD/°C. The overall temperature elasticity is -.09 (% change in net revenue/ % change in temperature). Consistent with earlier Ricardian analyses, the seasonal temperature effects are larger and offsetting. Higher spring temperatures are very harmful whereas warmer summer and especially winter temperatures are beneficial. Higher annual precipitation increases net revenue (15 USD/mm/mo). The overall precipitation elasticity is +0.8 (% change in net revenue/ % change in precipitation). As with the seasonal temperature effects, the seasonal precipitation effects are larger and offsetting. A wetter spring is harmful whereas a wetter winter is very beneficial.

We also examine a number of alternative specifications in the Table A-1 in the Annex. We examine one model with the log of net revenue as the dependent variable. This model yields much higher R squared values. The model does a better job of explaining some observations with much higher net revenue per hectare than the sample average. However, the log model yields very similar results to the linear model explored in this paper. Another specification that we explored examines the importance of controlling for land per household. The land per household is correlated with climate and so whether or not it is controlled affects the climate results. However, using the log of land or using a quadratic to approximate the role of farm size has similar effects. A third important variant that we explored concerns adding climate interaction terms. We found that these terms were generally insignificant except for the fall

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[4] The insignificant parameter may be explained by the following two factors: all villages are not very far from the township therefore the variation among villages is small and nearly all villages have roads connected to the townships. These imply that variations in transportation costs or transaction costs within townships are very small.

season. However, adding interaction terms confounds the role of temperature and precipitation so that marginal effects depend upon both variables. For simplicity, we rely on the model presented in this paper. However, the results are robust across a number of specifications.

Because of the importance of irrigation in China, it is helpful to understand the climate sensitivity of rainfed versus irrigated farms (as first suggested by Schlenker et al. 2005). Earlier research has indicated that rainfed and irrigated farms have different climate sensitivities in Africa (Kurukulasuriya and Mendelsohn 2007) and South America (Mendelsohn and Seo 2007). We consequently split the Chinese sample between farms that were in rainfed villages and farms that were in irrigated villages. Farms that were in villages with both were omitted. We then estimated the net revenue model on the two subsamples as shown in columns 2 and 3 of Table 3.

Most of the coefficients for rainfed and irrigated farms are not similar to each other. The one exception is that larger plots for both samples have lower net revenues. Other variables, such as percent clay soil, distance to township government, share of labor that is uneducated, and farmer characteristics remain insignificant. But the irrigated and rainfed regressions often had different coefficients. Silt soil and participating in a production association increased the net revenue of irrigated land but had no significant effect on rainfed land. Being on a plain increased the value of rainfed land but decreased the value of irrigated land. Being on a road increased the value of rainfed land but had no effect on irrigated land. Higher elevation decreased the value of rainfed land but had no effect on irrigated land.

The climate coefficients for the rainfed and irrigated regressions in Table 3 were also different. Many of the climate coefficients are still significant. Some had the same size though not the same magnitude. Finally, some coefficients switched sign, such as fall temperature, summer precipitation, and fall precipitation. However, to judge the effect of climate, it is helpful to calculate the marginal impacts. The results, shown in columns 2 and 3 of Table 4 reveal that temperature has a very different effect on irrigated versus rainfed farming. Higher annual temperatures increase the net revenue of irrigated farms by +68 USD/°C but reduce the net revenue of rainfed farms by -95 USD/°C. The seasonal effects are also different. Warmer falls are particularly harmful to irrigated farms whereas warmer summers and winters are beneficial. In contrast, warmer springs and falls are harmful to rainfed farms whereas warmer winters are beneficial. Higher annual precipitation, however, has almost identical effects on irrigated and rainfed farms. Wetter climates increase irrigated net revenues by 27 USD/mm/mo and rainfed net revenue by 23 USD/mm/mo. Both irrigated and rainfed farms prosper more than the full sample regression suggests. The lower marginal values in the full sample may be due to a measurement error because the full cost of irrigation is not measured. As rain increases, farmers find it profitable to switch from irrigation to rainfed agriculture to save irrigation costs. In practice, they earn more. But using this data without irrigation costs, it appears that they are switching from high valued irrigation to low valued rainfed farming.

## Regional Impacts

Although the average effect of temperature is negative and the marginal effect of precipitation is positive, the effects are quite different in different regions of the country. In order to understand how climate impacts vary across China, the marginal impact of temperature and rainfall for the full sample are mapped across China in Figures 4 and 5. The maps indicate what would happen with small changes in climate in the immediate future. Figure 4 on temperature suggests distinct spatial patterns with gains in the mid latitude region of China (up to 127 USD/ha/°C) but damages in the southern and northern latitudes (up to -165 USD/ha/°C). The marginal impact of precipitation is mapped for all farms in Figure 5. Additional precipitation in the wet southeast would be harmful (up to -153 USD/ha/mm/mo). Places that are already wet will lose from more rain. The rest of China would enjoy small gains (up to 65 USD/ha/mm/mo).

Maps 4 and 5 include both the effects on rainfed and irrigated farms. In order to understand what happens to each type of farm, we address them separately in the remaining figures. The marginal temperature results of the irrigation regression are shown in Figures 6. The temperature impacts in Figure 6 are not similar to those in Figure 4. With irrigated farms, warmer temperatures are more beneficial in the southeast and southwest region (128-255 USD/ha/°C). Further, irrigated farms in the far south are no longer harmed by warming. However, the rest of China has similar results. Farms in the central region continue to enjoy mild benefits from warming (up to 127 USD/ha/°C). The far north has the same marginal damages. The marginal precipitation effects for irrigated farms are shown in Figure 7. There remain some strong similarities with Figure 5 except for one major difference. The damages in the wet southeast disappear and become small benefits. All irrigated farms in China enjoy small benefits from increased rain.

The marginal temperature results of the rainfed farm regression are shown in Figure 8. The temperature impacts show a marked progression as one moves from the far south to the far north. There are large damages (-166 to -331 USD/ha/°C) in the far south from warming. These turn into smaller damages in most of the rest of the country (up to -165 USD/ha/°C). The far north and a few cold places in the southeast get small gains from warming (up to 127 USD/ha/°C). The results imply that most of China is slightly too warm for rainfed agriculture. Any further warming is therefore harmful except in the far north. The marginal precipitation effects are shown in Figure 9. Figure 9 is almost identical to Figure 5. Increased rain will damage rainfed farms in the wet southeast but benefit rainfed farms in the rest of the country.

## V. CONCLUSION AND POLICY IMPLICATIONS

This study conducts a Ricardian analysis on 8405 farm households across 28 provinces in China. Net revenues are regressed on seasonal climate and a number of control variables. Several specifications of the model are estimated. The empirical results are robust. The average impact of higher temperatures is negative and the average impact of more precipitation is positive. However, marginal increases in temperature and rainfall have very different effects on different farm types in different regions. Warming is beneficial to some farmers in China but harmful to others. Rainfed farmers are more vulnerable than irrigated farmers. Warming is likely helpful to rainfed farmers in very cold places but it will likely harm rainfed farmers in most of China and especially the far south. More rain is likely to be harmful to rainfed farmers in the wet southeast but will benefit farmers in the remaining regions. Irrigated farmers are less sensitive to temperature. However, irrigated farmers, like rainfed farmers, will gain from increased rainfall.

These basic results are similar to results from other countries (MNS 1994; Mendelsohn et al 2001; Mendelsohn and Dinar 2003; Kurukulasuriya et al 2006; Seo and Mendelsohn 2007). First, climate has an effect on net revenue in every country. Second, higher temperatures increase the net revenues of irrigated farms. Third, higher temperatures are beneficial to rainfed farms in cooler climates but harmful to rainfed farms in warm or hot climates. Fourth, more precipitation is beneficial unless there is an excessive amount of rain. Fifth, seasonal impacts vary and are offsetting.

