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HOW CHINESE FARMERS CHANGE CROP CHOICE TO ADAPT TO CLIMATE CHANGE

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A multinomial logit model is estimated across the crop choices of a sample of thousands of Chinese farmers. As temperatures warm, farmers are more likely to choose cotton and maize, but less likely to choose soybeans, and vegetables. As precipitation increases, farmers are more likely to choose wheat and less likely to choose vegetables and potatoes. We simulate how crop choice outcomes might change using the empirical results and a set of climate change predictions for 2100. The magnitude of the change is sensitive to the climate scenario and to the seasonal and regional variation of climate change predictions within China.

Keywords: Climate change; crop choice; adaptation; China.

1. Introduction

Although there is an extensive literature on the effects of climate on agriculture, there are very few agricultural studies that have measured climate adaptation (Mendelsohn and Dinar, 2009). Studies that compare the impacts of climate change that include adaptation, such as Ricardian studies (Mendelsohn *et al.*, 1994; Mendelsohn and Dinar, 1999; Mendelsohn *et al.*, 2001; Kurukulasuriya *et al.*, 2006; Seo and Mendelsohn, 2008a; Wang *et al.*, 2009), tend to find lower damages than studies that do not include adaptation, such as agronomic analyses (Rosenzweig and Parry, 1994;

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Parry *et al.*, 2004). However, the Ricardian studies do not explicitly model adaptation so that it is not possible to see how farmers adapt to climate.

Adaptations are actions that people and firms take in response to climate change in order 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 these questions. By comparing what farmers do in one climate zone versus another, the studies quantify how farmers have made long term adjustments to their current climate. For example, studies have examined how climate affects the choice of irrigation in Africa (Kurukulasuriya and Mendelsohn, 2007), the choice of livestock in Africa (Seo and Mendelsohn, 2008b), and the choice of crops in Africa (Kurukulasuriya and Mendelsohn, 2008) and South America (Seo and Mendelsohn, 2008c). All of the above mentioned adaptation studies find that farmers adjust irrigation practices, crop varieties, and livestock species to both temperature and precipitation levels. For example, the studies find that farmers are less likely to choose wheat and potatoes and more likely to choose fruit and vegetables in warmer temperatures.

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 test whether farmers in China have adapted to the range of climates across China by changing crops. Analyzing 8,405 farms sampled across 28 provinces in one year, we match the location of each farm to climate data and soils. We then estimate multinomial logit regressions of crop choice to examine the effect of climate on these endogenous choices by farmers while controlling for several other factors. We specifically examine the choice of nine major crops in China: wheat, rice, maize, soybean, potato, cotton, oil crops, sugar, and vegetables.

The paper is organized as follows. In the next section, we discuss the methodology. Section three presents 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 crop choice for three different climate scenarios in 2100. Assuming that the cross sectional results would apply to future climates as well, we forecast how crop choice would change in the future. We also explore the importance of information about climate change. We contrast what would happen using just the national average annual change in temperature and precipitation versus the change in each season and region of China. The results reveal that having more information about the seasonal and spatial detail of the climate change matters. The paper concludes with a summary of the key results and a discussion of policy implications.

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[1] Adapting to climate, which spans over a long period, is different from adapting to climate variance, the changes in weather from year to year (Leary *et al.*, 2006). Although an important topic as well, this study does not address adaptation to short term weather.

2. Methodology

We assume that farmers make choices that maximize their net revenue. We define net revenue broadly to include both products that are sold and also products consumed by the farmer. In this analysis, we are interested in modeling what affects this choice and specifically what role does climate play. A multinomial logit regression is used to study crop choice among 9 major crops, which account for 86.4% of the total crop area in China in 2008 (NSBC, 2009). The multinomial logit regression 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.

The probability that a crop is chosen depends on the net revenue of that crop. We assume that farmer i's net revenue, π, in choosing crop $j(j = 1, 2, \ldots, J)$ 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 net revenue function is composed of two components: the observable component V and an unobservable component that is in the error term ε. We assume that the farmer will choose the crop that yields the highest net revenue.

