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Impacts of climate change on net crop revenue in North and South China

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Abstract

Purpose – The purpose of this paper is to explore the impacts of climate change on crop net revenue by region. Particularly, the authors focus on the impact differences between north and south regions.
Design/methodology/approach – The authors applied the Ricardian approach which assumes that each farmer wishes to maximize revenue subject to the exogenous conditions of their farm. The climate data are based on actual measurements in 753 national meteorological stations and the socio-economic data covers 8,405 farms across 28 provinces in China.
Findings – On average, the rise of annual temperature will hurt farms both in the north or south. The impacts of climate change on both precipitation and temperatures have different seasonal impacts on producers in the north and the south of China. As a consequence, the impact on net farm revenues varies with farms in the north and the south being adversely affected (to different degrees) by a rise in the temperature, but both benefiting from an anticipated increase in rainfall. The results also reveal that irrigation is one key adaption measure to dealing with climate change. Whether in the north or south of China, increasing temperature is beneficial to irrigated farms, while for rainfed farms, higher temperature will result in a reduction in net revenues. The results also reveal that farms in the north are more vulnerable to temperature and precipitation variation than that in the south. Irrigated farms in the south are more vulnerable to precipitation variation than that in the north; but rainfed farms in the north are more vulnerable to precipitation variation than that in the south.
Originality/value – Applying empirical analysis to identify the differences of climate change impacts between north and south regions will help policy makers to design reasonable adaptation policies for various regions.

Keywords Climate change, Impacts, Net crop revenue, North China, South China

Paper type Research paper

1. Introduction

Despite the uncertainty, there is general agreement that the climate will continue to change in China and will do so at an accelerated pace. Projections by scientists in China show that the nation's overall annual mean air temperature will increase by 1.3-2.1°C by 2020 and by 2.3-3.3°C by 2050 from the 2000 levels (People's Republic of China, 2007). The magnitude of the warming is projected to be greatest in South and West China and somewhat diminished in North China. It is estimated that by 2030, the annual mean temperature could increase by 1.9-2.3°C in Northwestern China and by 1.6-2°C in Southwestern China. Precipitation in China is also expected to change, and Ren (2007) predicts an overall increase in precipitation nationwide. Specifically, Ren

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predicts that precipitation across China will increase by 2-3 percent by 2020 and by 5-7 percent by 2050. With precipitation, as with temperature, there are regional disparities and concerns about more frequent extreme weather events. The most significant impact of these extreme events is predicted to be in China's Southeastern coastal regions.

While climate influences virtually all aspects of life, its impact on agricultural production is likely to be particularly significant. For example, based on agronomic modeling studies, researchers have indicated that the expected effects of temperature increases and precipitation declines – under a worst-case scenario – could lead to a drop in China's rainfed yields of rice, wheat, and maize by 20-36 percent over the next 20-80 years (Solomon *et al.*, 2007; Xiong *et al.*, 2007). In contrast, cotton yields in China might increase (Solomon *et al.*, 2007). However, these figures may overestimate changes in yield, as they do not account for the adoption of new technologies or policy changes in response to climate change and assume that the same crops are grown in the same places under various climate change scenarios.

In the previous decade, some economists have attempted to analyze the impacts of climate change on agriculture. One of the most common approaches is Ricardian analysis based on econometric models (Mendelsohn *et al.*, 1994). Instead of studying the impacts of climate change (temperature and precipitation) on crop yields, Ricardian analysis focusses mainly on the effects on net farm revenue. Applying the Ricardian approach in Africa (Kurukulasuriya and Mendelsohn, 2008; Kurukulasuriya *et al.*, 2006) and South America (Seo and Mendelsohn, 2008), research results suggest that warming will reduce net farm revenues. Furthermore, climate change will have different impacts on different countries. Compared with agronomic models, the major advantage of a Ricardian model is that its analysis can take into account farms' adaptation responses to climate change.

In recent years, China's researchers also have begun to apply the Ricardian approach to do analysis. Liu *et al.* (2004) finds that warming will increase average farm net revenue in China. However, this Ricardian study is based on county-level data with potentially severe data limitations. Wang *et al.* (2009) apply data from a survey of more than 8,000 households across 28 provinces in China[1]. Their results suggest that global warming is likely to be harmful to rainfed farms but beneficial to irrigated farms. The net impacts will be only mildly harmful at first, but the damage will grow over time. More importantly, they find that the impacts vary substantially by region. Farms in the southeast will be only mildly affected but farms in the northeast and northwest will endure the largest damages. However, Wang *et al.* (2009) use similar climate parameters for the regional impacts and find that the differences of marginal effects are mainly owing to the variations of average climate conditions in each region. We know it is probably not true that farms in each region have similar climate sensitivities to climate change. Therefore, it is interesting and important to explore whether the responses to climate change differ between regions.

The overall goal of this study is to explore the impacts of climate change on net crop revenue by region. Particularly, we focus on the impact differences between North and South China, which have different climate conditions. Generally, South China is warmer than North China. Compared with the latter, regions in the former enjoy more annual precipitation, making water an important production constraint for farms in the north. Unsurprisingly, the various climate conditions may well-affect crop production and revenue differently. The significance of this regional difference may also affect the issues that policy makers need to consider.

The remainder of this paper is organized as follows. Section 2 presents the data and research methods employed in this study. Section 3 statistically describes the climate characteristics and its relationship with net crop revenue. Section 4 presents the econometric results on the impacts of climate change net crop revenue in two regions, North China and South China. The final section concludes with several remarks.

2. Data and research methods

2.1 Data sources

In this study, the climate data are based on actual measurements in 753 national meteorological stations located throughout China. The socio-economic data, obtained from China's National Bureau of Statistics (CNBS), were collected in 2001 by a highly trained, professional enumeration staff as part of the annual, nationwide Household Income and Expenditure Survey (HIES). The data cover 45,700 farms in 4,365 villages, 533 counties, and 31 provinces. Relying on a soil map downloaded from the Food and Agricultural Organization web site, we generate the land share of each type of soil (clay, sand, and loam). The county elevation is estimated from a county map of China.

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. The climate data were gathered from the National Meteorological Information Center in China. Although there are 752 counties with meteorological stations and 533 counties in which CNBS collects HIES data, not all sample counties having HIES data also have the meteorological stations. Based on data checking, only 124 counties have both meteorological stations and CNBS samples. In order to ensure that we have a relatively good match between crop revenue (and other socio-economic) data and climate information, we restrict our sample to only those farms in counties with meteorological stations. That is, through matching the climate data and farm data, we excluded those farms in counties without a weather station. In addition, since our focus on the effects of climate change on net crop revenue, we also excluded those farms that did not cultivate any crops (characterized by total cropping sown areas of zero). In total, our final sample has 8,405 farms in 915 villages in 124 counties in 28 provinces. By relying on the measurements of climate in the meteorological stations, we avoid some of the climate interpolation problems faced by previous Ricardian studies.