Our results, however, are not completely consistent with previous economic work on Chinese agriculture (Liu et al., 2004). Our study finds that warming is harmful to Chinese agriculture whereas Liu et al. found it was beneficial. We believe that this difference may lie in choice of data sets. We believe that the farm data set in this study is far more reliable than the county data set used by Liu et al. However, not all of the results of the two studies were different. Both studies found that increased rainfall was beneficial. Both studies found that climate effects are nonlinear and effects differ by season. Hence, although the temperature results are different, many of the results of the two studies are similar.

What about comparisons between our economic analysis and crop studies? Although both analyses predict that global warming will be harmful to China's agriculture, the economic analysis suggests that the impact will be smaller. What explains the difference between the economic results and the crop study results? We believe that the crop study models lead to more pessimistic results because they do not consider adaptation. They do not include the possibility of crop switching, changes in irrigation, or other changes that farmers might undertake. These adaptations are implicitly captured in the Ricardian method.

The marginal effect of higher temperature for China is only mildly harmful for two important reasons. First, a very large fraction of farms in China are irrigated. Second, the rainfed land in China is largely in temperate or cool regions. Small amounts of warming are consequently not as harmful. Of course, some regions of China may suffer large damages. The dry Western region is vulnerable to global warming scenarios. However, the agricultural sector as a whole in China is only mildly vulnerable.

An important message in the research is that irrigation is critical to China's agriculture system. Part of China's ability to cope with future climate change depends on its capacity to use water for irrigation; nearly 60 percent of cultivated land in China is irrigated. Our analysis assumes that water will continue to be available. Data was not available to measure the amount of water each farmer was using. It was therefore not possible to measure the importance of available water. This could be a critical problem for China if climate warming makes water increasingly scarce. The negative results of this study could become much larger if warming forces many irrigated farms to become rainfed farms. Clearly there is a strong need in China for further analysis of the effects of climate change on water.

Can China continue feeding itself if climate changes? Based on our empirical results, the answer is yes, the likely gains realized by some farmers will nearly offset the losses that will occur to other farmers in China. An important caveat, however, is that our analysis assumes that there will be no change in water supply. However, it is likely that with at least some climate scenarios, water supplies will be reduced which could lead to large losses. The effect of water needs to be incorporated in future studies.

It is also quite apparent that the effects of climate change are not going to be uniform across the country. Warming will assist areas that are currently very highly productive and will further handicap areas that have below average productivity. In particular, warming will help the southeast region but hurt the west and far north. Chinese policy makers need to be aware that warming is likely to impose additional costs on specific regions that already have below average incomes.

The fact that the crop studies predict much larger damages than the Ricardian studies suggests that adaptation matters. The ability of Chinese farmers to change and adapt to new conditions has allowed China to outperform other agricultural economies in the world and will continue to be important with respect to climate change. However, for farmers to be able to endure future climate changes, it is critical that policies allow them to get the most out of the available factors of production and natural resources. The results of this study suggest that the direct effect of temperature rise and precipitation change on farms may not be a great risk to China in the near future. However, the effect of climate change on water is likely to be quite important. Given that water is already a very critical resource in certain regions of China, policy makers may want to use this resource wisely, especially in regions where water is scarce. Climate change increases the pressure to develop institutions and infrastructure in water scarce regions to treat water as a valuable resource. Although uniform national policies have many desirable properties, when it comes to water, it is critical to develop efficient policies in the water scarce regions.

In order to address future warming, China may also consider developing management practices and new varieties (crops and livestock) for a warmer world. Finally, China would benefit from adaptation at large, by having new technologies (research), educating farmers about better technologies (extension), and building credit institutions to allow farmers to purchase and apply needed technology.

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Table 1 Descriptive statistics for major variables used for analyzing the determinants of net crop revenue

| | All farm | | Irrigated farm | | Rainfed farm | |
|---|---|---|---|---|---|---|
| | Mean | Standard deviation | Mean | Standard deviation | Mean | Standard deviation |
| Net cropping revenue per ha (Yuan/yr) | 10146 | 12280 | 12319 | 12846 | 7464 | 9736 |
| Spring temp ($^{o}$C) | 13.2 | 4.7 | 13.8 | 3.5 | 11.05 | 4.7 |
| Summer temp ($^{o}$C) | 24.2 | 3.2 | 25.1 | 2. 6 | 22.6 | 3.4 |
| Fall temp ($^{o}$C) | 13.7 | 5.6 | 14.4 | 4.9 | 11.1 | 5.6 |
| Winter temp ($^{o}$C) | 0.3 | 8.5 | 0.9 | 6.7 | -3.3 | 8.9 |
| Spring prec (mm/month) | 76.2 | 65.3 | 81.7 | 79.1 | 53.2 | 43.4 |
| Summer prec (mm/month) | 144.2 | 62.5 | 128.4 | 72.1 | 139.8 | 51.9 |
| Fall prec (mm/month) | 56.8 | 32.5 | 48.6 | 31.4 | 53.8 | 33.2 |
| Winter prec (mm/month) | 23.2 | 24.1 | 28.2 | 27.8 | 15.0 | 19.0 |
| Share of land areas with clay soil (%) | 30 | 38 | 31 | 40 | 17 | 31 |
| Share of land areas with silt soil (%) | 31 | 39 | 28 | 36 | 43 | 43 |
| Plain (1=Yes; 0=No) | 0.45 | 0.50 | 0.75 | 0.43 | 0.35 | 0.48 |
| Road (1=Yes; 0=No) | 0.97 | 0.18 | 0.97 | 0.18 | 0.95 | 0.22 |
| Distance to township government (km) | 6.1 | 4. 5 | 5.2 | 3.6 | 7.1 | 5.2 |
| Share of irrigated areas in village (%) | 48.9 | 39.9 | | | | |
| If participate production association (1=Yes; 0=No) | 0.03 | 0.18 | 0.05 | 0.22 | 0.01 | 0.11 |
| Share of labor without receiving education (%) | 7.5 | 18.5 | 6.1 | 16.1 | 9.6 | 21.6 |
| Cultivated land area per household (ha) | 0.72 | 1.00 | 0.57 | 0.72 | 0.99 | 1.29 |

Note: The observation for all households is 8405, the observation for irrigated households is 2750 and the observation for rainfed households is 2119.

Table 2  Net crop revenue, temperature and precipitation in 2001

| Grouped by net crop revenue | Average net crop revenue | Temperature | Precipitation |
|---|---|---|---|
| | | Annual | Annual |
| Yuan/hectare | Yuan/hectare | $^{o}$C | mm |
| All farm | | | |
| 7-3339 | 1886 | 8.2 | 595 |
| 3340-5895 | 4607 | 11.5 | 798 |
| 5895-8821 | 7238 | 13.9 | 946 |
| 8823-13595 | 10875 | 14.8 | 1015 |
| 13597-184346 | 26125 | 15.8 | 1152 |
| Irrigated farm | | | |
| 88-5399 | 3482 | 10.5 | 541 |
| 5402-7841 | 6635 | 13 | 740 |
| 7851-10456 | 9177 | 14.2 | 936 |
| 10484-15493 | 12670 | 14.4 | 946 |
| 15531-168394 | 29630 | 15.7 | 1141 |
| Rainfed farm | | | |
| 8-2147 | 1226 | 6.9 | 506 |
| 2151-3966 | 3013 | 8.1 | 703 |
| 3973-6217 | 5054 | 10.1 | 789 |
| 6227-10698 | 8104 | 12.8 | 971 |
| 10714-173210 | 19952 | 13.9 | 958 |

Note: We sort the net crop revenue and then divide the samples into five groups where each group has the same numbers of samples. In the all farm sample, the sample number of each group is 1681. In the irrigated farm sample, the sample number of each group is 550. In the rainfed farm sample, the sample number of each group is 424.