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

$$\begin{aligned} &P_{ij} = \Pr[\varepsilon_k(C,K,S) - \varepsilon_j(C,K,S) < V_j - V_k] \quad \forall k \neq j \\ &\quad \text{where } V_j = V_j(C,K,S) \end{aligned} \tag{2}$$

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

$$V_j(C_i, K_i, S_i) = C_i\alpha + C_i^2\beta + K_i\phi + S_i\omega \tag{3}$$

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

$$P_{ij} = \frac{e^{C_i\alpha + C_i^2\beta + K_i\phi + S_i\omega}}{\sum_{k=1}^{J} e^{C_k\alpha + C_k^2\beta + K_k\phi + S_k\omega}} \tag{4}$$

which is 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 a climate variable, c_l, is therefore:

$$\frac{\partial P_j}{\partial c_l} = P_j[\alpha_{jl} + 2c_l\beta_{jl}] - \sum_{k=1}^{J} P_k[\alpha_{kl} + 2c_l\beta_{kl}]. \tag{5}$$

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

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

3. 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. The monthly climate data is combined into four seasons: winter is the average of December, January, and February, spring is the average of March, April, and May, summer is the average of June, July, and August, and fall is the average of September, October, and November.

Socio-economic data is obtained from the Household Income and Expenditure Survey (HIES) administered by the National Bureau of Statistics of China 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 the national meteorological stations located in these counties). Our final sample has 8405 households in 915 villages in 124 counties from 28 provinces.

The HIES includes a number of household and village characteristics. Irrigation data was collected at the village level. Information about crop choice was collected at the farm level. The nine major crops studied are: cotton, maize, oil crops, potato, rice, soybean, sugar, wheat and vegetables. Household variables also 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. Education is included to see if knowledge alters the choice. Land area is included in case there are economies to scale for some crops. The number of family members is an indirect measure of the household labor supply. This may affect crop choice as some crops are more labor intensive. 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, the presence of paved roads and the distance to each township's government. Each of these variables can affect the productivity of certain crops and therefore choice.

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 soil variables measure the share of cultivated area with each type of soil. Again soils are likely to affect the productivity of crops differently and therefore affect choice.

4. Results

In this section, we report the empirical results of the cross sectional analysis. The analysis of crop choice indicates that farmers plant different crops depending on the climate they face, holding other variables constant (Table 1). 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 also important.

Many of the control variables are also significant in Table 1. 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 of selecting cotton. This may reflect the relative cost of transporting each of these products. The more distant the farmer is from a 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. We assume the above proximity variables capture all of the variation in prices. 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 the additional ginning and marketing (an association activity) is needed to make the final product. 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 are land intensive — but the less likely they will grow rice and vegetables — crops that are labor intensive.

Table 2 presents the marginal effects of temperature and precipitation on crop choice evaluated at the mean climate for the sample. Warmer temperatures increase the chance that farmers select cotton, rice, and maize but decrease the chance they select vegetables, soybeans, and potatoes. On the margin, wheat, oil crops, and sugar are not sensitive to warming. These annual effects can be dominated by the outcomes in one season. For example, the positive annual temperature effect for cotton and the negative annual temperature effect for vegetables are dominated by the summer temperature effect and the positive annual temperature effect for maize is dominated by a spring temperature effect. However, sometimes seasonal effects are offsetting. For example, wheat, soybeans, and oil crops have strong positive temperature effects in spring and fall seasons, but have negative in summer. These crops appear to benefit from warmth

Table 1. 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)

Table 1. (*Continued*)

	Wheat	Rice	Vegetable	Soybean	Potato	Cotton	Oil Crops	Sugar
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 is 13347 and the Pseudo R squared is 0.1034.