2.2 The Ricardian model

In this study, we apply mainly the Ricardian model, which assumes that each farmer wishes to maximize income subject to the exogenous conditions of their farm (Mendelsohn *et al.*, 1994). Specifically, the farmer chooses the crop and inputs for each unit of land that maximizes annual net income, as shown in Equation 1:

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

where π is net annual revenue; 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 farm) for each crop i; K_i is a vector of capital such as tractors and harvesting equipment for each crop i; IR_i is a vector of irrigation choices for each crop i; C is a vector of climate variables; 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, as shown in Equation 2:

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

With perfect competition for land, free entry and exit will ensure that excess profits are driven to zero. Consequently, land rentals will be equal to net income per hectare (Mendelsohn *et al.*, 1994).

The Ricardian model was developed to explain the variation in land value per hectare of cropland over climate zones (Mendelsohn *et al.*, 1994). In repeated studies in the USA, Sri Lanka, Brazil, and other countries in 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 and Mendelsohn, 2008; Seo *et al.*, 2005). In some countries, land markets do not function, and thus, land values cannot be ascertained. Instead, net revenue per unit of land is calculated. Similar results have also been found for net crop revenue in Africa, South America, India, and Israel (Mendelsohn and Dinar, 1999; Kurukulasuriya *et al.*, 2006; Seo and Mendelsohn, 2008; Fleischer *et al.*, 2008). Because the response is nonlinear, a quadratic functional form has been used in most Ricardian studies.

2.3 Model specification

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, as shown in Equation 3:

$$\begin{aligned} V = {} & b_0 + b_1 \cdot Tn + b_2 \cdot Tn^2 + b_3 \cdot Pn + b_4 \cdot Pn^2 + b_5 \cdot Ts + b_6 \cdot Ts^2 + b_7 \cdot Ps \\ & + b_8 \cdot Ps^2 + \sum_j d_j \cdot Z_j + e \end{aligned} \tag{3}$$

where the dependent variable V is net crop revenue for each farm. Net crop revenue is gross crop revenue (or total sales for each crop) less all expenditure for production, including expenditure on seed, fertilizer, irrigation, pesticide, machinery, plastic sheeting, hired labor, and custom services. All of the output consumed by each farm is given a value based on a price of the output as if it was sold on the market. Neither family labor nor a farm's rental for contracted land is counted as a cost. Therefore, net revenue is a measure of returns on land and family labor. Based on the total cultivated land area of each farm (measured in hectares), we can calculate net crop revenue per hectare.

The variables T and P represent vectors of temperature and precipitation, respectively. T_n and P_n measure the temperature and precipitation in North China; while for South China, these are measured by T_s and P_s. The division of North and South China is similar to the study of Li *et al.* (2010)[2], T_n^2 and P_n^2 measure the squared terms of temperature and precipitation in North China; and T_s^2 and P_s^2 are squared terms of temperature and precipitation in South China. We rely on the mean values of these variables (the climate norm) for each month over the time period from 1951 to 2001. Because of the high correlation in the climate data from month to month, it is not possible to include every month in the econometric analysis. Consequently, the monthly data are averaged into four seasons. Winter is the average 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. Therefore, T_n includes one set of four variables measuring four seasons' temperature in North China, they are average winter, spring, summer, and fall temperature, and T_n^2 are the squared term of these four variables. P_n includes one set of four variables measuring four seasons' precipitation in North China, average winter, spring, summer, and fall precipitation, and P_n^2 are the squared term of these four variables. Similarly, T_s, T_s^2, P_s, P_s^2 also represent four seasons' temperatures and their squared terms, four seasons' precipitation and their squared terms in South China, respectively.

In addition, we include a vector Z, of county-, village-, and farm-level socio-economic and other control variables. The county variables include two kinds of soil types, clay and silt soil and we measure them by the share of land areas with clay soil and share of land areas with silt soil. Their comparing basis is loam soil. Another county variable is the altitude. The village-level data include terrain (which equals 1 if the village is located on a plain and 0 if the village is on a mountain), a dummy for access to markets (which equals 1 if there is a road that connects the village to the outside world and 0 otherwise), a variable measuring the distance between the village and township government, and the share of a village's cultivated area that is irrigated. There are also a series of farm-level variables in Z, including a dummy variable measuring whether a farm belongs to a production cooperative, the average education level of each farm laborer, and a farm's land area. The symbols b_k and d_j are vectors of the coefficients to be estimated; e is an error term.

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 in the north (Equation 4) and south regions (Equation 5) is:

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

$$\begin{aligned} \frac{\partial V_i}{\partial T_s} &= b_5 + 2 \cdot b_6 \cdot T_s \\ \frac{\partial V_i}{\partial P_s} &= b_7 + 2 \cdot b_8 \cdot P_s \end{aligned} \tag{5}$$

Using data for the four seasons, we can calculate the marginal impact of each season in North and South China. The marginal effect depends on the levels of temperature and precipitation by region. 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 average marginal effect can be calculated as the sum of the average seasonal marginal effects across all farms.

In the above model (3), we have used the traditional climate variables similar to other Ricardian studies (such as Mendelsohn and Dinar, 1999; Kurukulasuriya *et al.*, 2006; Seo and Mendelsohn, 2008; Fleischer *et al.*, 2008; Wang *et al.*, 2009). In the Ricardian analysis, the regional variation of climate has been treated as long-term change of climate. That is, the climate differences across region are been considered as the change of climate over time in one certain region. Although these variables are good representatives to indicate the long-term change of climate (the change of average level of temperature and precipitation); they are hard to capture the impacts of climate variations on net crop revenue. In order to measure the impacts of climate variations on net crop revenue, we have specified one new mode (6). In the model (6), we have replaced the average value of climate variables in the model (3) by the deviation of four seasons' temperature and precipitation. The deviation is calculated as the differences of seasonal climate (seasonal temperature or precipitation) between the current year's value (2001) and average value in the long term (1951-2001). This long-term values of seasonal climate variables are also the variables used in the model (3). Different from model (3), we have not included nonlinear form of deviation variables in the model (6):

$$V = b_0 + b_1 \cdot TDn + b_2 \cdot PDn + b_3 \cdot TDs + b_4 \cdot PDs + \sum_j d_j \cdot Z_j + e \qquad (6)$$

In the above model (6), TD_n and PD_n measure the deviation variables of four seasons' temperature and precipitation in North China; while for South China, these are measured by TD_s and PD_s. Model (6) also includes similar control variables at the county, village and farm level as explained in model (3). The formulas used for estimating marginal effects of climate deviations are also similar to Equations (4) and (5).

3. Climate characteristics and its relationship with net crop revenue

3.1 China's climate characteristics and its historical change

In general, China's climate is best described as monsoonal (Ren, 2007). Across China, there are clear temperature and precipitation differences that vary by region and by season. The average annual temperature in China is 10.9°C. 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°C. In the middle part (in the Yangtze River Basin), the average annual temperature is 12-20°C. 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°C. As is typical of temperate regions, the temperature in China also differs significantly by season.