Table 3 Regressions of Net Crop Revenue

| | Net Crop Revenue (Yuan/ha) | | |
|---|---|---|---|
| | All Farms | Irrigated | Rainfed |
| Spring temp | 1,453 | 4,149 | 1,789 |
| | (2.18)* | (1.79) | (1.54) |
| Spring temp sq | -118.1 | -170.4 | -106.9 |
| | (5.88)** | (2.18)* | (2.97)** |
| Summer temp | -1,803 | 1,263 | -6,200 |
| | (2.01)* | (0.57) | (4.75)*** |
| Summer temp sq | 48.7 | 17.0 | 125.9 |
| | (2.53)* | (0.35) | (4.03)*** |
| Fall temp | 119 | -5,178 | 2,678 |
| | (0.20) | (2.55)* | (2.54)* |
| Fall temp sq | -12.1 | 67.7 | -116.1 |
| | (0.56) | (0.93) | (2.60)* |
| Winter temp | 1,226 | 2,064 | 911 |
| | (4.44)** | (3.64)** | (1.66) |
| Winter temp sq | 62.6 | 63.9 | 67.2 |
| | (7.34)** | (2.91)* | (4.87)** |
| Spring prec | -300.6 | -268.3 | -132.3 |
| | (8.52)** | (2.84)* | (1.50) |
| Spring prec sq | 1.0574 | 0.7255 | 0.6050 |
| | (8.56)** | (2.21)* | (1.69) |
| Summer prec | 5.61 | 151.1 | -76.5 |
| | (0.39) | (3.68)** | (2.70)* |
| Summer prec sq | -0.06078 | -0.2414 | 0.1322 |
| | (1.55) | (2.22)* | (1.64) |
| Fall prec | -107.4 | -413.8 | -171.6 |
| | (2.92)* | (3.67)** | (2.71)* |
| Fall prec sq | 0.9442 | 2.3112 | 1.2763 |
| | (5.31)** | (3.22)** | (4.25)** |
| Winter prec | 554.4 | 668.9 | 655.9 |
| | (8.07)** | (3.43)** | (5.33)** |
| Winter prec sq | -6.355 | -5.212 | -8.248 |
| | (7.96)** | (2.42)* | (5.27)** |
| Share of clay soil | 4,360 | 201 | -109 |
| | (7.26)** | (0.14) | (0.08) |
| Share of silt soil | 2,080 | 2,865 | 747 |
| | (3.85)** | (2.68)** | (0.79) |
| Plain (1=Yes; 0=No) | 856 | -1,459 | 1,248 |
| | (2.57)* | (1.96)* | (2.11)* |

|  |  |  |  |
|---|---|---|---|
| Road (1=Yes; 0=No) | 2,022 | 722 | 3,313 |
|  | (2.96)** | (0.55) | (3.66)** |
| Distance to township government | 21.9 | 83.4 | -35.8 |
|  | (0.77) | (1.19) | (0.93) |
| Share of irrigation in village | 4.6 |  |  |
|  | (1.11) |  |  |
| If participate production association (1=Yes; 0=No) | 1,713 | 2,940.6 | -2,168.4 |
|  | (2.50)* | (2.57)* | (1.27) |
| Share of labor without education | 4.901 | 24.6 | -9.3 |
|  | (0.71) | (1.71) | (0.90) |
| Log of cultivated land area per household | -5,189 | -4,942 | -3,934 |
|  | (29.46)** | (13.72)** | (14.53)** |
| Elevation | -1.956 | -0.920 | -3.493 |
|  | (4.56)** | (1.41) | (2.46)* |
| Constant | 26,242 | -4,167 | 70,431 |
|  | (3.28)** | (0.19) | (5.22)** |
| Observations | 8405 | 2750 | 2119 |
| Adjusted R-squared | 0.21 | 0.17 | 0.26 |
| F-test | 89.23 |  |  |

* denotes significant at 5%, ** denotes significant at 1% level

Table 4 Marginal impacts of climate on crop net revenue

| | All farm[a] | Irrigated farm[b] | Rainfed farm[c] |
|---|---|---|---|
| **Temperature** (USD/ha/°C) | | | |
| Spring | -230* | -49 | -143** |
| Summer | 76* | 286 | -15** |
| Fall | -29 | -458** | -68* |
| Winter | 173** | 288** | 130 |
| **Annual** | **-10*** | **68*** | **-95*** |
| **Annual Elasticity** | **-0.09*** | **0.62*** | **-0.88*** |
| **Precipitation (**USD/ha/mm/mo) | | | |
| Spring | -19** | -22** | -6 |
| Summer | -2 | 11** | -5* |
| Fall | -1 | -21** | -4* |
| Winter | 36** | 59** | 38** |
| **Annual** | **15*** | **27**** | **23*** |
| **Annual Elasticity** | **0.80*** | **1.48**** | **1.24*** |

* denotes significant at 5%, ** denotes significant at 1% level
Yuan converted to 2006 USD using exchange rate of 8 Yuan/USD. We wanted to allow easy comparison of marginal impacts with studies in other countries.

Figure 1: Relationship between Crop Net Revenue and Ricardian Net Revenue and Temperature

