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How China's Farmers Adapt to Climate Change

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Abstract

This paper uses a cross sectional method to analyze irrigation choice and crop choice across 8,405 farmers in 28 provinces in China. The findings show that Chinese farmers are more likely to irrigate when facing lower temperatures and less precipitation. Farmers in warmer places are more likely to choose oil crops, maize, and especially cotton and wheat, and are less likely to choose vegetables, potatoes, sugar, and especially rice and soybeans. In wetter locations, farmers are more likely to choose soybeans, oil crops, sugar, vegetables, cotton, and especially rice, and they are less likely to choose potatoes, wheat, and especially maize. The analysis of how Chinese farmers have adapted to current climate, provides insight into how they will likely adapt when climate changes. Future climate scenarios will cause farmers in China to want to reduce irrigation and shift toward oil crops, wheat, and especially cotton. In turn, farmers will shift away from potatoes, rice, vegetables, and soybeans. However, adaptation will likely vary greatly from region to region. Policy makers should anticipate that adaptation is important, that the magnitude of changes depends on the climate scenario, and that the desired changes depend on the location of each farm.

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. 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, adinar@worldbank.org (After 12/1/2008 adinar@ucr.edu), jkhuang.ccap@igsnrr.ac.cn.

HOW CHINA'S FARMERS ADAPT TO CLIMATE CHANGE

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SUMMARY

This paper examines how farmers have adapted to the current range of climates across China. A cross sectional method is used to analyze irrigation choice and crop choice across 8,405 farmers in 28 provinces in China. A discrete choice logit model is used to capture the choice of irrigation and a multinomial logit model is used to capture crop choice. We find that both irrigation and crop choice decisions are climate sensitive. Chinese farmers are more likely to irrigate when facing lower temperatures and less precipitation. Farmers in warmer places are more likely to choose oil crops, maize, and especially cotton and wheat, and are less likely to choose vegetables, potatoes, sugar and especially rice and soybeans. In wetter locations, farmers are more likely to choose soybeans, oil crops, sugar, vegetables, cotton and especially rice, and they are less likely to choose potato, wheat and especially maize.

The analysis of how Chinese farmers have adapted to current climate, provides insight into how they will likely adapt when climate changes. Future climate scenarios will cause farmers in China to want to reduce irrigation and shift crops towards oil crops, wheat, and especially cotton. In turn, farmers will shift away from potatoes, rice, vegetables, and soybeans. We find, however, that adaptation will likely vary from region to region. For example, irrigation is likely to fall in the eastern regions of China but increase in the western regions (provided there is sufficient water). One important weakness of this study is that it was not able to take into account water availability, which is a critical element of Chinese agriculture. The projections into the future take into account only climate change. The analysis does not take into account other background changes that may well occur including changes in prices, technology, and water availability.

Analyses of climate impacts must take adaptation into account or they will overestimate damages. Policy makers must be aware that adaptation is an endogenous response to climate. They should anticipate that adaptation is important, that the magnitude of changes depends on the climate scenario, and that the desired changes depend on the location of each farm.

I. INTRODUCTION

Although there is an extensive literature on the effects of climate on agriculture (Reilly et al 1996; McCarthy et al 2001), there are very few studies that have measured adaptation. Studies that compare the impacts of climate change that include adaptation, such as Ricardian studies (Mendelsohn, Nordhaus, and Shaw 1994, Mendelsohn and Dinar 1999; Mendelsohn et al. 2001; Mendelsohn and Dinar 2003; Seo et al. 2005; Kurukulasuriya et al. 2006; Fleischer et al 2007; Seo and Mendelsohn 2007, Wang et al. 2008), tend to find much lower damages than studies that do not include adaptation, such as agronomic analyses (Rosenzweig and Parry 2004; Reilly et al. 1996; McCarthy et al 2001; Parry et al. 2004). It is clear from this empirical evidence that it is very important to include adaptation in any impact analysis of long term climate change. Of course, adaptation is likely to be less important with respect to year to year weather fluctuations as farmers may have fewer options to adapt to sudden or abrupt changes.

Adaptations are actions that people and firms take in response to climate change to reduce damages or increase benefits (IPCC 2007).[1] What specifically do farmers do to adapt to climate? How have they adjusted to the climates that they live in today? A new series of studies have begun to examine this question. By comparing what farmers do in one climate zone versus another, the studies quantify how farmers have made long term adjustments to climate. For example, studies have examined how climate affects the choice of irrigation in Africa (Kurukulasuriya and Mendelsohn 2006a) and South America (Mendelsohn and Seo 2007). Studies have explored how climate affects livestock choice in Africa (Seo and Mendelsohn 2006) and South America (Seo and Mendelsohn 2007a). Previous studies have explored how climate alters crop choice in Africa (Kurukulasuriya and Mendelsohn 2006) and South America (Seo and Mendelsohn 2007b). All of the above mentioned adaptation studies find that farmers adjust irrigation practices, crop varieties, and livestock species to both temperature and precipitation levels.

[1] One should distinguish between adaptation to climate change, which spans over a long period, which differs from adaptation to climate variance, the changes in weather from year to year (Leary et al. 2006). Adapting to weather is important but it should not be confused with adapting to climate.

In the present analysis, we use the same cross sectional methods used in the above studies of Africa and South America to study farm adaptation in China. We expect that farmers in China have also adapted to the range of climates that they face in China. Analyzing a sample of 8,405 farms sampled across 28 provinces in one year, we estimate logit models of irrigation and multinomial logit regressions of crop choice to detect how these choices vary with long term temperature and precipitation. Matching the location of each farm to climate data and soils, it is possible to examine the effect of climate on these endogenous choices by farmers while controlling for several other factors.