There are even greater seasonal and regional differences in precipitation. Average annual precipitation rates in China as a whole are near to the world average at about 820 mm. In the south, however, annual precipitation is from 1,000 to 1,500 mm. In the Huaihe River and Yellow River Basins located in North China, annual precipitation is from 600 to 1,000 mm. However, in other regions of North China, annual precipitation is even lower: only 500-600 mm. In West China also, it is generally quite dry.

The seasonal patterns of precipitation vary by region. In the north, more than 70 percent of annual precipitation is concentrated in the summer. Precipitation during the winter months is very low at <5 percent of the annual total (Ren, 2007). In contrast, in the south, precipitation is concentrated mainly in the spring and summer.

3.2 Historical records of climate change

Over the previous 60 years, China's annual temperatures have presented an increasing trend in the north as well as the south; however, the temperatures in the north have increased more quickly. According to data from China's national meteorological stations, the national annual temperature increased by 0.28°C/10 a (every ten years) during 1951-2009 (Table I). However, the annual temperature in North China increased

Table I.
Change in temperature and precipitation during 1951-2009 in North and South China

	North China	South China	China
Temperature change (°C/10 a)			
Spring	0.55	0.40	0.48
Summer	−1.82	−1.21	−1.52
Fall	0.47	−0.05	0.23
Winter	3.05	1.68	2.41
Annual	0.34	0.22	0.28
Precipitation change (mm/10 a)			
Spring	3	−11	−4
Summer	−33	−32	−32
Fall	0	5	3
Winter	12	37	24
Annual	1	−26	−12

Source: China's National Meteorological Information Center

by 0.34°C/10 a, higher than the national average. At the same time, the increase of the annual temperature in South China was 0.22°C/10 a, lower than the national average. A possible reason for the faster temperature increase in the north is the lower base temperature from which it is measured.

Despite the increasing temperature trend, for the same time period, annual precipitation shows a declining trend, with the decrease mainly occurring in the regions in South China. Based on historical data over the previous 60 years, annual precipitation in China declined by 12 mm/10 a (Table I). In addition, the data show that the trends of precipitation changes differed over regions. In the south, annual precipitation declined by 26 mm every ten years, while in the north, there was only a minimal annual precipitation change, increasing by 1 mm/10 a. If such trends continue in the future, the implication is that wet South China will become drier, but the dry regions in North China will not have much obvious relief from their dry conditions.

The analysis also indicates that the change of temperature and precipitation differs by season (Table I). At the national level, the most obvious increase in temperature occurred in winter, while precipitation decreased clearly in summer. In the previous 60 years, the increase in winter temperature reached 2.41°C/10 a, but summer temperature increased only 1.52°C/10 a. In contrast, summer precipitation decreased by 32 mm/10 a, while winter precipitation presented a slightly increased trend (24 mm/10 a). In North and South China, there are similar trends in seasonal temperature and precipitation changes.

In different periods reviewed, the regional change of climate has presented various characteristics (Table II). Based on statistical analysis, temperature in North China was

Table II.
Annual temperature and precipitation in various periods in North and South China

	Periods					
Region	1951-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009
Annual temperature (°C)						
North China	8.0	8.1	8.1	8.3	8.9	9.6
South China	17.3	17.2	17.1	17.2	17.7	18.4
Annual precipitation (mm)						
North China	563	547	536	528	528	507
South China	1,375	1,295	1,346	1,343	1,393	1,302

lowest in the 1950s, but tended to increase during the 1960s-1970s. From the 1980s, the temperature increase accelerated. In South China, during the 1950s-1970s, the temperature tended to decrease and was lowest in the 1970s. Thereafter, the temperature in the south increased quickly. On the other hand, precipitation in North China has presented a declining trend since the 1950s. Precipitation changes in South China differed by time periods. From Table II, we can see precipitation decreased during the 1950s-1960s. After the 1970s, precipitation in South China increased obviously until the most recent ten years, when it presented a declining trend.

In general, seasonal temperature and precipitation have presented similar change trends to the annual average, despite some differences (Table II). For example, since the 1980s, temperatures in all seasons in North China have increased quickly, similar to the change in the annual temperature. However, during the 1950s-1970s, the summer temperature decreased. In addition, precipitation in the fall and winter increased after the 1990s in North China. We also find some seasonal differences from the annual average in South China. For example, winter temperature was lowest in the 1980s and began to increase thereafter. Precipitation in the fall increased during the 1950s-1980s and reached the highest level in the 1980s.

3.3 Relationship between net crop revenue and climate

In 2001, net crop revenue in China was on average 10,146 Yuan/ha (1,353 USD). Reliance on irrigation and ample availability of rain in certain regions of China has led to relatively high-net revenues compared to other countries (even developed countries such as the USA). The high levels of output per hectare in China are offset by somewhat lower real prices. Net crop revenues differ by region, with net crop revenues in the south being higher in general than in the north.

Equally significantly, if not more so, net crop revenues also vary between irrigated and rainfed villages (Table III). The average net crop revenue in irrigated villages was 12,319 Yuan/ha (1,643 USD), a rate that is more than 20 percent higher than the average. In contrast, average net revenue in rainfed villages was only 7,464 Yuan/ha (995 USD), more than 25 percent lower than the average.

Table III. Crop net revenue, temperature and precipitation in 2001

	Annual mean of net crop revenue (yuan/ha)	Annual average Temp. (°C)	Annual average Prec. (mm)	Deviation Temp. (°C)	Deviation Prec. (mm)
Group of net revenue					
North China					
7-2,152	1,205	6.7	435	0.82	−73
2,152-3,952	3,029	6.8	493	0.75	−112
3,952-6,132	4,981	8.5	495	0.66	−103
6,132-9,860	7,721	10.5	503	0.65	−122
9,860-168,394	18,018	11.4	512	0.57	−103
South China					
13-5,655	3,820	16.9	1,298	0.46	−16
5,655-8,225	6,921	16.8	1,302	0.47	−43
8,225-11,300	9,690	16.7	1,308	0.53	−74
11,300-17,120	13,821	16.8	1,286	0.59	−54
17,120-184,346	32,387	17.5	1,398	0.54	49

Notes: We order the net crop revenue and then divide the data into five groups by the same samples. In the group of North China, the sample is 844 and in the group of South China, the sample is 837

Descriptive statistical analyses indicate that there is possibly some relationship between the average level of climate and net crop revenue. In Table III, we group farms by net revenue. Farms with higher net revenues tend to have higher temperatures and more rain. For example, in North China, the 20 percent of farms with the lowest net revenues had annual temperatures of 6.7°C and annual precipitation of 431 mm. In contrast, the 20 percent of farms with the highest net revenues had temperatures of 10.9°C and precipitation of 506 mm. We can find a similar relationship in South China. For example, when farms' net crop revenues increase from the lowest to highest group, temperatures (from 16.2°C to 17°C) as well as precipitation (from 1,273 mm to 1,325 mm) tend to increase. This positive association between net revenue, precipitation, and temperature applies to rainfed as well as irrigated farms.