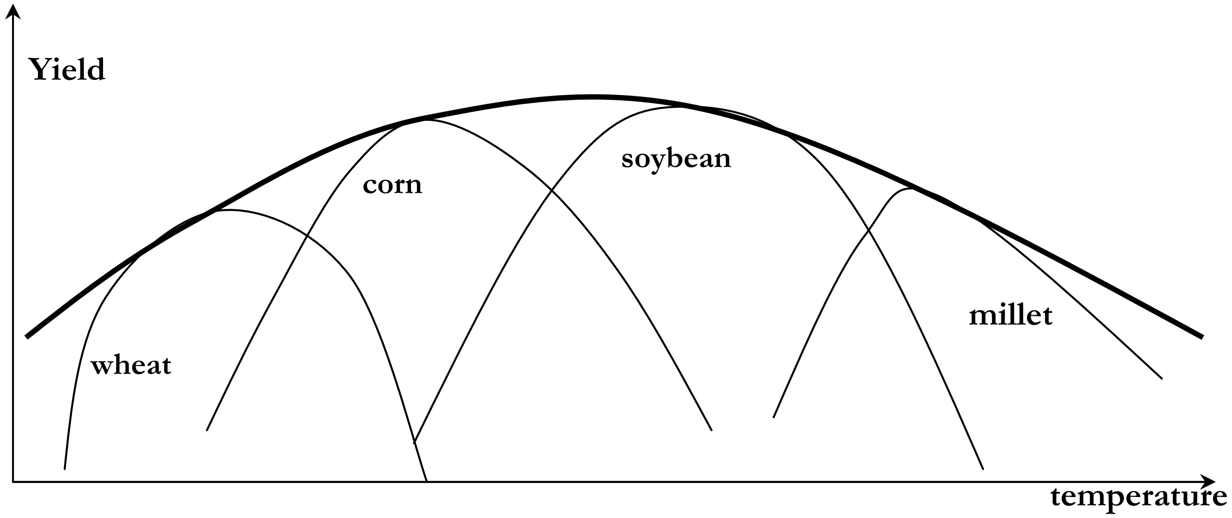
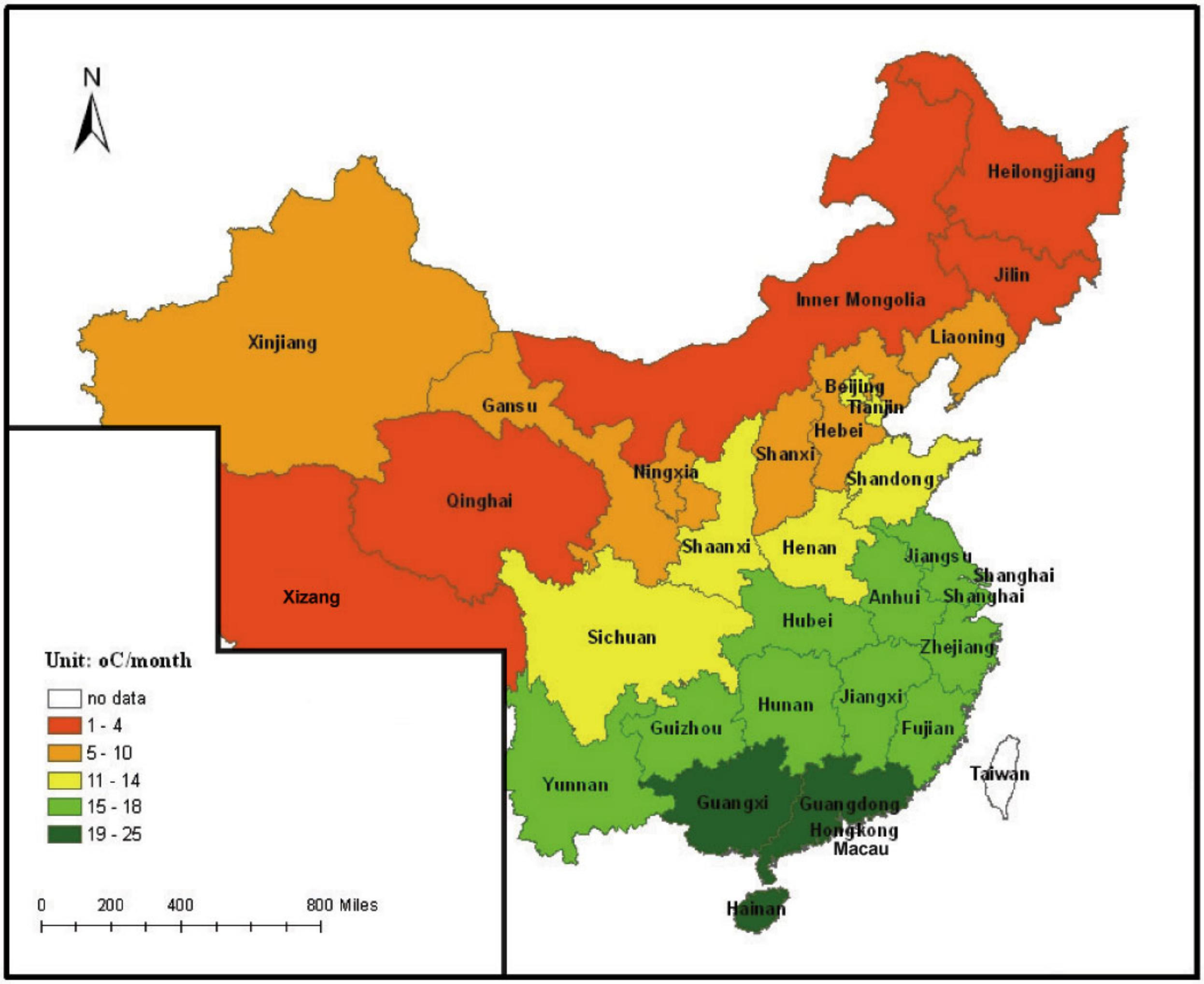
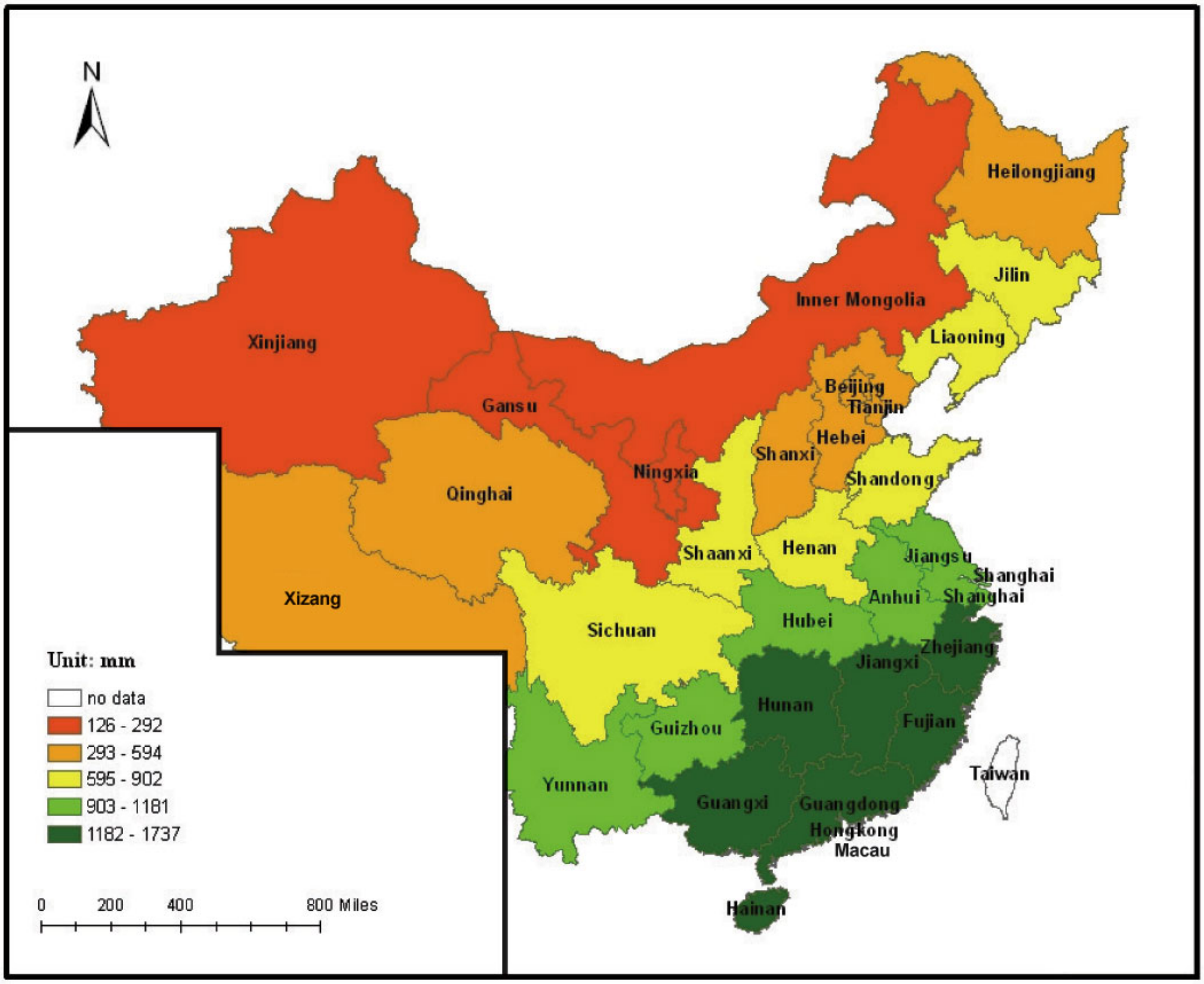