The available data allow us to measure the direct effects of temperature and precipitation on irrigation choice and crop choice. We specifically examine the choice of 9 major crops in China: wheat, rice, maize, soybean, potato, cotton, oil crops, sugar, and vegetables. Unfortunately, the amount of irrigation water a farmer uses is not available in the dataset. We do not know water availability or cost. If future climate scenarios reduce available water supplies, this is likely to affect these choices and the present study does not take this into account. This is an important omission for an agricultural system such as in China that relies heavily on irrigation.

The paper is organized as follows. We briefly review the methodology of adaptation analysis in the next section. Section three discusses the available data and the construction of the variables in the data set. In the fourth section, we present the estimation results for current farmers. The fifth section then forecasts how future farmers would change their irrigation and crop choice for three different climate scenarios in 2050 and 2100. The paper concludes with a summary of the key results and a discussion of policy relevance.

II. METHODOLOGY

We assume that farmers make choices that maximize their income. We define income broadly to include both products they sell and consume. In this analysis, we are interested in modeling how they select from a number of discrete and mutually exclusive choices (McFadden 1981). In order to study irrigation choice, we rely on a dichotomous logit. We test how climate influences the probability of choosing whether to irrigate or not, while controlling for a number of other independent variables such as soils, household characteristics and farm characteristics.

In order to study crop choice, we rely on a multinomial logit regression. The multinomial logit examines the probability that a farmer chooses one of the 9 major crops grown in China. We do not examine minor crops. We assume that the choice among the 9 crops is independent of these other choices. The multinomial tests the influence of climate on the probability of choosing each crop controlling for a number of other independent variables such as soils, household characteristics, and farm characteristics. We model irrigation choice and crop choice separately.

We assume that farmers choose the crop that yields the highest net profit. Hence, the probability that a crop is chosen depends on the profitability of that crop. We assume that farmer *i*'s profit in choosing crop *j* (*j*=1, 2,…, *J*) is:

$$\pi_{ij} = V_j(C_i, K_i, S_i) + \varepsilon_j(C_i, K_i, S_i) \tag{1}$$

where C is a vector of climate variables, K is a vector of exogenous characteristics of the farm, and S is a vector of characteristics of the farmer. The vector K includes soils, elevation and access variables; S includes variables such as the education of the farmer and land size. The profit function is composed of two components: the observable component V and an unobservable component that is in the error term ε. The farmer will choose the crop that yields the highest profit. Similarly, the farmer also chooses irrigation or rainfed farming based on which type of farming yields the highest income.

The farmer will choose crop *j* over all other crops *k* (*j*≠*k*) if:

$$\pi_j^*(Z_i) > \pi_k^*(Z_i) \text{ for } \forall \text{ k} \neq \text{j.[or if } \varepsilon_k(Z_i) - \varepsilon_j(Z_i) < V_j(Z_i) - V_k(Z_i) \text{ for k} \neq \text{j] .} \tag{2}$$

The probability P_{ij} for the jth crop to be chosen is then:

$$P_{ij} = \Pr[\varepsilon_k(Z_i) - \varepsilon_j(Z_i) < V_j - V_k] \ \forall \text{ k} \neq \text{j where } \mathrm{V_j} = \mathrm{V_j(Z_i)} \tag{3}$$

We are interested in the following specific model where climate has a quadratic functional form:

$$V_j(C_i, K_i, S_i) = C_i\alpha + C_i^2\beta + K_i\phi + S_i\omega \tag{4}$$

Assuming that ε is independently Gumbel distributed and the profit function can be written linearly in its parameters, the probability can be calculated as follows:

$$P_{ij} = \frac{e^{C_i\alpha + C_i^2\beta + K_i\phi + S_i\omega}}{\sum_{k=1}^{J} e^{C_k\alpha + C_k^2\beta + K_k\phi + S_k\omega}} \tag{5}$$

which gives the probability that farmer *i* will choose crop j from among J species (McFadden 1981).

The marginal change in probability of selecting a crop with respect to climate is therefore:

$$\frac{\partial P_j}{\partial c_l} = P_j[\alpha_{jl} + 2c_{il}\beta_{jl}] - \sum_{k=1}^{J} P_k[\alpha_{kl} + 2c_{il}\beta_{kl}] \quad . \tag{6}$$

The marginal probability of choosing a new crop depends on the underlying climate of the farm.

A critical assumption of the multinomial logit is *Independence of Irrelevant Alternatives*. We assume that the relative probability of any two alternatives is not affected by adding a third choice.

The same discrete choice model applies to irrigation except in this case there are only two choices. In the irrigation analysis, we rely on a logit regression to estimate the probability of irrigation. The logit model predicts that the probability of irrigation can vary between 0 and 1 depending on the values of the independent variables. We again test the influence of climate controlling for a number of other independent variables such as soils, household characteristics, and farm characteristics.

III. DATA

The climate data (monthly temperature and precipitation) were obtained 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 normal) over this time period for each month. We average the monthly climate data into four seasons in the following way: 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.

Socio-economic data is obtained from the Household Income and Expenditure Survey (HIES) administered by China National Bureau of Statistics in 2001. There are more than 50,000 observations in the HIES. We have selected a sub-sample from only those counties for which we have climate data (from meteorological stations located in these counties). Our final sample has 8,405 households in 915 villages in 124 counties in 28 provinces.