The relationship between the climate deviation and net crop revenue presents some regional differences, particularly for temperature deviation. Analysis results show that either having lower or higher net crop revenue, all farms face with positive deviation of temperature in North China (Table III). That is, their average annual temperature in 2001 is higher than average level in the past 50 years (1951-2001). Importantly, we found that temperature increased less for richer farms. For example, temperature for the 20 percent of farms with the lowest net revenues increased by 0.82°C, while this number was lower for the 20 percent of farms with the lowest net revenues (0.57°C). Therefore, results show that in the North China, farms with higher net revenue possibly enjoy smaller variation of temperature. However, we found the opposite relationship in South China. This possibly indicates that farms in North China are more vulnerable to temperature variation than that in South China. For the variation of precipitation, either in North or South China, we cannot find its consistent relationship with net crop revenue. Table III 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 complete analysis of how climate and other factors affect net revenues.

4. Econometric results

Based on the econometric model embodied in Equations (3) and (6), we conduct a regression analysis for all the samples. Because of the importance of irrigation in China, it is helpful to understand the sensitivity of irrigated vs rainfed farms, as first suggested by Schlenker *et al.* (2005). Earlier research has indicated that irrigated and rainfed farms have different climate sensitivities in Africa (Kurukulasuriya and Mendelsohn, 2007) and South America (Seo and Mendelsohn, 2008). As a result, in this study we examine one sub-sample of farms in irrigated villages and another sub-sample of farms in rainfed villages. We omit farms in villages that were irrigated as well as rainfed because we could not identify the method used on these farms. After dividing the sample in this manner, we then estimate the net revenue model on the two sub-samples as shown in columns 2 and 3 in Table IV (model 3) and columns 2 and 3 in Table V (model 6).

The goodness of fit measures (adjusted R^2) for all of the models are from 0.2 to 0.3, a relatively high level for cross-sectional farm data (Tables IV and V). The adjusted R^2 of our estimation results are similar to that in other countries. For example, in a study of Africa, the adjusted R^2 is 0.35 (Kurukulasuriya and Mendelsohn, 2006). In studies of Brazil and India, the adjusted R^2 is 0.4 and 0.56, respectively (Mendelsohn *et al.*, 2007).

Many of the control variables in Tables IV and V are highly significant. For example, in the regression results of the entire samples in these two tables, clay soil can significantly

Table IV. Regression results of determinants of net crop revenue

	Net crop revenue per hectare		
	All farms	Irrigated farms	Rainfed farms
Seasonal temperature in North China			
Spring temp.	1,083.2	18,118.9	2,809.7
	(1.15)	(4.81)***	(1.82)*
Spring temp. sq	−134.4	−771.0	−125.5
	(3.49)***	(5.04)***	(2.07)**
Summer temp.	1,472.1	11,480. 5	−6,111.2
	(0.96)	(2.44)**	(2.46)**
Summer temp. sq	−1.590	−217.6	102.6
	(0.04)	(2.02)**	(1.68)*
Fall temp.	−2,494.3	−24,441.3	2,409. 3
	(2.02)**	(5.79)***	(1.23)
Fall temp. sq	121.8	1,114.3	−51.5
	(1.78)*	(4.96)***	(0.52)
Winter temp.	718.2	−1,986.5	98.4
	(1.55)	(1.53)	(0.11)
Winter temp. sq	15.8	−140.1	56.5
	(0.91)	(2.26)**	(2.16)**
Seasonal precipitation in North China			
Spring prec.	860.0	2,907.1	1,026.0
	(3.08)***	(4.54)***	(2.75)***
Spring prec. sq	−14.7	−50.0	−15.1
	(2.84)***	(4.14)***	(2.26)**
Summer prec.	−95.4	−335.9	−275.3
	(1.93)*	(2.12)**	(3.31)***
Summer prec. sq	0.279	1.979	0.912
	(1.27)	(2.71)***	(2.49)**
Fall prec.	−620.3	−1,444.7	−795.2
	(3.26)***	(2.80)***	(3.02)***
Fall prec. sq	8.782	27.6	10.5
	(2.72)***	(3.31)***	(2.53)**
Winter prec.	−521.0	−2,884.8	−809.5
	(1.18)	(2.63)***	(1.37)
Winter prec. sq	41.7	161.6	49.0
	(1.83)*	(2.99)***	(1.64)
Seasonal temperature in South China			
Spring temp.	3,372.7	24,791.6	16,160.7
	(1.18)	(2.22)**	(1.42)
Spring temp. sq	−190.0	−902.8	−877.4
	(2.34)**	(2.69)***	(1.93)*
Summer temp.	7,438.8	27,144.0	−33,852.0
	(2.65)***	(1.88)*	(3.27)***
Summer temp. sq	−96.4	−415.3	784.4
	(1.91)*	(1.63)	(3.42)***
Fall temp.	−14,025.6	−44,133.7	17,102.5
	(5.64)***	(2.26)**	(1.93)*
Fall temp. sq	270.5	1,031.9	−604.0
	(4.40)***	(2.02)**	(2.53)**
Winter temp.	3,353.6	5,807.7	−468.3
	(3.19)***	(1.21)	(0.19)
Winter temp. sq	56.7	104.1	759.7
	(1.45)	(0.48)	(2.79)***

(*continued*)

	Net crop revenue per hectare		
	All farms	Irrigated farms	Rainfed farms
Seasonal precipitation in South China			
Spring prec.	−333.7	−601.0	467.3
	(6.04)***	(3.51)***	(2.10)**
Spring prec. sq	1.093	1.806	−1.356
	(5.99)***	(3.18)***	(1.73)*
Summer prec.	127.9	−136.5	1,153.7
	(2.79)***	(0.85)	(5.06)***
Summer prec. sq	−0.316	0.322	−2.400
	(3.07)***	(0.90)	(5.02)***
Fall prec.	15.6	−418.4	−284.9
	(0.19)	(0.94)	(0.89)
Fall prec. sq	0.428	2.583	−0.127
	(1.11)	(1.14)	(0.09)
Winter prec.	895.9	1,219.0	−1,286.3
	(8.07)***	(3.55)***	(2.41)**
Winter prec. sq	−8.463	−10.4	12.1
	(6.95)***	(2.79)***	(2.16)**
Control variables			
Share of land areas with clay soil	2,601.0	1,372.2	−2,713.8
	(3.38)***	(0.68)	(1.26)
Share of land areas with silt soil	213.2	−2,652.7	−37.3
	(0.31)	(1.62)	(0.03)
Plain (1 = Yes; 0 = No)	799.7	−320.8	1,091.1
	(2.25)**	(0.39)	(1.52)
Road (1 = Yes; 0 = No)	2,315.2	798.3	4,769.7
	(3.35)***	(0.59)	(4.92)***
Distance to township government	20.7	76.3	−41.6
	(0.71)	(1.05)	(1.04)
Share of irrigated areas in village	6.766		
	(1.62)		
If participate production association (1 = yes; 0 = no)	2,023.9	3,987.2	−5,510.7
	(2.88)***	(3.30)***	(3.17)***
Share of labors without receiving education	12.2	26.1	−0.678
	(1.76)*	(1.80)*	(0.07)
Cultivated land per farm	−5,044.5	−4,893.1	−4,187.9
	(27.13)***	(13.40)***	(14.03)***
Altitude	−1.274	1.708	−4.708
	(2.58)***	(2.17)**	(2.71)***
Constant	−5,235.9	−125,882.8	71,445.2
	(0.38)	(2.98)***	(3.07)***
Observations	8,405	2,750	2,119
R^2 (adjusted)	0.23	0.20	0.30