Table 2. 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	−0.73	4.17	0.67	−1.61	−1.16	−1.13	−2.99	0.02	2.76
Summer	1.72	−5.27	−3.39	1.27	−1.34	8.60	2.25	0.09	0.09
Fall	−2.93	6.57	0.40	−2.54	0.05	−0.63	−3.38	−0.66	−0.66
Winter	1.57	−4.53	−1.43	1.77	0.73	−0.56	4.45	0.91	0.91
Annual	−0.37	0.94	−3.75	−1.11	−1.72	6.28	0.33	0.36	3.10
Precipitation (mm/mo)									
Spring	0.27	0.06	−0.17	0.00	0.08	0.08	−0.17	0.00	−0.16
Summer	5.56	−0.67	−1.27	−0.50	−1.16	−0.19	−0.64	−0.05	−0.05
Fall	−0.18	0.16	0.06	−0.08	0.06	−0.07	0.04	−0.05	−0.05
Winter	−0.38	0.01	0.24	0.16	−0.26	0.38	0.36	0.14	0.14
Annual	5.27	−0.44	−1.14	−0.42	−1.36	0.20	−0.41	0.04	−0.12

Note: The marginal effects reported are the mean marginal effects across the sample calculated using the coefficients from Table 1 and the climate at each observation.

that extends their growing season but are hurt by extreme summer temperatures. Rice has negative spring and fall temperature effects, but positive summer effects. Because it is often irrigated, rice can survive and even prosper in extreme summer temperatures but it does not gain as much from an extended growing season.

Results also show that each crop has a different response to precipitation and so precipitation alters crop choice. More precipitation increases the chance that farmers pick wheat and decrease the chance they pick vegetables, potatoes, rice, soybeans, and oil crops (Table 2). Cotton, sugar, and maize do not appear to be sensitive to marginal changes in precipitation. Similar to temperature, the annual effects of precipitation can be dominated by the outcomes in one season. For example, the positive annual precipitation effect for wheat and the negative annual precipitation effect for vegetables and potatoes are dominated by the effect in summer. Sometimes, seasonal effects are offsetting. For example, rice is more likely with more precipitation in spring, fall and winter seasons, but is less likely if there is more summer precipitation. Cotton is more likely with more precipitation in both spring and winter, but is less likely if there is more precipitation in summer and fall.

5. Climate Impact

The empirical results in the previous section describe how farmers in China have adapted to the climate that they currently face. In this section, we project how these decisions would change if climate changes. The analysis takes into account changes in temperature and precipitation. However, the analysis does not explicitly model changes in water flows for irrigation. Temperature and precipitation will not reflect changes in flows without a proper hydrological model. We assume that all other features of each farm remain the same and that only climate will change. The analysis is not a forecast of what crops will be grown in China in 2100. The analysis is simply trying to quantify what role climate change might play in future crop decisions. In order to forecast future crop decisions, one would have to consider future changes in technology, prices, capital intensity, and other features of the farm that are likely to change over the next century. Very importantly, the availability of water for irrigation might change over time in China even without climate change and this would have a very important effect on crop choice in the future. Note that the analysis is not measuring the impact of climate change on crops but simply how farmers might adapt by switching crops.

We examine a set of climate scenarios from three climate models that reflect the range of climate outcomes considered likely by the Intergovernmental Panel on Climate Change (IPCC, 2007). We use the difference between the 1970–2000 climate prediction and the 2070–2100 climate prediction to calculate climate change in 2100. The climate scenarios come from the Parallel Climate Model (PCM) (Washington *et al.*, 2000), Hadley Center Model (HADCM3) (Murphy *et al.*, 2009), and Canadian Centre Model (CCM2) (Boer *et al.*, 2000) climate models using the A2 SRES emission scenario (IPCC, 2000). For China as a whole, the PCM model predicts a 3°C warming with a modest 10% increase in precipitation, the HADCM3 model predicts a 4.9°C warming with a 23% increase in precipitation, and the CCM2 model predicts a 5.2°C warming with a 7% increase in precipitation. HADCM3 predicts a large increase in rainfall (+23%) across China, PCM predicts a moderate increase (+10%) and CCM2 predicts a small increase (+5%). The future climate scenarios, however, are more complicated than these average annual national changes imply because the climate scenarios also vary by season and region within China (see Table A-1).