The HIES includes a number of household and village characteristics. Irrigation data were collected at the village level. Information about crop choice was collected at the farm level. Nine major crops were identified: cotton, maize, oil crops, potato, rice, soybean, sugar, wheat and vegetables. Additional household variables include the education level of members of the farm household, each family's land area, the number of family laborers that belong to the household. Additional village variables include indicators about the topographical environment of each village (e.g., if it is located on a plain or in a mountainous region), the share of cultivated area that is irrigated in the village, membership in associations, extension service, and access to markets (e.g., the presence of paved roads between the village and key services; the distance to each township's government).

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 soil variables for our analysis was created by generating a variable measuring the share of cultivated area with each type of soil.

IV. RESULTS

In this section, we report the results concerning irrigation choice and crop choice across farmers operating under present situation. This is a cross sectional analysis exploring how the range of current climate across China affects choices of irrigation and crops today.

Irrigation choice

We estimate two logit regressions of irrigation using a quadratic model of climate (Table 1). Because the household characteristics could be considered endogenous, they are included in one model and excluded from the second model. The regression results confirm that climate has a significant impact on a farmer's irrigation adoption decision. Both temperature and precipitation variables are significant. The quadratic climate terms are significant suggesting the climate relationship is nonlinear as expected. The seasonal coefficients are not alike suggesting that the consequences of warming and precipitation are not the same in each season. Several of the control variables are significant. Irrigation is more likely with clay and silt soils, when the farm is on a flat plain, and near a road. Farms further away from township governments are less likely to irrigate possibly because the farm is more remote and possibly because the farm is less likely to receive extension services. Household characteristics such as participating in production associations and the level of education of the labor increase the likelihood of irrigation. More land per household member reduces the likelihood of irrigation, probably because irrigated land is more labor intensive relative to rainfed land.

In order to interpret the coefficients of the logit model, we calculate marginal impacts for each climate variable (Table 2). The results suggest that seasons have strong but offsetting effects. Warmer summer and fall temperatures increase the likelihood of irrigation selection but warmer spring and winter temperatures reduce it. Wetter springs, summers and falls reduce the likelihood of irrigation selection but wetter winters increase it. In general, warmer annual temperatures reduce irrigation selection likelihood. It implies that farmers in warmer locations are much less likely to choose irrigation and farmers in cooler places are more likely to irrigate. In addition, farmers in locations with more rainfall are also less likely to irrigate because farmers get sufficient moisture without the expense of irrigation. However, the marginal effects depend on the distribution of seasonal rainfall and temperature so that it can vary from place to place.

The analysis does not include water availability. This remains an important caveat to the results. If there is not enough water, farmers may want to shift to irrigation but they may not be able to. Higher temperatures could lead to a reduction in irrigation if higher evaporation reduces available water. Changes in precipitation could also change flows. As China uses all of its available water in some regions, changes in flows are likely to have very important consequences for irrigation.

Results of crop choice

The analysis of crop choice indicates that farmers plant different crops depending on the climate they face (Table 3). Both temperature and precipitation play a role in crop choice. The quadratic climate coefficients are significant, implying that the response function is nonlinear. The climate coefficients are quite different across seasons suggesting that seasonal effects are, once again, important.

Many of the control variables are significant (Table 3). Soils, as expected, influence crop choice. Cotton and sugar are more likely to be planted on clay soils whereas rice, wheat, vegetables, soybeans and oil crops are less likely. Farmers with silt soils are more likely to choose potatoes but less likely to choose rice, sugar, and several other crops. Cotton and sugar are much more likely to be grown on plains but potato and oil crops are not. Being close to a road increases the likelihood that a farmer will select wheat, rice, vegetables and oil crops and reduces the chance the farmer will select cotton. This may reflect the relative cost of transporting each of these products. The farther the farmer is from the township government, the more likely the farmer will grow wheat and the less likely he will grow oil crops. Proximity to township government makes public extension more accessible. Access to extension may help farmers grow wheat whereas oil crops are relatively simple to grow and so do not require extension services. If a farmer is in a village with major irrigated areas, the farmer is more likely to grow wheat, rice, and sugar but less likely to grow potatoes. Rice and sugar tend to be irrigated whereas potatoes are never irrigated. Farmers who join production associations are more likely to grow cotton, because of the additional ginning and marketing needed for the final product, that are taken care by the association. Farms with less educated workers are more likely to grow soybeans and oil crops, which are the least sophisticated crops to grow. The more cultivated land per household member, the more likely the farmer will grow cotton, oil crops, sugar, and wheat—crops that take advantage of economies of scale—but the less likely they will grow rice and vegetables—crops that can be grown on small fields.

In Table 4, we calculate the marginal effects of temperature and precipitation on crop choice. Across China, farmers are more likely to select cotton, wheat, oil crops and maize as temperatures warm and they are less likely to select rice, vegetables, soybeans, potatoes and sugar. With more precipitation, farmers are more likely to pick rice, cotton, vegetables, soybean, oil crops and sugar and less likely to pick maize, wheat and potato. However, the seasonal effects are quite different from the annual effects. For example, warmer summers favor cotton, wheat, and oil crops whereas warmer falls favor rice, vegetables and potato. Wetter springs are very bad for vegetables, oil crops and maize but good for wheat, potato, cotton, and rice. Wetter winters are good for most of the crops (cotton, oil crops, vegetables, soybeans, maize, sugar and rice) but bad for wheat and potato. The actual impact in each location is therefore going to depend on the seasonal distribution of temperature and precipitation, and not just the annual average.