Notes: Absolute values of *t*-statistics in parentheses. *,**,***Significant at 10, 5, and 1 percent, respectively

Table IV.

increase net revenues compared to sandy soil. It is advantageous for a farm to be on a plain. Having access to a road is beneficial to farms, particularly rainfed farms. Participating in a production association significantly increases net revenues of irrigated farms. Having a larger plot reduces net revenues per hectare for irrigated as well as

	Net crop revenue per hectare		
	All farms	Irrigated farms	Rainfed farms
Deviation of seasonal temperature in North China			
Spring temp.	−592.5*	1,205.3*	−2,569.3***
	(1.75)	(1.75)	(4.45)
Summer temp.	387.3	2,419.6**	−1,350.8
	(0.80)	(2.57)	(1.44)
Fall temp.	664.1	−1,901.8*	3,438.2***
	(1.37)	(1.87)	(4.38)
Winter temp.	−673.3***	−760.0	−16.2
	(3.48)	(1.39)	(0.06)
Deviation of seasonal precipitation in North China			
Spring prec.	112.9***	136.7	43.2
	(4.27)	(1.48)	(1.20)
Summer prec.	1.120	30.6	1.767
	(0.14)	(1.53)	(0.18)
Fall prec.	27.1	−26.6	88.4***
	(1.39)	(0.36)	(3.05)
Winter prec.	198.4***	160.2	265.7***
	(4.29)	(1.26)	(3.50)
Deviation of seasonal temperature in South China			
Spring temp.	−2,468.5***	−4,135.7***	−2,838.9**
	(3.82)	(2.73)	(2.10)
Summer temp.	2,903.9***	3,684.9***	6,522.8***
	(3.92)	(2.69)	(3.36)
Fall temp.	−1,777.2***	−2,205.0**	1,552.7
	(3.78)	(1.98)	(1.48)
Winter temp.	4,357.2***	2,400.4**	2,288.1*
	(8.65)	(2.14)	(1.72)
Deviation of seasonal precipitation in South China			
Spring prec.	39.6***	40.9***	−3.722
	(6.30)	(3.73)	(0.08)
Summer prec.	12.2**	22.0*	11.7
	(2.56)	(1.67)	(1.12)
Fall prec.	−35.2***	−26.2	−65.8*
	(4.24)	(1.21)	(1.74)
Winter prec.	114.1***	163.8***	11.5
	(8.54)	(4.51)	(0.28)
Control variables			
Share of land areas with clay soil	2,161.0***	3,348.2***	−1,310.3
	(4.32)	(3.48)	(1.31)
Share of land areas with silt soil	1,242.3**	2,119.3*	−177.5
	(2.23)	(1.68)	(0.20)
Plain (1 = Yes; 0 = No)	1,586.1***	103.7	1,287.3**
	(5.10)	(0.15)	(2.24)
Road (1 = Yes; 0 = No)	1,469.5**	876.8	2,535.5***
	(2.18)	(0.68)	(2.77)
Distance to township government	39.5	128.5*	−0.901
	(1.39)	(1.80)	(0.02)
Share of irrigated areas in village	7.379**		
	(2.00)		

(*continued*)

Table V. Regression results of determinants of net crop revenue

Table V.

	Net crop revenue per hectare		
	All farms	Irrigated farms	Rainfed farms
If participate production association (1 = Yes; 0 = No)	1,397.5**	2,668. 9**	−3,939.9**
	(2.05)	(2.39)	(2.29)
Share of labors without receiving education	−2.905	19.6	−12.9
	(0.43)	(1.38)	(1.24)
Cultivated land per farm	−4,708.5***	−4,359.3***	−3,979.5***
	(30.02)	(14.47)	(16.18)
Altitude	−0.995***	−1.376***	−1.413***
	(3.56)	(2.92)	(2.87)
Constant	2,344.1***	4,612.2***	3,717.8***
	(2.71)	(2.74)	(2.92)
Observations	8,405	2,750	2,119
R^2 (adjusted)	0.23	0.17	0.30

Notes: Absolute values of *t*-statistics in parentheses. *,**,***Significant at 10, 5, and 1 percent, respectively

rainfed farms. Finally, the net revenues of irrigated farms increase with increase in altitude, while those of rainfed farms do not.

4.1 Impacts of long-term change of climate on net crop revenue

The results are largely consistent – especially in their signs and levels of significance – and show that most variables representing the long-term change of climate are significant (Table IV). For example, except for summer and winter temperatures in North China and precipitation in fall in South China, at least one precipitation and temperature coefficient in every season is significant in every regression. In addition, many quadratic terms of climate variables are significant. This implies that the impacts of climate on net crop revenue are nonlinear. In order to understand the impacts of temperature and precipitation on net crop revenue for farms in North and South China, we also calculated the seasonal and annual marginal effects of temperature and precipitation for all farms in both regions. Based on the calculated results of marginal effects, the impacts of temperature and precipitation on farms in North and South China can be summarized as the following eight aspects.

First, revenues of all farms in North and South China will decrease owing to the increase in annual temperature and this decrease will be greater for farms in the south. Results show that holding all other conditions constant, if the annual temperature increases marginally, the farms in the north will see a reduction of 371 USD/ha in net crop revenue (Table VI). Faced with the same increase in annual temperature as farms in the north, the net crop revenue of farms in the south will decrease more, that is, by 546 USD/ha. Based on the estimated elasticity, the results show that if the annual temperature increases by 10 percent, the net crop revenue will decline by 12.9 percent in North China and by 36.3 percent in South China. Therefore, we can see that farms in the south are more vulnerable to the increase in temperature.