The marginal results suggest that the actual impact in each location depends on the seasonal distribution of temperature and precipitation as well as the average level. In general, it is best to include all the reliable detail that is in a climate projection. The paper compares the results of using just the national average annual changes, seasonal changes, and seasonal and regional changes. The variation across seasons and regions matters.

Table 3 presents the national results assuming uniform national changes in temperature and precipitation by 2100 for each climate model. It relies on a single prediction for all of China. The first three columns assume that the climate change is the same in every season and the second three columns allow the climate change to vary by season. The most prominent crops today are rice (26%), maize (21%), wheat (16%), and vegetables (13%). With uniform warming over all seasons, wheat and especially potatoes become more prevalent while soybeans, vegetables, and sugar become rarer. The remaining crops remain the same though rice also falls in the CCM2 scenario.

Table 3. Change in crop choice for China assuming uniform national climate change but alternative seasonal changes.

	Uniform climate change every season			Seasonal climate change		
	PCM	HADCM3	CCM2	PCM	HADCM3	CCM2
Wheat	3.35	4.81	8.38	11.85	−4.09	26.88
Rice	0.24	−0.34	−5.05	−6.26	−9.80	−9.43
Vegetable	−3.80	−6.22	−7.04	−1.37	−8.90	−3.26
Soybean	−2.09	−3.33	−3.84	−0.82	−5.69	−2.80
Potato	6.02	12.45	16.73	−3.14	58.03	−6.91
Cotton	−0.60	−1.10	−0.98	6.79	−5.60	5.47
Oil Crops	−0.18	−0.26	−0.26	0.06	−0.33	0.33
Sugar	−2.63	−4.89	−7.00	−3.55	−15.01	−6.87
Maize	−0.31	−1.12	−0.95	−3.56	−8.61	−3.41

Note: Analysis compares climate change between 1990–2000 and 2090–2100, using SRES A2 emission scenario. Data for each climate model is available at http://cera-www.dkrz.de/CERA/index.html.

With the seasonal climate changes, wheat and cotton increase more in the PCM and CCM2 scenario but actually fall in the HADCM3 scenario. Potatoes increase more in the HADCM3 but fall in the PCM and CCM2 scenario. Rice and maize fall in every scenario. Sugar falls sharply in the HADCM3 scenario. So the crop predictions using the seasonal climate changes are quite different from the crop predictions using the uniform warming changes every season.

But looking at national averages does not tell the entire story. In Tables 4 and 5, China is divided into five major climatic regions: Northeast, Southeast, Middle, Northwest and Southwest.[2] The Northeast and Northwest are cooler while the rest of the country is relatively hot. The Northeast and Northwest are also dry while the Southeast is quite wet and the Middle region is the wettest. The current distribution of crops is quite different in each region as well. The Southwest is split between rice, maize, and vegetables. The Southeast is dominated by rice but also has vegetables, the Middle region is dominated by rice but also has maize, the Northeast is dominated by maize but also has soybeans, and the Northwest is dominated by wheat but also has maize.

Table 4 explores a uniform annual climate change scenario across every region and season in China. Even if the predicted changes in each region are the same, each region responds in a different way to the climate scenarios. Across the climate models, farmers in the Northeast, Southeast, and Northwest region increase wheat, farmers

[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.

Table 4. Regional change in crop choice based on uniform annual national forecast.