V. CLIMATE FORECAST

The empirical results in the previous section describe how farmers in China have adapted to the climate that they currently face. They have altered their irrigation and crop choice to fit the climate they live in. In this section, we project how these decisions would change in the future if climate changes. We assume that all other features of each farm will remain the same and that only climate will change. This is obviously a simplification as the technology, capital intensity, and other features of the farm are all likely to change over the next century. However, the analysis does provide a sense of the role of climate and the extent of endogenous adaptation to expect.

We examine a set of climate scenarios from climate models for 2050 and 2100. These climate scenarios are complicated as they predict very different changes in each season, they vary from one region to another within China, and they involve a combination of temperature and precipitation effects. The climate scenarios come from the PCM, HADIII, and CCM2 climate models. All the models are assuming a business as usual (no abatement) A2 emission scenario. Table 5 presents the average change in temperature and precipitation for China according to each climate scenario. The PCM scenario predicts a small change in temperature and a small increase in precipitation. The HADCM3 scenario predicts a middle temperature increase and a precipitation decline in 2050 but not in 2100. The CCM2 scenario predicts the greatest warming and no change in precipitation in 2050 but a small decline in precipitation in 2100.

Table 5 also presents the effect of each climate scenario on the choice of irrigation and crop choice in 2050 and 2100. All three climate scenarios predict that the likelihood of choosing irrigation will fall in China by 2050. The reductions will range from -13% to -23%, depending on the future climate scenario. By 2100, the percentage of land in irrigation will fall by -1% to -17% depending on the future climate scenario. In addition, all three scenarios also suggest that the likelihood wheat and cotton are selected will slightly increase and that the likelihood of rice and soybeans will slightly decrease by 2050. By 2100, the size of these changes is distinctly larger. Depending on the climate scenario, the likelihood of selecting rice will fall by -1% to -5%, the likelihood of selecting vegetables will fall by -1% to -4%; the likelihood of selecting soybeans will fall by -3% to -4%, and the likelihood of selecting potatoes will fall by -1% to -3%. In turn, the likelihood of selecting wheat will increase by +2% to +3%, the likelihood of selecting oil crops will increase by +1% to +3%, and the likelihood of choosing cotton will increase by +5% to +12%, depending on the climate scenario. These reductions and increases reflect how the percentage of cropland will change. They imply relatively large changes in the mix of crops that will be grown in China.

But the all-China results do not tell the entire story. Table 6 reveals that current irrigation and crop choices vary across regions in China. In order to see this spatial variation, we divide China into 5 major climatic regions: Northeast, Southeast, Middle, Northwest and Southwest.[2] Results show that farmers in the Southeast region are more likely to choose irrigation compared to the other regions. Southeast farmers currently irrigate 68% of their cropland. The share of irrigated land in the Northwest is also very

[2] The Northeast region includes Liaoning, Jilin, Heilongjiang, Tianjin and Hebei provinces; the Southeast region includes Shanghai, Jiangsu, Zhejiang, Fujian, Shandong and Guangdong provinces; the Middle region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Inner Mongolia and Guangxi provinces; the Northwest region includes Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang provinces; and the Southwest region includes Chongqing, Sichuan, Guizhou and Yunnan provinces.

high (60%). In contrast, farmers in the Northeast region use irrigation on only 25% of their cropland.

Farmers in different regions also choose different cropping patterns. For example, in the Northeast region, farmers currently allocate more of their cropland to maize and vegetables, and less to sugar and cotton. While in the Southeast region, farmers choose to have more of their cropland growing vegetables and rice, and less growing sugar and cotton. Each of the regions has a different cropping pattern because they have different regional conditions (Table 7). For example, the Northeast region is much colder than the other regions; its annual average temperature is 6.5^{o}C, while it is warmer in both the Southeast and Southwest regions, their average annual temperature reaches 16^{o}C. In addition, the Southeast region is wetter than the other regions with an average precipitation per month of 9.9cm, while it is very dry in the Northwest region with an average precipitation per month of only 2.2cm.

Each region responds in a different way to the climate scenarios (Table 8). For example, with the 2100 climate of the PCM model, farmers in Northwest and Southwest regions are more likely to irrigate their land, while farmers in the other three eastern regions (Northeast, Southeast and Middle regions) are less likely to irrigate. The national numbers hide these much larger changes in each region by averaging across all regions. Farmers will also adjust crop choice differently in each region. For example, with the 2100 PCM climate, farmers in the Southwest region will be less likely to grow wheat by -1%, while in the other four regions the likelihood of farmers growing wheat will increase by +4% to +14% depending on the climate scenario. Under the HADCM3 climate scenario, the likelihood of farmers in the Southeast, Middle and Northwest regions growing rice will increase by up to +2%, while the fraction of cropland devoted to rice in the Southeast and Southwest regions is reduced by -1% to -2%, depending on the future climate scenario. Similar variations in crop choice across regions apply to the other crops as well and for each climate change scenario.

VI. CONCLUSION AND POLICY IMPLICATIONS

The results of the adaptation analysis strongly suggest that Chinese farmers do adapt to climate by shifting to irrigation (where possible) and by switching crops. With warmer temperatures, they are more likely to increase irrigation and grow oil crops, wheat, and especially cotton. As precipitation increases, they may also increase irrigation and choose to grow more soybean, oil crops, and especially rice, cotton, and vegetables. However, all of these results are dependent on no changes in water flow. Since all of these decisions are likely to be affected by water flow and climate change is likely to change water flows, the results must be interpreted cautiously. It is clearly very important to follow this study with an additional analysis where water flow can be taken into account.[3]

The projections of changes in future climates must be viewed cautiously. First, the climate projections themselves are uncertain and range from mild to severe changes. Second, the impact analysis in this paper only examines changes in climate. There are many other changes that are likely to take place as well. There is likely to be new crop varieties, changes in relative prices, new management practices, and new technologies. Water availability is likely to change with and without climate change. All of these changes must be taken into account to obtain an accurate forecast of future conditions.