Second, an increase in annual precipitation will benefit farms in North and South China, and farms in the south will earn more net crop revenue. Based on the estimation results, when increasing annual precipitation by the margin and keeping other factors

Table VI. Marginal impacts of long-term change of climate on net crop revenue

	All farms		Irrigated farms		Rainfed farms	
	North	South	North	South	North	South
Temperature (USD/ha/°C)						
Spring	−184	−431	1,239	1,440	208	−1,273
Summer	0	681	860	3,732	−435	−2,875
Fall	−188	−1,257	−1,723	−3,492	0	1,411
Winter	0	461	0	0	−83	434
Annual	−371	−546	376	1,680	−310	−2,303
Annual elasticity	−1.29	−3.63	1.28	9.08	−1.63	−13.13
Precipitation (USD/ha/mm/mo)						
Spring	66	−27	276	−47	59	52
Summer	−13	9	−25	0	−19	117
Fall	−48	0	−118	0	−42	0
Winter	32	76	−303	93	0	−141
Annual	37	58	−170	47	−1.72	27
Annual elasticity	0.59	2.51	−1.65	1.72	−0.06	1.01

Note: If the estimated coefficients for some seasonal temperatures or precipitation are not significant, their marginal effects will be zero

constant, the marginal impacts of climate on net crop revenue show that farms in the south will earn 58 USD/ha, which is higher than that of farms in the north (37 USD/ha) (Table VI). In addition, as revealed by the annual elasticity, if annual precipitation increases by 10 percent, the increase in net crop revenue of farms in the north will be 5.9 percent, while that for farms in the south will be much higher at 25.1 percent. Thus, the findings indicate that farms in the south are more sensitive than those in the north to increases in not only temperature but also precipitation.

Third, in both the regions, irrigated farms obtain increased benefits from the increase in annual temperature, while rainfed farms do not. For example, for irrigated farms in the north, if the annual temperature increases marginally, net crop revenue of farms will increase by 376 USD/ha and in the south, the revenue increase will be about four times that of the north (1,680 USD/ha) (Table V). In contrast, rainfed farms do not benefit from an increase in temperature, even marginally, as revenues from these farms will decrease in both the regions. Rainfed farms in the south will see a greater decrease (2,303 USD/ha) than those in the north (310 USD/ha). The results imply that if irrigation conditions are good, higher temperatures are beneficial for farms. On the other hand, higher temperatures would possibly reduce soil moisture of farms that depend only on rainfed conditions, resulting in a reduction of net crop revenue.

Fourth, in South China, irrigated and rainfed farms will yield increased revenues owing to an increase in annual precipitation, but the results are opposite for farms in North China. Estimated results show that owing to a marginal increase in annual precipitation in the south, net crop revenue of irrigated farms will increase by 47 USD/ha and that of rainfed farms will increase by 27 USD/ha (Table V). Compared with the marginal temperature effect of irrigated farms in the south (1,680 USD/ha), the marginal benefits of an increase in annual precipitation are much smaller. On the other hand, in the north, irrigated and rainfed farms will lose income because of an increase in precipitation, particularly so in the case of irrigated farms, whose revenue will decline by 170 USD/ha. This result is a little difficult to understand. One possible explanation is that in North China, if the temperature does not increase, farms might be hard-pressed to reap the benefits of a precipitation increase. Another possibility is that underlying seasonal effects offset the impacts of climate change calculated on an annual basis.

Fifth, in both the regions, higher temperatures in the spring and summer seasons are beneficial to irrigated farms, while higher temperature in the fall is harmful for irrigated farms. Estimation results of the marginal effects show that with an increase in spring temperature, the revenue of irrigated farms in the north increases by 1,239 USD/ha, which is lower than that in the south (1,440 USD/ha). The marginal summer temperature also results in higher income (3,732 USD/ha) for irrigated farms in the south than those in the north (860 USD/ha). However, if the temperature increases occur in the fall, revenues of irrigated farms in both the regions will decrease. As seasonal effects offset changes in the annual temperature, the annual marginal benefit of temperature increase will be somewhat lower than the total benefit in spring and summer.

Sixth, rainfed farms in the north benefit from a temperature increase in spring but not in other seasons; farms in the south benefit from a temperature increase in fall and winter but not in spring and summer. The results indicate that if temperature increases in spring, the net crop revenue of farms in the north will increase by 208 USD/ha. However, if a temperature increase occurs in summer or winter, farms will lose 435 USD/ha and 83 USD/ha, respectively. The seasonal effects for rainfed farms in the south are positive in fall and winter (1,411 USD/ha and 434 USD/ha, respectively), but negative in spring and summer (1,273 USD/ha and 2,875 USD/ha, respectively). Since the negative effects are larger than the positive effects, the annual temperature effect for rainfed farms in the south is negative.

Seventh, irrigated farms in the north benefit from the increase in precipitation only in spring, but in the south, farms benefit only in winter. Estimation results also indicate the obvious seasonal effects for precipitation in both the regions. In the north, if spring precipitation increases marginally, revenue of irrigated farms will increase by 276 USD/ha. If the increase in precipitation occurs in the other three seasons, the revenue of these farms will decrease by 25-303 USD/ha. Because of larger negative marginal effects for these three seasons, the annual marginal effect of precipitation for farms in the north is also negative. The seasonal effects of precipitation for farms in the south are opposite to that in the north. In the south, farms benefit from increased precipitation in the winter (by 93 USD/ha) but their revenue decreases from an increase in spring precipitation (by 47 USD/ha). Overall, we find that farms in the south are not as sensitive to an increase in precipitation as those in the north.

Finally, similar to irrigated farms, rainfed farms in the north also benefit from an increase in spring precipitation, but not in other seasons, while for rainfed farms in the south, increases in spring as well as summer precipitation are beneficial. Results indicate that positive marginal effects for spring precipitation (59 USD/ha) are almost offset by the negative marginal effects for summer and fall precipitation (19 USD/ha and 42 USD/ha, respectively). In the south, the positive marginal effects in spring and summer seasons (52 USD/ha and 117 USD/ha, respectively) are only slightly higher than that in winter (141 USD/ha).

4.2 Impacts of climate variation on net crop revenue

Most climate deviation variables are significant, particularly in the South China (Table VII). For example, except for fall temperature deviation in the rainfed farms' model, all temperature deviation variables in South China are statistically significant in all three

	All farms		Irrigated farms		Rainfed farms	
	North	South	North	South	North	South
Temperature deviation (USD/ha/°C)						
Spring	−81	−339	166	−569	−353	−390
Summer	0	399	333	507	0	897
Fall	0	−244	−261	−303	473	0
Winter	−93	599	0	330	0	315
Annual	−174	415	237	−35	119	821
Annual elasticity	−0.05	0.08	0.06	−0.006	0.05	0.14
Precipitation deviation (USD/ha/mm/mo)						
Spring	16	5	0	6	0	0
Summer	0	2	0	3	0	0
Fall	0	−5	0	0	12	−9
Winter	27	16	0	23	37	0
Annual	43	18	0	31	49	−9
Annual elasticity	−0.14	−0.02	0	−0.02	−0.29	0.02

Note: If the estimated coefficients for some seasonal temperatures or precipitation are not significant, their marginal effects will be zero

Table VII. Marginal impacts of climate deviation on net crop revenue

models. In North China, seven temperature deviation variables are statistically significant and five are not. It possibly indicates that net crop revenue is South China is more sensitive to the temperature variation than that in North China. For the precipitation deviation variables, eight are statistically significant in South China while this number is only four for North China. This further indicates that farms in South China are also more sensitive to precipitation variation than that in South China. In order to understand the impacts of climate variation (temperature and precipitation deviation) on net crop revenue for farms in North and South China, we also calculated the seasonal and annual marginal effects of temperature and precipitation deviation for all farms in both regions. Based on the calculated results of marginal effects, the impacts of temperature and precipitation deviation on farms in North and South China can be summarized as the following several aspects.