Model	Temp Δ (°C)	Precip Δ (%)	Percentage change of probability of crop								
			Wheat	Rice	Vegetable	Soybean	Potato	Cotton	Oil crops	Sugar	Maize
Northeast											
PCM	2.95	10.42	8.61	2.21	−8.00	−3.34	1.75	−0.62	−0.16	−2.99	2.55
HADCM3	4.92	23.43	12.46	−0.27	−13.34	−6.36	30.08	−2.49	−0.20	−12.25	−7.63
CCM2	5.19	6.84	6.72	−3.73	−14.99	−7.39	55.64	−3.25	−0.20	−16.93	−15.88
Southeast											
PCM	2.95	10.42	2.59	−2.98	−3.52	−0.22	−0.23	4.08	−0.16	−0.48	0.91
HADCM3	4.92	23.43	4.08	−5.44	−5.50	−0.65	−0.32	7.20	−0.26	−0.56	1.45
CCM2	5.19	6.84	8.59	−11.44	−5.95	−0.68	−0.24	10.50	−0.23	−2.95	2.40
Middle											
PCM	2.95	10.42	−0.38	0.74	−3.57	−0.57	0.06	2.81	−0.64	0.74	0.81
HADCM3	4.92	23.43	−2.61	1.76	−5.71	−0.80	−1.27	5.68	−0.97	2.43	1.50
CCM2	5.19	6.84	4.75	−5.72	−6.81	−2.06	5.82	5.60	−0.88	−2.31	1.61
Northwest											
PCM	2.95	10.42	7.49	0.15	−1.07	−4.61	8.41	−3.96	−0.46	−3.81	−2.15
HADCM3	4.92	23.43	6.65	−0.11	−2.56	−7.29	28.50	−7.40	−0.59	−9.37	−7.83
CCM2	5.19	6.84	5.18	−0.43	−3.21	−8.00	36.64	−8.04	−0.60	−11.05	−10.49
Southwest											
PCM	2.95	10.42	−0.58	−0.96	−0.56	−1.73	0.00	1.29	−0.04	−0.15	2.72
HADCM3	4.92	23.43	−0.02	−2.08	−2.51	−3.67	0.00	2.92	−0.08	−0.02	5.45
CCM2	5.19	6.84	−0.31	−5.47	−0.82	−2.59	0.00	3.78	−0.01	−0.72	6.15

Note: A2 emission scenario for 2100. Assumes same climate change in each season and each region.

Table 5. Regional change in crop choice based on regional and seasonal variation in climate forecast.

Model	Temp Δ (°C)	Precip Δ (%)	Percentage change of probability of crop								
			Wheat	Rice	Vegetable	Soybean	Potato	Cotton	Oil crops	Sugar	Maize
Northeast											
PCM	2.92	15.64	10.03	−0.43	−4.82	−3.38	1.92	0.87	−0.13	−4.66	0.59
HADCM3	5.07	34.68	0.94	−5.89	−16.13	−8.52	82.75	−4.55	−0.21	−22.17	−26.24
CCM2	5.05	6.68	18.95	−6.98	−11.96	−7.33	48.91	0.65	−0.13	−20.24	−21.88
Southeast											
PCM	2.09	11.45	−0.49	3.97	−2.10	−0.98	−0.39	−0.37	−0.13	0.01	0.47
HADCM3	4.09	24.6	1.04	−2.44	−3.80	−0.03	−0.37	6.64	−0.09	−0.20	−0.76
CCM2	4.67	8.24	−0.39	−6.30	2.19	−1.58	−0.41	−1.33	1.09	2.65	4.08
Middle											
PCM	2.59	13.87	−1.15	2.21	0.71	0.27	−12.29	5.77	0.71	3.92	−0.16
HADCM3	4.8	26.03	−6.94	−13.24	−9.49	−6.23	68.24	−9.66	−1.34	−16.05	−5.29
CCM2	5.54	8.13	3.02	−9.14	−1.56	−0.81	−13.62	12.16	4.36	3.47	2.12
Northwest											
PCM	3.36	10.77	10.34	−1.02	−0.99	−6.70	27.10	0.82	−0.21	−12.26	−17.08
HADCM3	5.37	14.55	−11.15	−1.14	−4.41	−9.71	79.29	−11.27	−0.64	−18.46	−22.50
CCM2	5.8	9.91	21.84	−0.85	−2.94	−8.31	24.91	−6.64	−0.45	−13.09	−14.46
Southwest											
PCM	2.51	6.36	−0.57	−3.31	1.84	0.62	0.00	−0.65	0.19	−0.93	2.82
HADCM3	4.57	26.69	−4.09	4.16	−4.28	−3.07	0.00	−0.67	−0.15	−1.62	9.73
CCM2	4.32	−4.46	−2.24	−8.07	5.70	−4.24	0.00	6.49	2.44	4.72	−4.81