One point that is clear from the results concerning adaptation is that Chinese farmers already have adapted to climate. Climate affects irrigation choice and crop choice. Therefore, it is very likely that Chinese farmers will adapt to climate change. Examining a set of future climate scenarios, the model predicts there will be substantial changes in both the irrigation mix and the crop mix across China with climate change. The magnitude of the change will depend on the climate scenario. Future studies of the impacts of climate change on Chinese agriculture must take these adaptations into account. Failing to account for adaptation will overestimate the damages from climate change.

The analysis also revealed that adaptations will vary dramatically across regions. The analysis predicts that some regions will increase irrigation while other regions will move towards rainfed agriculture. Warming will also cause changing cropping patterns across China. Global warming will cause some crops to increase in one region and fall in

[3] Such a study may need hydrological modeling of the river basin within which the observed farms are located.

another. Policy makers must be aware of this spatial variation of adaptation. They must resist the temptation to move towards nation wide adaptation policies and instead make sure that adaptation is sensible at the local level.

The analysis in this paper examined irrigation and crop choice. Farmers can take other measures as well in response to climate change. They can adjust varieties, not just species. They can alter when they plant and harvest. They can choose different tillage practices. They can adopt different irrigation technologies. They can adjust other inputs such as labor, capital, and fertilizer. All of these measures need to be examined.

Farmers can select from an arsenal of adaptation alternatives. This implies that adaptation options have to be available. This is a policy matter. Government and the private sector may be in a position to prepare sets of adaptation options to be available for use by individual farmers, and to provide needed knowhow via efficient public extension services or private agents. The government could also help establish the background or prerequisites for private adaptation. That includes establishing accessible credit lines, and enforcing private property ownership.

Additional public adaptations are also needed at the government level. One of the most important adaptations that China can make concerns water management. By reallocating water to its best use, the government can make important adaptations. This includes sending signals of the economic value of water by establishing water markets or efficient quotas and/or regulatory policies. Water management may also involve engineering efforts to store water or transfer water from water abundant to water shortage regions. Another important adaptation concerns developing new crop varieties. If the government can develop new crops suited for a warmer world, it would provide farmers with new opportunities that could be very valuable in the future.

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Table 1: Regression of Irrigation Choice

Variables	If irrigate (1=Yes; 0=No)	
	Without household variables	With household variables
	Quadratic	Quadratic
Spring temp	-1.2439	-1.3439
	(8.83)***	(9.30)***
Spring temp sq	0.0293	0.0314
	(6.75)***	(7.11)***
Summer temp	0.6607	0.6795
	(3.28)***	(3.31)***
Summer temp sq	-0.0008	-0.0009
	-0.17	-0.19
Fall temp	0.2180	0.3189
	(1.68)*	(2.42)**
Fall temp sq	-0.0277	-0.0316
	(5.18)***	(5.81)***
Winter temp	0.6087	0.6319
	(8.75)***	(8.92)***
Winter temp sq	0.0086	0.0102
	(4.50)***	(5.19)***
Spring prec	-0.7896	-0.7931
	(8.02)***	(8.02)***
Spring prec sq	0.0343	0.0345
	(8.80)***	(8.82)***
Summer prec	-0.1559	-0.1826
	(4.92)***	(5.59)***
Summer prec sq	0.0003	0.0008
	(0.29)	(0.82)
Fall prec	-0.1123	-0.1199
	(1.25)	(1.33)
Fall prec sq	0.0071	0.0074
	(1.63)	(1.71)*
Winter prec	1.2560	1.2345
	(7.47)***	(7.31)***
Winter prec sq	-0.1455	-0.1432
	(7.02)***	(6.88)***
Share of land areas with clay soil	1.1462	1.1690
	(7.47)***	(7.54)***
Share of land areas with silt soil	0.1272	0.1395
	(1.01)	(1.11)
Plain (1=Yes; 0=No)	0.5169	0.4861
	(6.49)***	(6.09)***
Road (1=Yes; 0=No)	0.8485	0.8304
	(5.49)***	(5.34)***
Distance to township government	-0.0548	-0.0492
	(8.63)***	(7.65)***
If participate production association		0.8579
(1=Yes; 0=No)		(3.88)***
Share of labor without receiving		-0.0030
education		(1.93)*
Cultivated land area per household		-0.1438
		(4.27)***
Constant	1.6391	1.928
	(0.97)	(1.11)
Pseudo R^2	0.19	0.2
Observations	8405	8405

Values in parenthesis are t-statistics. One asterisk implies significant at 5% level and two asterisks implies significant at 1% level.

Table 2 Marginal effect of climate change on irrigation choice

Without household variables	Temperature ˚C	Precipitation cm/mo
Spring	-0.2110	-0.3647
Summer	0.0751	-0.0245
Fall	0.0414	-0.0151
Winter	-0.0001	0.1218
Annual	**-0.0204**	**-0.1217**
With household variables		
Spring	-0.2310	-0.3654
Summer	0.0758	-0.0295
Fall	0.0540	-0.0161
Winter	-0.0130	0.1197
Annual	**-0.0276**	**-0.1354**

Note：Marginal effects calculated using regressions coefficients from Table 1 evaluated at each climate point in sample.