Figure 2: Annual Temperature by Province



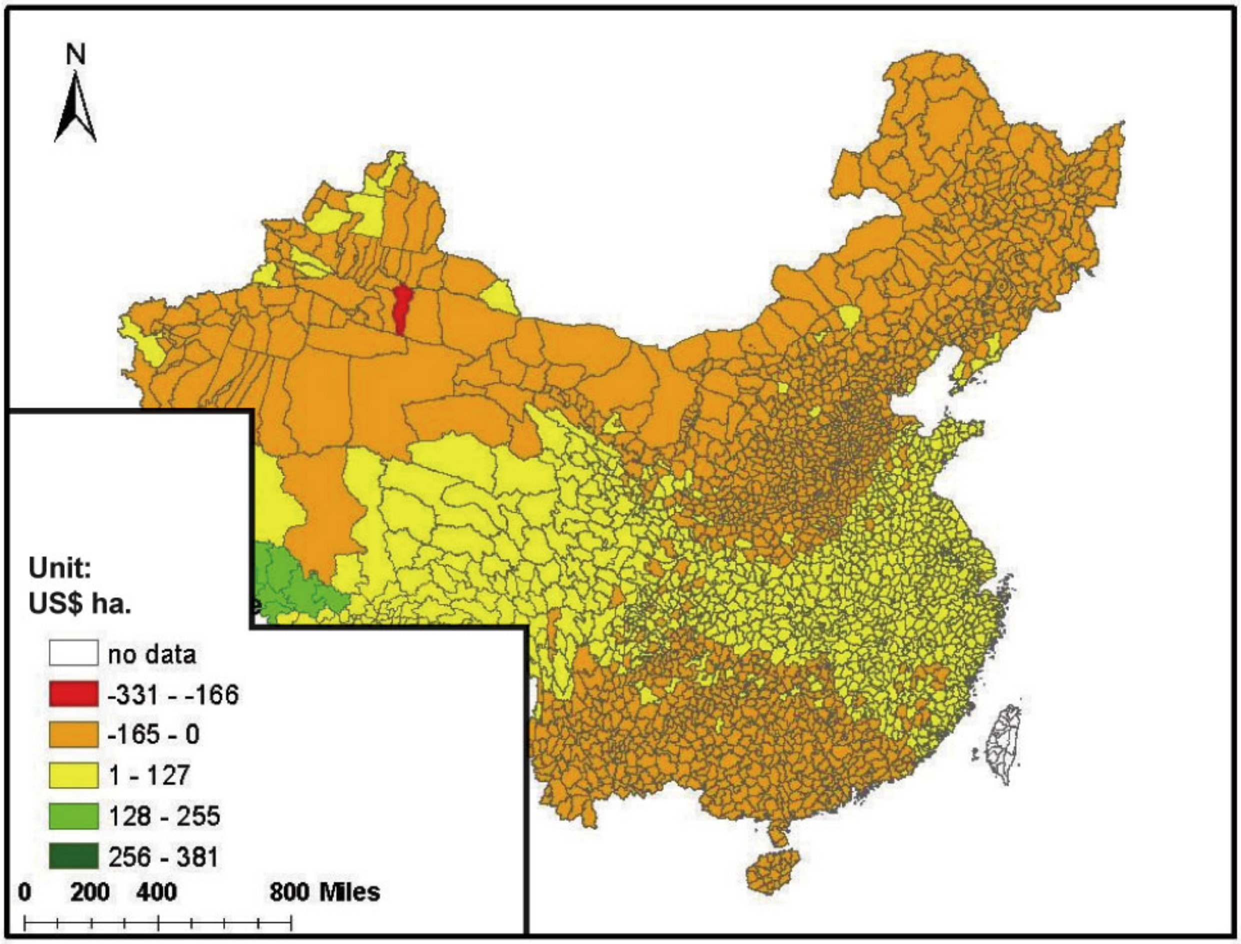
Note: Due to World Bank policies some parts of the map have to be covered or removed.

Figure 3: Annual Precipitation by Province



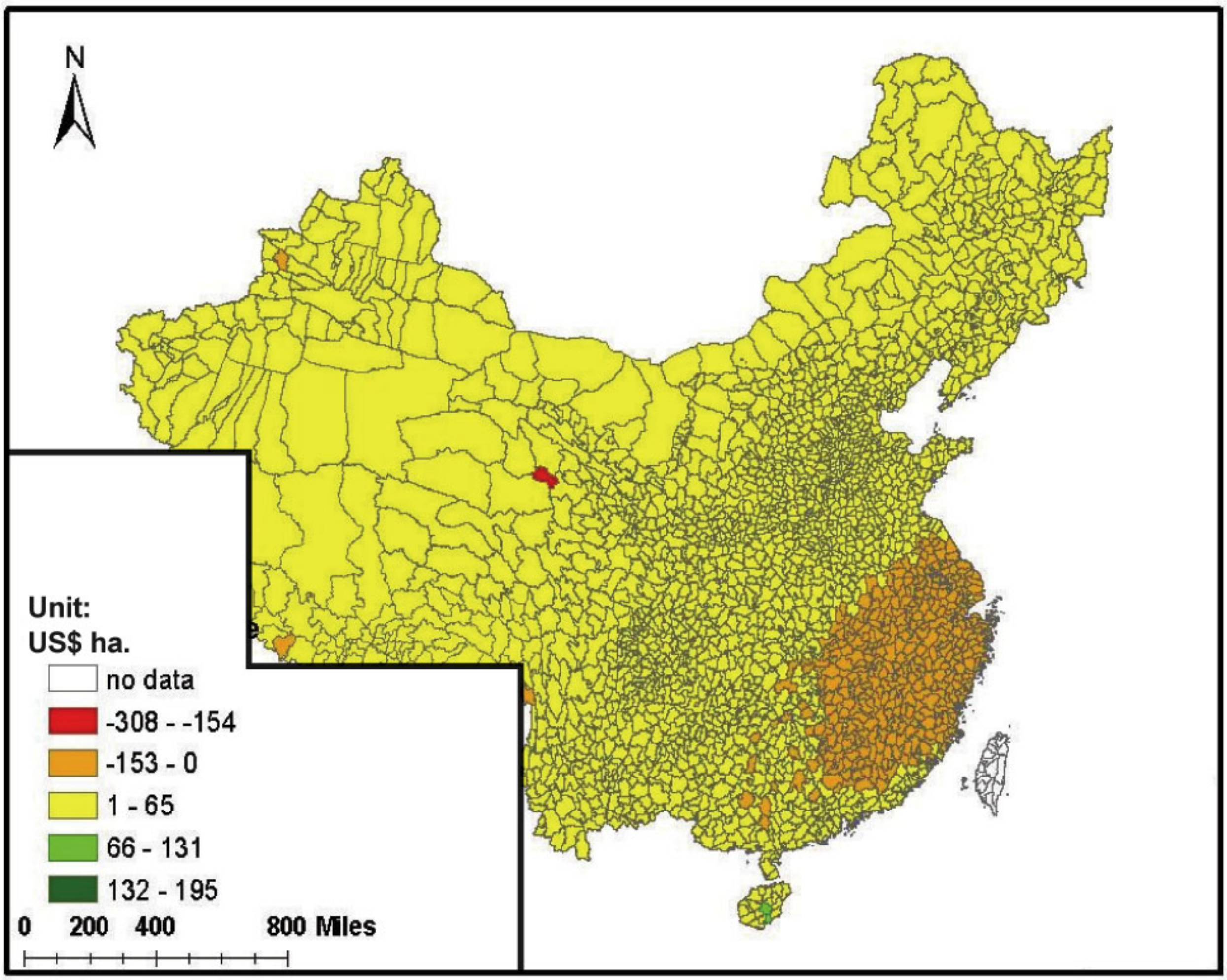
Note: Due to World Bank policies some parts of the map have to be covered or removed.