Note: A2 scenario for 2100. Assumes different changes in each region and each season.

in the Northeast and Northwest increase potatoes, and farmers in the Southeast, Southwest, and Middle increase cotton and maize. Farmers in the Southeast and Southwest decrease rice, farmers in every region decrease vegetables, farmers in the Northeast, Northwest, and Middle decrease soybeans, and farmers in the Northeast and Northwest decrease cotton, sugar, and maize. In general, the magnitude of the change in crop mix increases from the PCM to HADCM3 to CCM2 climate scenarios. Since this is also how the models are ranked by temperature change, it is likely that temperature dominates the outcome in Table 4. However, there are some exceptions where precipitation may be playing an important role. For example, in the Middle region, wheat, rice, potatoes, and sugar have different effects depending on precipitation.

Table 5 incorporates all the regional and seasonal detail from the climate model, not just the national annual scenario. Table 5 takes full advantage of the information available from the climate models. There are large regional differences comparing Table 4 and Table 5. For example, in Table 5 with the PCM and CCM2 climate scenarios, wheat increases more in the Northeast and Northwest but falls in the Southeast and Southwest. With the HADCM3 climate scenario, wheat decreases across the board. With the PCM scenario, rice increases in the Southeast and Middle but falls in the Southwest. With HADCM3, rice increases in the Southwest, falls less in the Southeast but falls precipitously in the Middle region. With CCM2, rice falls in the Northeast, Middle and Southwest regions, but falls less in the Southeast. With HADCM3, potatoes increase dramatically and cotton, maize, and sugar decrease in the Northeast, Northwest, and Middle. With CCM2, there are also large decreases in maize in the Northeast, Northwest, and Southwest. There are consequently many regional changes in crops if both regional and seasonal variations in climate are included.

6. Conclusion and Policy Implications

The empirical analysis reveals that climate influences the choice of crops that Chinese farmers make today. The empirical evidence explains how current crop choice has adapted to the range of climates across China today. A marginal increase in temperature increases the chance that farmers choose maize and especially cotton and decreases the chance they will choose vegetables and potatoes. A marginal increase in precipitation increases the chance that farmers choose wheat and decreases the chance they choose rice, soybeans, oil crops, and especially vegetables.

It is interesting to note that although the results from China are consistent with the results from Africa (Kurukulasuriya and Mendelsohn, 2008) and South America (Seo and Mendelsohn, 2008c), they are not identical. This is partly because there are some crops that are common in one continent but rare in the others such as cowpea, groundnut and millet in Africa, potatoes and squash in South America, and oil crops in China. Partly, there may be some combinations of climate, water, and soils that are only present in one continent. Finally, there may be missing variables in the analysis that explain why the quantitative results are not identical across continents. The disparity of the results suggests that it is advisable to have different crop choice models in each continent.

The analysis suggests that the climate scenarios for 2100 will encourage China's farmers to change their mix of crops. The changes, however, will vary by region and climate scenario. With PCM, the Northeast will move towards wheat and away from vegetables, soybeans, and sugar. The Northwest will move towards wheat and potatoes, and away from soybeans, sugar and maize. The Middle will move away from potato and towards cotton, sugar, and maize. With CCM2, the Northeast will move towards wheat and potato and away from rice, vegetables, soybeans, sugar, and maize. The Northwest will move towards wheat and potatoes, and away from soybeans, cotton, sugar, and maize. The Middle will move away from rice and potato and towards cotton, oil crops, wheat, sugar, and maize. The Southeast will move away from rice and towards vegetables, sugar, and maize. The Southwest will move away from rice, soybeans, maize, and wheat and towards vegetables, cotton, oil crops, and sugar. The HADCM3 results are quite different. Northeast, Northwest, and Middle farmers move away from the myriad of crops they grow now and instead plant mostly potatoes. In the Southwest, farmers move away from wheat, soybeans and vegetables and towards rice and maize. The results vary by region but also depend greatly on the climate scenario.