First, due to variation of temperature, revenues of all farms in North China will decrease while in South China, farms' revenue will increase. Results show that holding all other conditions constant, if the current year's annual temperature is higher than the long-term average level (or having positive deviation, Appendix Table AI), net revenue of farms in the north will be reduced by 174 USD/ha (Table VII). However, in South China, farms' net revenue can even increase by 415 USD/ha. Since farms' net revenues are negatively related with the variation of two seasons' temperature, spring and winter seasons; it is not hard to understand why farms in North China will lost money due to deviation of temperature. For South China, farms' net revenue are positively responsive to summer and winter's variation but negatively related with spring and fall's variation. Due to larger positive responses, farms in South China can benefit more from the temperature variation. Therefore, we can see that farms in the north are more vulnerable to the temperature variation. Based on the estimated elasticity, if the deviation of annual temperature increases by 10 percent, the net crop revenue will decline by 0.5 percent in North China but increase by 0.8 percent in South China.

Second, on the annual basis, all farms in the north and south will be hurt by precipitation variation and the hurt is more serious in the north. As demonstrated in

Appendix Table AI, the current year's annual precipitations in both North and South China are lower than long-term value. Since the annual marginal effects of precipitation are positive in both North and South China, it implies that due to lower precipitation in the current year (2001), farms' net revenue will be negatively influenced (Table VII). For example, the marginal change of precipitation deviation will result in the reduction of net revenue by 43 USD/ha in North China, higher than that in South China (18 USD/ha). Seasonal marginal effects indicate that farms in North China are sensitive to precipitation variation in both spring and winter seasons, but in South China, precipitation variation in three seasons (spring, summer, and winter seasons) hurt farms. In addition, as revealed by the annual elasticity, if the annual deviation of precipitation increases by 10 percent, net crop revenue in the north will be reduced by 1.4 percent, while that for farms in the south, this number is only 0.2 percent. Thus, the findings indicate that farms in the north are more vulnerable to the precipitation variation than that in the south.

Third, irrigated farms in the north enjoy the temperature deviation, but the farms in the south will be hurt. The marginal effects by season indicate that temperature in both spring and summer seasons are beneficial to farms in the north. Due to higher benefit in these two regions, despite some offsetting in the fall, the annual marginal effect in the north is still positive. Results show that holding all other conditions constant, if having positive deviation for annual temperature (Appendix Table AI), net revenue of irrigated farms in the north will be increased by 237 USD/ha. However, in the south, since the positive effects in spring and fall seasons are higher than the positive effects in summer and winter seasons, the annual marginal effect in the south is negative, 35 USD/ha. In addition, the annual elasticity reveals that 10 percent increase of temperature deviation will result in 0.6 percent increase of annual revenue in the north, 0.06 percent decrease of annual revenue in the south.

Fourth, rainfed farms in both two regions obtain increased benefits from the annual temperature variation, and the benefit in the south is higher than that in the north. If checking the marginal effects by season, we found that temperature deviation in both summer and winter seasons are beneficial to farms in the south, due to smaller hurt in the spring season, the overall annual revenue in the south is still positive. In the north, the positive effect in the fall offsets the negative effect in the spring and the overall annual marginal effect of temperature deviation also is positive. Results show that holding all other conditions constant, if having positive deviation for annual temperature (Appendix Table AI), net revenue of rainfed farms in the north will be increased by 119 USD/ha, lower than that in the south (821 USD/ha (Table VII). It implies that rainfed farms in the south enjoy more benefit of temperature deviation than that in the north. As indicated by annual elasticity, 10 percent increase of temperature deviation will result in 1.4 percent increase of annual revenue in the south, but this number is only 0.5 percent in the north.

Fifth, irrigated farms in the north are not sensitive to precipitation variation; while in the south, farms will be hurt. Results show that since all deviation coefficients in the model of irrigated farms are not significant (Table VI), the marginal effects of temperature deviation for irrigated farms in the north are zero (Table VII). Different from irrigated farms in the north, irrigated farms in the south will be hurt, reducing revenue by 31 USD/ha. Based on the calculated elasticity, if the deviation of annual precipitation decreases by 10 percent, the net crop revenue of irrigated farms will decline by 0.2 percent in South China. Therefore, it seems that irrigated farms in the south are more vulnerable to precipitation variation than that in the north.

Finally, precipitation deviation will hurt rainfed farms in the north, but for rainfed farms in the south, they can enjoy some small benefit. Results show that on the annual basis, rainfed farms' net revenue will be reduced by 49 USD/ha (Table VII). But for rainfed farms in the south, their net revenue can increase by 9 USD/ha due to precipitation deviation. Based on the calculated elasticity, if the deviation of annual precipitation decreases by 10 percent, the net revenue of rainfed farms will decline by 2.9 percent in North China; and net revenue of rainfed farms in South China will increase by 0.2 percent. Therefore, rainfed farms in the north are more vulnerable to precipitation variation than that in the south.

5. Conclusions

This study conducted a Ricardian analysis by estimating the climate sensitivities for North and South China separately. In the analysis, based on farm household-level data, the net crop revenues were regressed on the long-term change of seasonal climate and climate variation by the two regions and a number of control variables. Because of the importance of irrigation and considering farms' various responses, the sum-samples for the irrigated and rainfed farms were also regressed. All the specified empirical models are robust. Many variables in the models are significant and have the expected sign.

The findings indicate that long-term temperature and precipitation have various marginal effects on farms in North and South China, and farms in the latter region are more sensitive to a change in climate. At the annual level, if temperature increases marginally, net crop revenues of all farms in both the regions will decrease, with farms in the south being hurt more. On the other hand, a change in annual precipitation – as opposed to temperature – will have positive impacts on the revenue of farms, particularly of farms in the south.

Despite finding some similar trends in impacts at the annual level, by checking the results according to seasonal aspects, we found that long-term temperature and precipitation have different impacts on farms in the north and south. The results showed rainfed farms in the north benefit from a temperature increase in spring, but rainfed farms in the south benefit from an increase in fall and winter temperatures. Irrigated farms in the north benefit from an increase in precipitation only in spring, but revenues for irrigated farms in the south increase only with an increase in winter precipitation.