Table 3 Multinomial logit regression of crop choice

	Wheat	Rice	Vegetable	Soybean	Potato	Cotton	Oil Crops	Sugar
Spring temp	0.119	0.27	-0.025	-1.21	0.229	-1.191	-0.176	-0.181
	(-0.82)	(1.84)*	(-0.25)	(8.84)***	(2.03)**	(2.20)**	(-1.38)	(-0.46)
Spring temp sq	-0.013	-0.0048	-0.0034	0.0313	-0.0177	0.0158	-0.0094	0.0015
	(2.86)***	(-1.07)	(-1.11)	(7.05)***	(5.12)***	(-0.77)	(2.39)**	(-0.13)
Summer temp	-1.027	-0.681	-0.125	2.446	0.237	-2.541	0.436	1.457
	(6.22)***	(2.82)***	(-0.88)	(10.03)***	(-1.53)	(2.45)**	(2.56)**	(2.24)**
Summer temp sq	0.031	0.0078	0.0042	-0.0427	-0.0034	0.0903	0.0002	-0.0225
	(8.06)***	(-1.57)	(-1.32)	(8.37)***	(-0.98)	(4.17)***	(-0.07)	(-1.56)
Fall temp	-0.118	1.05	0.177	-0.458	-0.445	-0.589	-0.9	-1.411
	(-0.90)	(7.11)***	(1.88)*	(3.70)***	(4.03)***	(-0.85)	(7.09)***	(3.22)***
Fall temp sq	-0.014	-0.024	-0.0113	-0.0016	0.0094	0.0025	0.0118	0.0044
	(2.81)**	(5.07)***	(3.13)***	(-0.34)	(2.31)**	(-0.09)	(2.67)**	-0.31
Winter temp	0.347	-0.294	0.111	0.365	0.242	-0.307	0.542	0.813
	(6.83)***	(4.46)***	(2.50)**	(5.94)***	(4.54)***	(-1.42)	(9.92)***	(4.94)***
Winter temp sq	0.0004	0.0094	0.007	-0.0023	0.0073	-0.0972	-0.0001	0.0136
	(-0.20)	(4.94)***	(5.27)***	(-1.17)	(4.79)***	(5.79)***	(-0.06)	(2.26)**
Spring prec	0.831	0.11	-0.08	0.27	0.162	0.447	-0.189	0.64
	(8.43)***	(1.75)*	(-1.40)	(3.64)***	(2.52)**	(1.84)*	(2.84)***	(3.40)***
Spring prec sq	-0.048	-0.0013	0.0038	-0.0127	-0.0017	-0.0002	0.0056	-0.0314
	(10.63)***	(-0.58)	(1.81)*	(4.78)***	(-0.72)	(-0.02)	(2.31)**	(4.92)***
Summer prec	-0.213	-0.038	-0.108	0.021	-0.075	-0.253	-0.0052	-0.009
	(7.69)***	(-1.32)	(5.19)***	(-0.70)	(2.85)***	(2.81)***	(-0.20)	(-0.12)
Summer prec sq	0.00676	0.0003	0.0023	-0.0002	0.0002	-0.0028	-0.0008	0.001
	(7.17)***	(-0.36)	(3.59)***	(-0.18)	(-0.28)	(-0.66)	(-1.01)	(-0.53)
Fall prec	-0.522	0.416	0.129	0.218	0.247	-0.799	-0.223	-1.026
	(6.59)***	(5.57)***	(2.21)**	(2.97)***	(3.59)***	(3.61)***	(3.23)***	(3.93)***
Fall prec sq	0.0257	-0.0203	-0.0098	-0.0271	-0.016	0.0479	0.0083	0.0184

	(6.47)***	(5.76)***	(3.47)***	(7.62)***	(4.88)***	(3.92)***	(2.53)***	(-1.41)
Winter prec	-0.173	0.892	0.892	0.194	0.201	2.771	1.293	1.198
	(-1.10)	(7.13)***	(8.12)***	(-1.33)	(-1.56)	(4.91)***	(9.92)***	(2.58)***
Winter prec sq	0.0694	-0.0603	-0.057	0.0582	-0.0051	-0.3558	-0.0946	0.0177
	(3.55)***	(4.20)***	(4.40)***	(3.45)***	(-0.35)	(5.52)***	(6.22)***	(-0.35)
Share of land areas with clay soil	-0.69	-0.913	-0.528	-0.382	-0.2	0.873	-0.39	0.801
	(5.09)***	(8.03)***	(5.14)***	(2.82)***	(1.66)*	(2.77)***	(3.36)***	(2.26)**
Share of land areas with silt soil	-0.243	-0.67	-0.026	0.055	0.706	-0.207	-0.194	-0.894
	(2.77)**	(5.82)***	(-0.32)	(-0.50)	(6.63)***	(-1.20)	(1.97)*	(2.28)**
Plain (1=Yes; 0=No)	-0.0412	-0.0968	-0.0028	-0.0761	-0.3192	1.6194	-0.3589	0.6544
	(-0.59)	(-1.53)	(-0.05)	(-1.13)	(4.95)***	(9.59)***	(5.56)***	(4.20)***
Road (1=Yes; 0=No)	0.362	0.449	0.376	0.002	0.427	-0.222	0.2709	0.0917
	(3.03)***	(4.11)***	(3.81)***	(-0.01)	(3.79)***	(-1.07)	(2.42)**	(-0.29)
Distance to township government	0.0115	-0.0098	-0.0091	-0.0021	0.0004	-0.0166	-0.0115	-0.0182
	(2.15)**	(1.86)*	(2.07)**	(-0.39)	(-0.09)	(-1.39)	(2.18)**	(-1.29)
Share of irrigated areas in village	0.00501	0.005	0.0007	-0.0014	-0.004	-0.0004	0.0014	0.006
	(6.40)***	(6.32)***	(-1.05)	(-1.64)	(4.77)***	(-0.32)	(1.82)*	(2.48)**
If participating in a production association	0.076	0.074	-0.116	-0.291	0.278	1.052	0.162	-0.433
	(-0.55)	(-0.57)	(-0.95)	(1.72)*	(1.96)*	(5.17)***	(-1.22)	(-1.12)
Share of labors without receiving education	0.0005	0.0016	0.001	0.0037	0.0022	0.0026	0.0034	-0.0033
	(-0.38)	(-1.28)	(-0.94)	(2.60)**	(1.80)*	(-1.13)	(2.79)**	(-0.85)
Cultivated land area per household	0.232	-0.164	-0.0967	0.009	0.06	0.422	0.305	0.26
	(7.22)***	(3.84)***	(3.53)***	(-0.31)	(1.98)*	(5.37)***	(10.05)***	(4.17)***
Constant	11.64	-4.21	0.92	-19.87	-1.68	27.2	2.74	-6.7
	(7.91)***	(1.93)*	-0.74	(9.67)***	(-1.29)	(2.88)**	(1.92)*	(-1.17)