Figure 4: Marginal Temperature Effect, All Farms



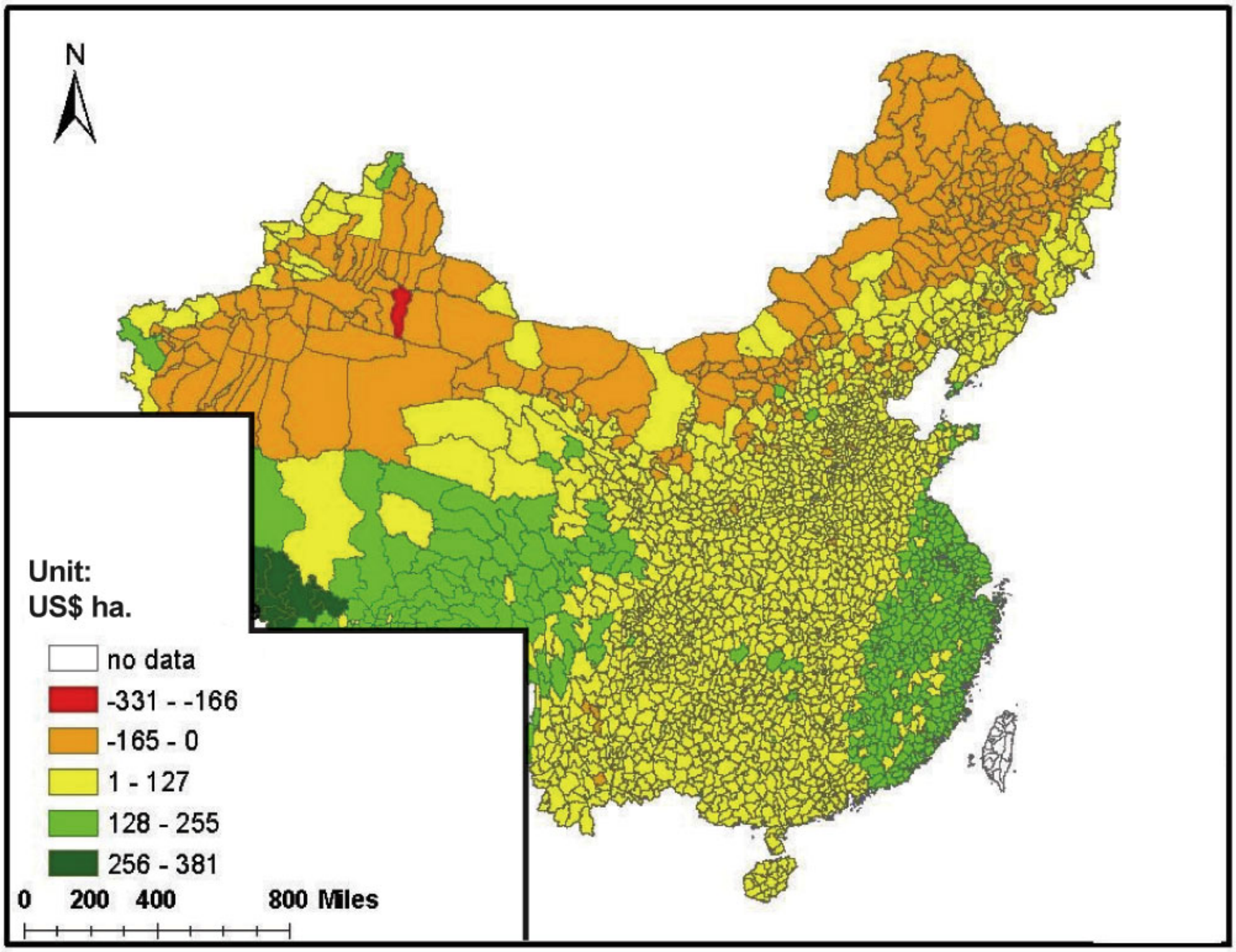
Note: Due to World Bank policies some parts of the map have to be covered or removed.

Figure 5: Marginal Precipitation Effect, All Farms



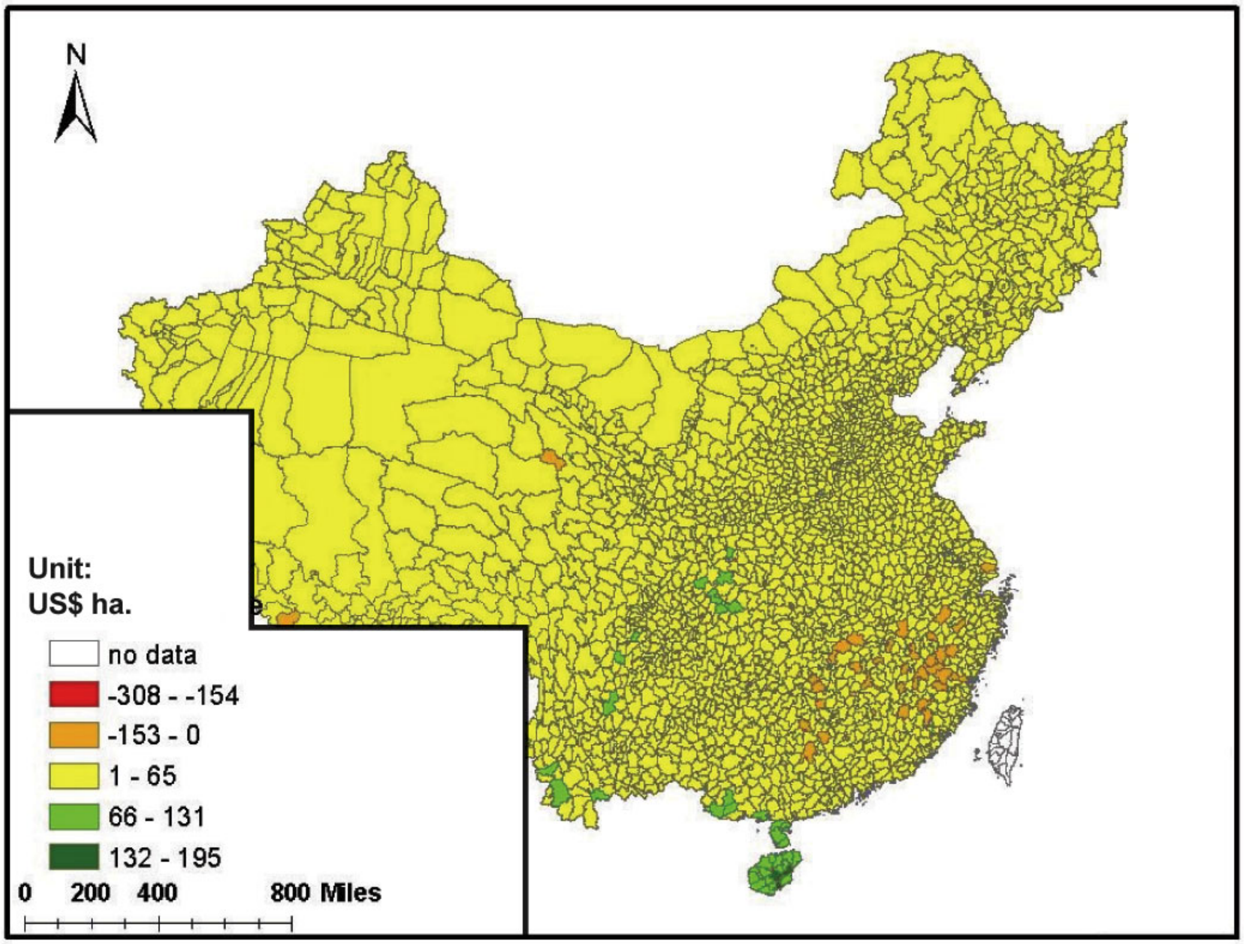
Note: Due to World Bank policies some parts of the map have to be covered or removed.