Further analyses indicate that in addition to long-term change of climate, farms' net revenue is also influenced by climate variation. Results show farms in the north are more vulnerable to temperature and precipitation variation than that in the south. Temperature variation results in the decrease of farms' net revenue in North China, while in South China, farms' revenue will increase. On the annual basis, all farms in the north and south will be hurt by precipitation variation and the hurt is more serious in the north. Irrigated farms in the south are more vulnerable to precipitation variation than that in the north; but rainfed farms in the north are more vulnerable to precipitation variation than that in the south.

Our results reveal that irrigation is one key adaption measure for dealing with climate change. In North and South China, increasing temperatures are beneficial for irrigated farms, while for rainfed farms, higher temperatures will cause revenue losses. Thus, part of China's success to cope with future climate change lies in its ability to use water for irrigation; nearly 60 percent of cultivated land is irrigated. Our analysis assumes that water supply will not change. Data to measure the amount of water used by each farmer were unavailable. It was therefore not possible to measure the importance of available water. Water availability could be a critical problem for China if climate warming makes water increasingly scarce (Wang *et al.*, 2010). Clearly, there is a strong need for further analysis of the effects of climate change on water in China.

Notes

1. Temperature here means the surface air temperature.
2. North China includes the provinces of Liaoning, Jilin, Heilongjiang, Tianjin, Hebei, Shandong, Shanxi, Henan, Inner Mongolia, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang; South China includes the provinces of Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong, Anhui, Jiangxi, Hubei, Hunan, Guangxi, Chongqing, Sichuan, Guizhou, and Yunnan.

References

Fleischer, A., Lichtman, I. and Mendelsohn, R. (2008), "Climate change, irrigation, and Israeli agriculture: will warming be harmful?", *Ecological Economics*, Vol. 65 No. 3, pp. 109-116.

Kurukulasuriya, P. and Mendelsohn, R. (2006), "A Ricardian analysis of the impact of climate change on African cropland", Discussion Paper No. 8, CEEPA.

Kurukulasuriya, P. and Mendelsohn, R. (2007), "Modeling endogenous irrigation: the impact of climate change on farmers in Africa", Policy Research Working Paper No. 4278, World Bank, Washington, DC.

Kurukulasuriya, P. and Mendelsohn, R. (2008), "A Ricardian analysis of the impact of climate change on African cropland", *African Journal of Agricultural and Resources Economics*, Vol. 2, pp. 1-23.

Kurukulasuriya, P., Mendelsohn, R., Hassan, R., Benhin, J., Diop, M., Eid, H.M., Fosu, K.Y., Gbetibouo, G., Jain, S., Mahamadou, A., El-Marsafawy, S., Ouda, S., Ouedraogo, M., Sène, I., Seo, N., Maddison, D. and Dinar, A. (2006), "Will African agriculture survive climate change?", *World Bank Economic Review*, Vol. 20 No. 3, pp. 367-388.

Li, H., Lin, Z. and Chen, H. (2010), "Interdecadal variability of spring precipitation over South China and its associated atmospheric water vapor transport", *Atmospheric and Oceanic Science letters*, Vol. 2 No. 2, pp. 113-118.

Liu, H., Li, X., Fischer, G. and Sun, L. (2004), "Study on the impacts of climate change on China's agriculture", *Climatic Change*, Vol. 65 Nos 1-2, pp. 125-148.

Mendelsohn, R. and Dinar, A. (1999), "Climate change, agriculture, and developing countries: does adaptation matter?", *The World Bank Res. Obs.*, Vol. 14 No. 2, pp. 277-293.

Mendelsohn, R. and Dinar, A. (2003), "Climate, water, and agriculture", *Land Econ.*, Vol. 79 No. 3, pp. 328-341.

Mendelsohn, R., Nordhaus, W. and Shaw, D. (1994), "Measuring the impact of global warming on agriculture", *American Economic Review*, Vol. 84 No. 4, pp. 753-771.

Mendelsohn, R., Kurukulasuriya, P., Basist, A., Kogan, F. and Williams, C. (2007), "Climate analysis with satellite versus weather station data", *Climatic Change*, Vol. 81 No. 1, pp. 71-83.

People's Republic of China (2007), *China's National Assessment Report on Climate Change*, Science Publishing House, Beijing.

Ren, G. (2007), *Climate Change and Water Resources in China*, China Meteorological Press, Beijing.

Schlenker, W., Hanemann, M. and Fisher, A. (2005), "Will US agriculture really benefit from global warming? Accounting for irrigation in the hedonic approach", *American Economic Review*, Vol. 95 No. 1, pp. 395-406.

Seo, S.N. and Mendelsohn, R. (2008), "A Ricardian analysis of the impact of climate change on South American farms", *Chilean Journal of Agricultural Research*, Vol. 68 No. 1, pp. 69-79.

Seo, S.N., Mendelsohn, R. and Munasinghe, M. (2005), "Climate change and agriculture in Sri Lanka: a Ricardian valuation", *Environmental and Development Economics*, Vol. 10 No. 5, pp. 581-596.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (2007), *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, New York, NY

Wang, J., Huang, J. and Yang, J. (2010), "Climate change, water security and agricultural development in 3H region", report submitted to the World Bank, September 26, pp. 1-87.

Wang, J., Mendelsohn, R., Dinar, A., Huang, J., Rozelle, S. and Zhang, L. (2009), "The impact of climate change on China's agriculture", *Agricultural Economics*, Vol. 40, pp. 323-337.

Xiong, W., Matthews, R., Holman, I., Lin, E. and Xu, Y. (2007), "Modelling China's potential maize production at regional scale under climate change", *Climate Change*, Vol. 85 No. 3, pp. 433-451.

Appendix

	All farms		Irrigated farms		Rainfed farms	
	North	South	North	South	North	South
Temperature deviation (°C)						
Spring	1.17	0.70	1.18	0.81	1.06	0.55
Summer	0.97	0.05	0.87	0.04	0.96	0.04
Fall	1.04	0.65	0.90	0.53	1.07	0.66
Winter	−0.42	0.67	−0.10	0.73	−0.63	0.63
Annual	0.69	0.52	0.71	0.53	0.62	0.47
Precipitation deviation (mm)						
Spring	−13.42	−19.08	−11.52	−30.50	−13.99	−17.95
Summer	−17.62	8.95	−14.26	18.36	−13.76	1.24
Fall	−7.48	−12.56	−2.97	−19.08	−9.55	−12.66
Winter	4.32	13.55	4.69	23.01	3.45	8.09
Annual (monthly mean)	−8.55	−2.29	−6.02	−2.05	−8.46	−5.32

Table AI.
Deviation of temperature and precipitation in North and South China

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