We also test the importance of seasonal and regional variation in climate change. The results indicate that they are both important, especially in combination. It is critical that impact studies take into account the available regional and seasonal details of climate model predictions. These variations have large impacts. Since these variations are not consistent across models, the analysis also suggests that it is critical to include more than one climate model in impact analysis in order to comprehend the range of possible climate effects.

The analysis suggests that crop choice is very likely to change in China because of climate change. These predictions are illuminating, but one must view these projections cautiously. First, the climate projections 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. Third, water availability is likely to change with and without climate change. The analysis does not take into account water availability or future changes in water availability. Given that half of China's farms are irrigated, water availability is likely to be a very important issue. This is an important subject of future research.[3] All of these changes must be taken into account to obtain an accurate forecast of future conditions.

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

The analysis reveals that adaptations will vary significantly across regions within China. Climate change will cause some crops to increase in one region and fall in 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 also suggests that crop choice will depend upon the actual climate change scenario. It is prudent for policy makers and farmers to make contingent plans but they should actually wait and see how climate unfolds before making changes.

The analysis in this paper examines 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 adoption alternatives. This implies that adoption options have to be available. This is a policy matter. The government and private sector could help develop new crop varieties. New crops suited for a warmer world would provide farmers with new opportunities to adapt. The government could provide needed information via efficient public extension services or private agents. The government could help establish favorable conditions for private adaptation including establishing accessible credit lines and enforcing private property ownership.

Additional public adaptations are also needed at the government level. It is likely that climate change will make water scarce. One of the most important adaptations that China can make concerns increasing the efficiency of water management. By reallocating water to its best use, the government can make the best use of available water. 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 short regions.

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Appendix

Table A-1. Actual and forecasted temperature and precipitation change by 2100 in each region in China (A2 scenario).

		China	Northeast	Southeast	Middle	Northwest	Southwest
Actual							
Temp (°C)	Annual	12.4	6.5	16.1	15.0	8.5	16.0
	Spring	13.0	7.6	15.5	15.1	10.2	16.4
	Summer	23.9	22.0	26.4	25.9	21.2	24.2
	Autumn	13.2	7.5	17.6	15.9	8.3	16.6
	Winter	−0.3	−11	5.0	3.2	−5.8	7.1
Prec (mm/mo)	Annual	71.5	26	102	117	16	86
	Spring	137.6	126	181	153	48	180
	Summer	55.4	34	74	59	20	90
	Autumn	20.4	5	39	38	2	18
	Winter	70.8	48	99	92	22	93
PCM							
Temp (°C)	Annual	2.95	2.92	2.09	2.59	3.36	2.51
	Spring	2.77	2.63	2.30	2.62	2.80	2.66
	Summer	2.71	2.54	1.60	2.20	3.66	1.83
	Autumn	2.55	2.91	2.12	2.43	2.57	2.30
	Winter	3.76	3.61	2.33	3.09	4.43	3.26
Prec (%)	Annual	10.42	15.64	11.45	13.87	10.77	6.36
	Spring	11.11	14.77	5.20	12.13	15.95	6.27
	Summer	10.43	18.59	16.51	13.80	−4.00	12.4
	Autumn	8.43	7.03	18.27	12.74	19.50	2.35
	Winter	11.65	20.04	15.38	22.25	41.59	−10.85
HADCM3							
Temp (°C)	Annual	4.92	5.07	4.09	4.80	5.37	4.57
	Spring	4.72	4.55	3.89	4.52	4.94	4.72
	Summer	5.43	6.58	4.02	5.70	6.11	4.07
	Autumn	4.89	5.20	4.25	4.98	5.00	4.85
	Winter	4.66	3.94	4.21	4.00	5.45	4.66
Prec (%)	Annual	23.43	34.68	24.60	26.03	14.55	29.69
	Spring	24.62	22.02	25.77	30.57	18.29	33.41
	Summer	21.21	40.59	18.77	14.63	6.11	25.52
	Autumn	25.33	32.58	25.81	40.74	14.3	38.11
	Winter	26.73	47.09	41.16	55.67	35.91	23.13
CCM2							
Temp (°C)	Annual	5.19	5.05	4.67	5.54	5.80	4.32
	Spring	5.50	4.59	6.38	6.27	5.89	5.19
	Summer	4.63	4.60	3.27	4.85	5.44	3.13
	Autumn	4.21	3.90	2.99	4.13	5.21	2.88
	Winter	6.42	7.10	6.03	6.90	6.65	6.08