Figure 6: Marginal Temperature Effect, Irrigated Farms



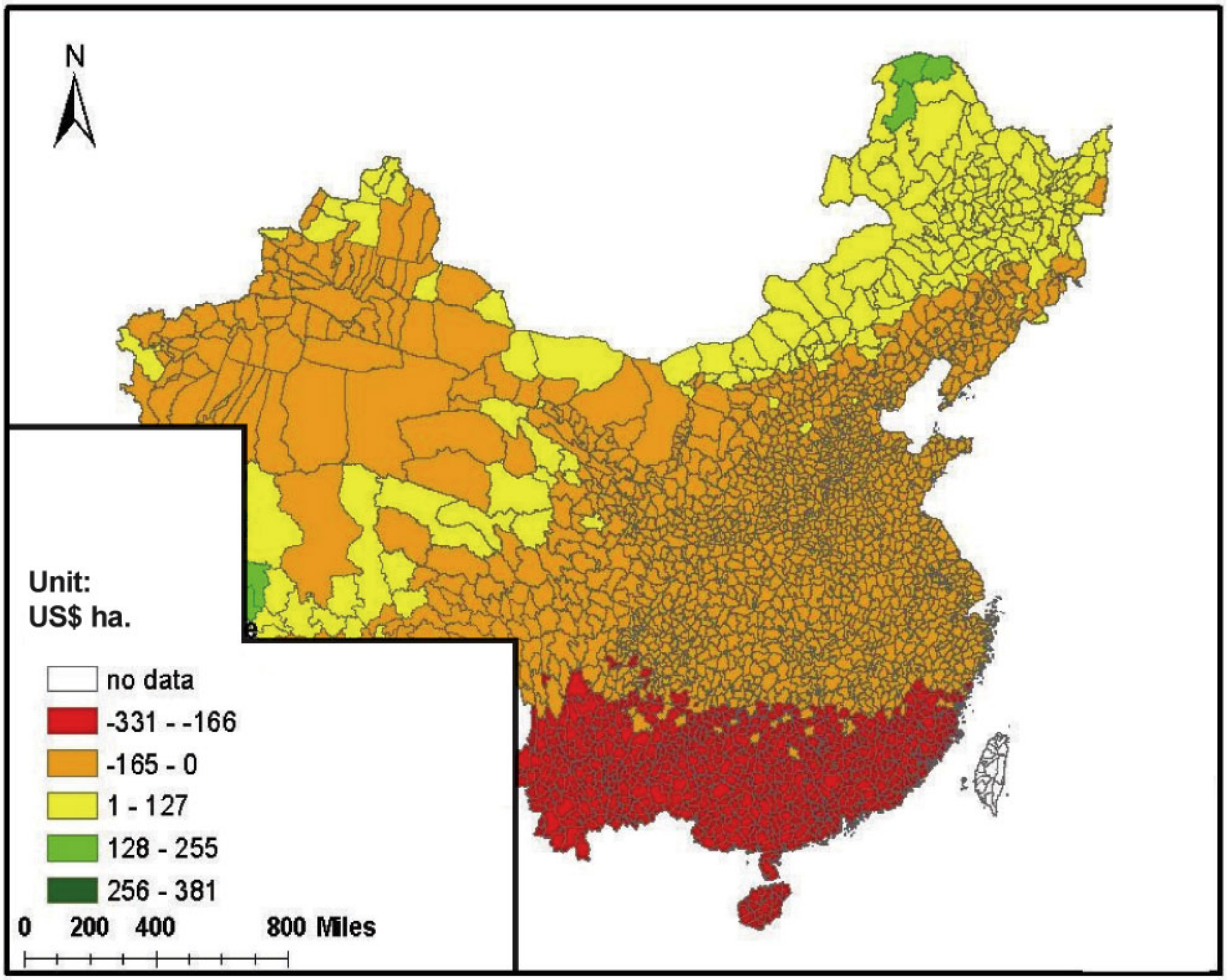
Note: Due to World Bank policies some parts of the map have to be covered or removed.

Figure 7: Marginal Precipitation Effect, Irrigated Farms



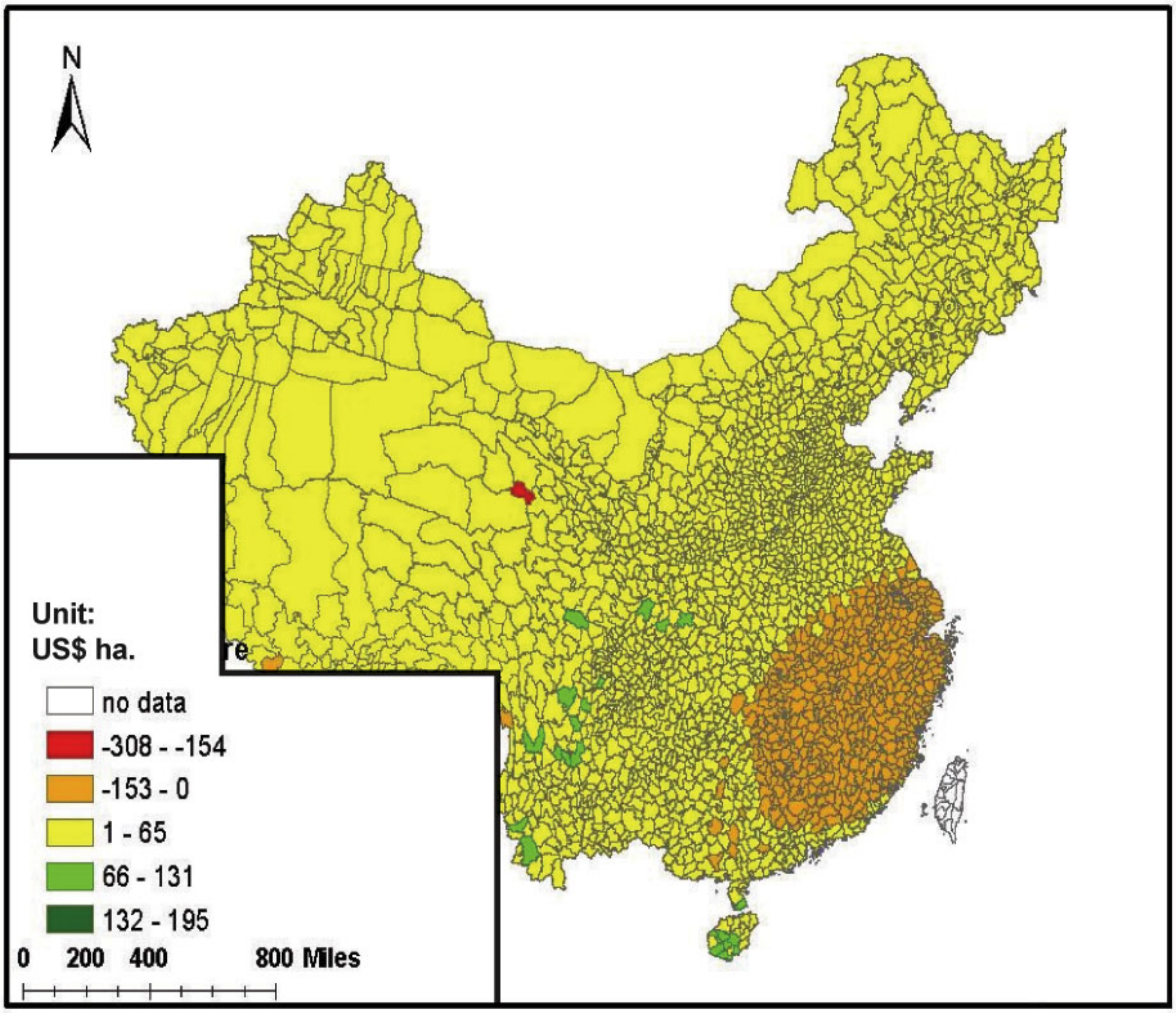
Note: Due to World Bank policies some parts of the map have to be covered or removed.

Figure 8: Marginal Temperature Effect, Rainfed Farms



Note: Due to World Bank policies some parts of the map have to be covered or removed.

Figure 9: Marginal Precipitation Effect, Rainfed Farms



Note: Due to World Bank policies some parts of the map have to be covered or removed.