Note: Absolute value of z statistics in parentheses. Maize is the omitted choice. There are 8405 observations. The LR chi2 of the regression is13347 and the Pseudo R squared is 0.1034.

Table 4 Marginal effect of climate change on crop choice

	Change of probability of choosing crops								
	Wheat	Rice	Vegetable	Soybean	Potato	Cotton	Oil Crops	Sugar	Maize
Temperature (°C)									
Spring	-0.0073	0.0417	0.0067	-0.0161	-0.0116	-0.0113	-0.0299	0.0002	0.0276
Summer	0.0172	-0.0527	-0.0339	0.0127	-0.0134	0.0860	0.0225	0.0009	0.0009
Fall	-0.0293	0.0657	0.0040	-0.0254	0.0005	-0.0063	-0.0338	-0.0066	-0.0066
Winter	0.0157	-0.0453	-0.0143	0.0177	0.0073	-0.0056	0.0445	0.0091	0.0091
Annual	0.0090	-0.0092	-0.0054	-0.0113	-0.0052	0.0168	0.0048	-0.0014	0.0019
Precipitation (cm/mo)									
Spring	0.0274	0.0057	-0.0170	0.0003	0.0083	0.0075	-0.0167	0.0000	-0.0155
Summer	0.5562	-0.0665	-0.1269	-0.0500	-0.1160	-0.0190	-0.0639	-0.0053	-0.0053
Fall	-0.0176	0.0160	0.0064	-0.0081	0.0055	-0.0068	0.0042	-0.0053	-0.0053
Winter	-0.0378	0.0012	0.0238	0.0156	-0.0260	0.0382	0.0361	0.0141	0.0141
Annual	-0.0327	0.0326	0.0237	0.0100	-0.0128	0.0266	0.0110	0.0021	-0.0602

Note: Marginal effects calculated using coefficients from Table 3, evaluated at each climate point in sample.

Table 5 Simulation results on the annual effect of climate change on crop and irrigation choice

		2040-2050			2090-2100		
		PCM	HADCM3	CCM2	PCM	HADCM3	CCM2
Change of temp.	(◦C)	0.74	1.08	1.5	2.45	4.01	4.1
Change of Prec.	(%)	3.44	-1.31	0.18	8.23	7.69	-1.71
Change of probability of choosing crops							
	Wheat	0.0062	0.0100	0.0131	0.0202	0.0283	0.0273
	Rice	-0.0010	-0.0123	-0.0143	-0.0139	-0.0372	-0.0508
	Vegetable	-0.0024	-0.0065	-0.0092	-0.0141	-0.0349	-0.0437
	Soybean	-0.0077	-0.0125	-0.0170	-0.0269	-0.0429	-0.0439
	Potato	-0.0039	-0.0056	-0.0079	-0.0136	-0.0236	-0.0253
	Cotton	0.0092	0.0196	0.0280	0.0466	0.1042	0.1215
	Oil Crops	0.0004	0.0063	0.0073	0.0057	0.0176	0.0265
	Sugar	-0.0019	-0.0011	-0.0018	-0.0041	-0.0042	-0.0019
	Maize	0.0012	0.0021	0.0019	0.0002	-0.0074	-0.0096
Change of probability of choosing irrigation							
	Without household variables	-0.2299	-0.1766	-0.1649	-0.1665	-0.0763	-0.0231
	With household variables	-0.1951	-0.1443	-0.1310	-0.1263	-0.0370	0.0096

Note: 1) The base year is 1990-2000;

2) Climate scenario for A2 Emissions Scenario. Data for each model is available at http://cera-www.dkrz.de/CERA/index.html

Table 6 Irrigation and crop choice of farmers under current climate conditions

	Five regions				
	Northeast	Southeast	Middle	Northwest	Southwest
Share of irrigated areas (%)	25	68	53	60	30
Share of crop sown areas (%)					
Wheat	7	11	9	28	10
Rice	8	24	15	1	17
Maize	28	9	17	17	21
Soybean	14	6	9	3	6
Patato	10	7	9	12	17
Cotton	2	3	2	7	0
Oil crops	4	12	14	14	8
Sugar	0	1	1	1	1
Vegetables	26	27	25	17	22
Total	100	100	100	100	100

Note: 1) The Northeast region includes Liaoning, Jilin, Heilongjiang, Tianjin and Hebei provinces;
2) The Southeast region includes Shanghai, Jiangsu, Zhejiang, Fujian, Shandong and Guangdong provinces;
3) The Middle region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Inner Mongolia and Guangxi provinces;
4) The Northwest region includes Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang provinces;
5) The Southwest region includes Chongqing, Sichuan, Guizhou and Yunnan provinces.