Table A-1. (*Continued*)

		China	Northeast	Southeast	Middle	Northwest	Southwest
Prec (%)	Annual	6.84	6.68	8.24	8.13	9.91	−4.46
	Spring	12.16	14.73	12.37	19.86	30.2	−6.57
	Summer	9.65	19.02	6.43	11.88	4.57	−10.68
	Autumn	0.04	−2.04	16.99	−3.22	−2.91	9.33
	Winter	−1.54	−20.81	−13.13	−8.96	15.48	11.75

Table A-2. Current cropping pattern in each region in China (%).

	China	North East	South East	Middle	North West	South West
Wheat	15.5	7.3	15.0	11.6	41.2	9.6
Rice	25.7	11.8	41.2	35.8	1.5	23.5
Vegetable	12.9	7.6	18.0	10.3	6.9	20.4
Soybean	6.0	20.6	1.5	3.9	3.2	1.8
Potato	6.4	5.4	3.3	4.3	7.1	14.8
Cotton	3.3	1.3	3.1	1.7	12.9	0.0
Oil Crops	8.6	3.7	9.5	11.7	10.4	6.6
Sugar	0.5	0.5	0.2	0.9	0.4	0.5
Maize	21.1	41.8	8.2	19.8	16.5	22.9
Total	100	100	100	100	100	100

Table A-3. Descriptive statistics for major variables used for analyzing the determinants of net crop revenue.

	All farm		Irrigated farm		Rainfed farm	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Net cropping revenue per ha (Yuan/yr)	10146	12280	12319	12846	7464	9736
Spring temp (°C)	13.2	4.7	13.8	3.5	11.05	4.7
Summer temp (^{o}C)	24.2	3.2	25.1	2. 6	22.6	3.4
Fall temp (°C)	13.7	5.6	14.4	4.9	11.1	5.6
Winter temp (°C)	0.3	8.5	0.9	6.7	-3.3	8.9
Spring prec (mm/month)	76.2	65.3	81.7	79.1	53.2	43.4
Summer prec (mm/month)	144.2	62.5	128.4	72.1	139.8	51.9
Fall prec (mm/month)	56.8	32.5	48.6	31.4	53.8	33.2
Winter prec (mm/month)	23.2	24.1	28.2	27.8	15.0	19.0
Share of land areas with clay soil (%)	30	38	31	40	17	31

Table A-3. (*Continued*)

	All farm		Irrigated farm		Rainfed farm	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Share of land areas with silt soil (%)	31	39	28	36	43	43
Plain (1 = Yes; 0 = No)	0.45	0.50	0.75	0.43	0.35	0.48
Road (1 = Yes; 0 = No)	0.97	0.18	0.97	0.18	0.95	0.22
Distance to township government (km)	6.1	4. 5	5.2	3.6	7.1	5.2
Share of irrigated areas in village (%)	48.9	39.9				
If participate production association (1 = Yes; 0 = No)	0.03	0.18	0.05	0.22	0.01	0.11
Share of labor without education (%)	7.5	18.5	6.1	16.1	9.6	21.6
Cultivated land area per household (ha)	0.72	1.00	0.57	0.72	0.99	1.29

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

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