# ANNEX: CAN CHINA CONTINUE FEEDING ITSELF?
## The Impact of Climate Change on Agriculture

Table A-1 Alternative Ricardian Regressions of All Farms

| | With interaction terms | | Without interaction terms | |
|---|---|---|---|---|
| | Net crop revenue | Log net crop revenue | Net crop revenue | Log net crop revenue |
| Spring temp | -457.7 | -0.2487 | 609.0 | -0.2420 |
| | (0.63) | (5.02)*** | -0.92 | (5.31)*** |
| Spring temp sq | -92.0 | -0.00612 | -113.7 | -0.00316 |
| | (3.94)*** | (3.83)*** | (5.50)*** | (2.23)** |
| Summer temp | -3,702 | -0.2419 | -2,121 | -0.3572 |
| | (3.39)*** | (3.25)*** | (2.38)** | (5.84)*** |
| Summer temp sq | 105.48 | 0.01057 | 68.99 | 0.01219 |
| | (4.44)*** | (6.52)*** | (3.47)*** | (8.95)*** |
| Fall temp | 2,403 | 0.415 | 719.6 | 0.4800 |
| | (2.85)*** | (7.21)*** | (1.14) | (11.07)*** |
| Fall temp sq | -81.05 | -0.01529 | -5.69 | -0.01911 |
| | (2.33)** | (6.43)*** | (0.25) | (12.22)*** |
| Winter temp | 1,593 | 0.2519 | 1,194 | 0.1972 |
| | (5.23)*** | (12.11)*** | (4.18)*** | (10.07)*** |
| Winter temp sq | 76.37 | 0.01072 | 58.08 | 0.00996 |
| | (7.55)*** | (15.52)*** | (6.49)*** | (16.23)*** |
| Spring prec | -325.27 | -0.03730 | -304.86 | -0.02262 |
| | (5.78)*** | (9.71)*** | (8.31)*** | (8.99)*** |
| Spring prec sq | 1.06 | 0.00010 | 1.002 | 0.00009 |
| | (7.50)*** | (10.40)*** | (7.79)*** | (10.46)*** |
| Summer prec | -63.78 | -0.00126 | 39.28 | 0.00460 |
| | (1.72)* | (0.49) | (2.93)*** | (5.01)*** |
| Summer prec sq | -0.11 | -0.00001 | -0.12 | -.00001 |
| | (2.67)*** | (2.90)** | (3.10)*** | (5.26)*** |
| Fall prec | 20.28 | 0.00264 | -61.53 | -0.02041 |
| | (0.39) | (0.74) | (1.62) | (7.83)*** |
| Fall prec sq | 1.24 | 0.00018 | 0.792 | 0.00015 |
| | (5.20)*** | (11.13)*** | (4.31)*** | (11.60)*** |
| Winter prec | 538.53 | 0.05703 | 469.33 | 0.04787 |
| | (7.10)*** | (11.01)*** | (6.56)*** | (9.76)*** |
| Winter prec sq | -6.88 | -0.00075 | -5.46 | -0.00068 |
| | (7.23)*** | (11.55)*** | (6.56)*** | (11.98)*** |
| Spring prec*temp | -0.835 | 0.00062 | | |
| | (0.28) | (3.01)*** | | |
| Summer prec*temp | 4.08 | 0.00014 | | |
| | (2.63)*** | (1.31) | | |
| Fall prec*temp | -8.62 | -0.00172 | | |

| | | | | |
|---|---|---|---|---|
| | (2.79)*** | (8.18)*** | | |
| Winter prec*temp | 15.93 | -0.00023 | | |
| | (2.44)** | (0.51) | | |
| Share of land areas with clay soil | 5,477 | 0.556 | 5,345 | 0.423 |
| | (8.07)*** | (12.01)*** | (8.55)*** | (9.88)*** |
| Share of land areas with silt soil | 3,412 | 0.300 | 3,259 | 0.311 |
| | (6.02)*** | (7.76)*** | (5.87)*** | (8.18)*** |
| Plain (1=Yes; 0=No) | 727 | 0.171 | 975 | 0.196 |
| | (2.06)** | (7.11)*** | (2.83)*** | (8.30)*** |
| Road (1=Yes; 0=No) | 2,771 | 0.108 | 2,584 | 0.103 |
| | (3.86)*** | (2.21)** | (3.64)*** | (2.11)** |
| Distance to township government | -32.02 | -0.001 | -30.89 | 0.002 |
| | (1.07) | (0.69) | (1.04) | (1.11) |
| Share of irrigated areas in village | 17.21 | 0.00362 | 15.68 | 0.003 |
| | (4.01)*** | (12.36)*** | (3.68)*** | (11.82)*** |
| If participate production association (1=Yes; 0=No) | 2,747 | 0.168 | 2,601 | 0.137 |
| | (3.86)*** | (3.45)*** | (3.67)*** | (2.82)*** |
| Share of labor without receiving education | 0.364 | -0.00073 | 0.517 | -0.001 |
| | (0.05) | (1.48) | (0.07) | (1.88)* |
| Cultivated land area per household | -1,992 | -0.310 | -1,925 | -0.303 |
| | (11.66)*** | (26.55)*** | (11.35)*** | (26.09)*** |
| Constant | 41,700 | 10.41 | 22,465 | 11.12 |
| | (4.05)*** | (14.81)*** | (2.97)*** | (21.44)*** |
| Observations | 8405 | 8405 | 8405 | 8405 |
| Adjusted R-squared | 0.15 | 0.39 | 0.15 | 0.39 |
| F-test | 51.21 | 189.32 | 58.47 | 213.53 |

Absolute value of t statistics in parentheses

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

Table A-2 Alternative Specifications of Irrigated and Rainfed Farms

| | Net crop revenue | |
|---|---|---|
| | Irrigated farm | Rainfed farm |
| Spring temp | 6,811 | -1,466 |
| | (2.80)*** | (1.37) |
| Spring temp sq | -324.8 | -76.5 |
| | (3.85)*** | (1.84)* |
| Summer temp | 7,285 | -8,742 |
| | (2.11)** | (5.80)*** |
| Summer temp sq | -119.55 | 254.25 |
| | (1.67)* | (6.78)*** |
| Fall temp | -8,845 | 6,780 |
| | (3.35)*** | (5.19)*** |
| Fall temp sq | 331.65 | -258.73 |
| | (3.05)*** | (4.07)*** |
| Winter temp | 2,238 | 1,583 |
| | (3.04)*** | (2.67)*** |
| Winter temp sq | 51.61 | 97.91 |
| | (1.41) | (6.55)*** |
| Spring prec | -294.88 | -177.44 |
| | (2.41)** | (1.39) |
| Spring prec sq | -0.99 | 0.61 |
| | (2.47)** | (1.44) |
| Summer prec | 148.14 | 17.94 |
| | (1.05) | (0.28) |
| Summer prec sq | -0.158 | 0.087 |
| | (1.41) | (1.06) |
| Fall prec | -127.11 | 102.74 |
| | (0.73) | (1.16) |
| Fall prec sq | 5.631 | 3.519 |
| | (5.12)*** | (5.61)*** |
| Winter prec | 13.25 | 864.14 |
| | (0.06) | (5.91)*** |
| Winter prec sq | 6.461 | -14.785 |
| | (2.22)** | (7.09)*** |
| Spring prec*temp | 26.918 | -3.269 |
| | (3.37)*** | (0.46) |
| Summer prec*temp | 0.117 | -2.701 |
| | (0.02) | (1.02) |
| Fall prec*temp | -50.82 | -33.10 |
| | (3.23)*** | (4.16)*** |
| Winter prec*temp | -33.27 | 82.57 |
| | (1.90)* | (4.84)*** |

|  |  |  |
|---|---|---|
| Share of land areas with clay soil | -1,934 | -1,591 |
|  | (1.29) | (1.02) |
| Share of land areas with silt soil | 4,141 | 3,746 |
|  | (3.58)*** | (3.61)*** |
| Plain (1=Yes; 0=No) | -463 | 1,095 |
|  | (0.56) | (1.75)* |
| Road (1=Yes; 0=No) | 564 | 4,660 |
|  | (0.42) | (4.84)*** |
| Distance to township government | 72.0 | -50.7 |
|  | (0.98) | (1.26) |
| If participate production association (1=Yes; 0=No) | 3,138 | -2,586 |
|  | (2.70)*** | (1.46) |
| Share of labor without receiving education | 32.9 | -9.87 |
|  | (2.21)** | (0.92) |
| Cultivated land area per household | -2,720 | -1,189 |
|  | (5.78)*** | (5.95)*** |
| Constant | -66240 | 65,090 |
|  | (2.10)** | (4.47)*** |
| Observations | 2750 | 2119 |
| Adjusted R-squared | 0.12 | 0.20 |
| F-test | 14.94 | 20.25 |