Table 7 Current climate condition by region

		Five regions				
		Northeast	Southeast	Middle	Northwest	Southwest
Temp. (^oC)						
	Spring	7.6	15.5	15.1	10.2	16.4
	Summer	22.0	26.4	25.9	21.2	24.2
	Fall	7.5	17.6	15.9	8.3	16.6
	Winter	-11.0	5.0	3.2	-5.8	7.1
	Annual	6.5	16.1	15.0	8.5	16.0
Prec. (cm/mo)						
	Spring	2.6	10.2	11.7	1.6	8.6
	Summer	12.6	18.1	15.3	4.8	18.0
	Fall	3.4	7.4	5.9	2.0	9.0
	Winter	0.5	3.9	3.8	0.2	1.8
	Annual	4.8	9.9	9.2	2.2	9.3

Note: 1) The Northeast region includes Liaoning, Jilin, Heilongjiang, Tianjin and Hebei provinces;
2) The Southeast region includes Shanghai, Jiangsu, Zhejiang, Fujian, Shandong and Guangdong provinces;
3) The Middle region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Inner Mongolia and Guangxi provinces;
4) The Northwest region includes Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang provinces;
5) The Southwest region includes Chongqing, Sichuan, Guizhou and Yunnan provinces.

Table 8 Simulation results on predicting changes in crop and irrigation choice by region for different climate scenarios in 2090-2100

Model	Change of temp. (°C)	Change of Prec. (%)	Change of probability of choosing crops									Change of probability of choosing irrigation	
			Wheat	Rice	Vegetable	Soybean	Potato	Cotton	Oil Crops	Sugar	Maize	Without hh. variables	With hh variables
Northeast													
PCM	2.45	8.23	0.0778	0.0244	-0.0656	-0.0414	0.0076	-0.0056	-0.0026	-0.0320	0.0375	-0.0749	-0.0993
HADCM3	4.01	7.69	0.1314	0.0114	-0.1124	-0.0628	0.1221	-0.0125	-0.0030	-0.0784	0.0042	-0.0484	-0.0845
CCM2	4.1	-1.71	0.1270	-0.0025	-0.1217	-0.0665	0.1844	-0.0127	-0.0030	-0.0892	-0.0159	0.0534	0.0246
Southeast													
PCM	2.45	8.23	0.0859	0.0366	-0.0342	-0.0154	0.0019	0.0042	-0.0007	-0.0541	-0.0242	-0.0690	-0.0864
HADCM3	4.01	7.69	0.1196	-0.0137	-0.0524	-0.0174	0.0016	0.0431	-0.0013	-0.0649	-0.0144	0.0113	-0.0029
CCM2	4.1	-1.71	0.1454	-0.0494	-0.0559	-0.0179	0.0022	0.0596	-0.0011	-0.0751	-0.0079	0.0181	0.0060
Middle													
PCM	2.45	8.23	0.0681	0.0528	-0.0441	-0.0651	0.1393	-0.0297	-0.0010	-0.0826	-0.0378	-0.0791	-0.0942
HADCM3	4.01	7.69	0.0928	0.0193	-0.0673	-0.0731	0.1676	-0.0097	-0.0030	-0.0950	-0.0315	-0.0197	-0.0336
CCM2	4.1	-1.71	0.1434	-0.0192	-0.0751	-0.0804	0.1949	-0.0121	-0.0027	-0.1182	-0.0307	-0.0016	-0.0111
Northwest													
PCM	2.45	8.23	0.0352	0.0026	0.0032	-0.0302	0.0614	-0.0308	-0.0042	-0.0303	-0.0068	0.0363	0.0313
HADCM3	4.01	7.69	0.0539	0.0002	-0.0101	-0.0551	0.1888	-0.0557	-0.0056	-0.0702	-0.0463	0.0729	0.0663
CCM2	4.1	-1.71	0.0549	-0.0013	-0.0137	-0.0589	0.2154	-0.0573	-0.0056	-0.0767	-0.0569	0.0937	0.0882
Southwest													
PCM	2.45	8.23	-0.0120	0.0028	0.0155	-0.0084	-0.0000003	0.0022	-0.00005	-0.0126	0.0126	0.0862	0.0822
HADCM3	4.01	7.69	-0.0113	-0.0232	0.0139	-0.0147	-0.0000003	0.0164	0.00004	-0.0150	0.0339	0.2050	0.2029
CCM2	4.1	-1.71	-0.0106	-0.0447	0.0223	-0.0111	-0.0000003	0.0225	0.00057	-0.0171	0.0381	0.1967	0.1951

Note: 1) The base year is 1990-2000; 2) Climate scenario for A2 Emissions Scenario. Data for each model is available at http://cera-www.dkrz.de/CERA/index.html

3) The Northeast region includes Liaoning, Jilin, Heilongjiang, Tianjin and Hebei provinces; the Southeast region includes Shanghai, Jiangsu, Zhejiang, Fujian, Shandong and Guangdong provinces; the Middle region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Inner Mongolia and Guangxi provinces; the Northwest region includes Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang provinces; and the Southwest region includes Chongqing, Sichuan, Guizhou and Yunnan provinces.