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The impacts of climate change on the People's Republic of China's grain output

Regional and crop perspective

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Abstract

Purpose – This paper aims to investigate the impacts of climate change on the People's Republic of China's (PRC) grain output using rural household survey data. The paper highlights the regional differences of impacts by estimating output elasticities (with respect to climate change) for different grain crops and different regions.

Design/methodology/approach – The paper uses production function to investigate the responses of grain output to climate variables as well as other traditional input variables. The use of production function approach allows us to do away with the competitive land market assumption as required in the Ricardian approach. The paper will use interaction terms of climate variables and regional dummies to capture the regional differences of climate change impact on grain crops.

Findings – The results indicate that the overall negative climate impacts on the PRC's grain output range from −0.31 to −2.69 percent in 2030 and from −1.93 to −3.07 percent in 2050, under different emission scenarios. The impacts, however, differ substantially for different grain crops and different regions.

Originality/value – This paper addresses the limitations of existing literature by highlighting regional differences and crop varieties using the most recent nationwide rural household survey data. The results indicate pronounced regional differences and crop differences in the impacts of climate changes on PRC's grain output.

Keywords China, Resource economics and environment protection, Rural household behavior

Paper type Research paper

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I. Introduction

Due to the growing attention elicited by the impacts of climate change on agriculture, an increasing number of studies have attempted to investigate these impacts. A number of studies suggest that temperature will increase by 1.5°C-5.0°C within the twenty-one century (Darwin *et al.*, 1995). China National Climate Center (CNCC) (2009) projects that People's Republic of China's (PRC) temperature will rise by less than 2.5°C by the end of twenty-one century. Various studies generally concluded that global warming will alter the regional patterns of production and productivity (Darwin *et al.*, 1995; Rosenzweig and Parry, 1994). In the PRC, discussions focus on the impacts of climate change on agriculture, in general, and on the country's grain production, in particular. Despite the growing interests in the impacts of climate changes on PRC's grain production, different studies have produced different findings and conclusions, due to different models and data used. Some studies indicate that global warming will decrease the country's grain production, while others argue that the impacts are positive. For example, Wang *et al.* (2009) find that global warming is harmful to rainfed farms but beneficial to irrigated farms. The magnitudes of the impacts also differ across studies. As another example, Harasawa *et al.* (2003) report that climate change will decrease the PRC's rice production by 0.25 percent, wheat by 3.97 percent, and other grains by 1.39 percent. Tsigas *et al.* (1997) suggest that climate change will lead to a 3 percent increase in the country's crop production with CO_2 fertilization and a decrease by 17 percent if without CO_2 fertilization. Kane *et al.* (1992) report that climate changes will result in a reduction in the PRC's crop production by 10-20 percent. Zhai *et al.* (2009) find that China's rice output will fall by 0.5 percent, wheat will increase by 4.2 percent, and other grains will fall by 0.5 percent[1].

Previous studies are limited in terms of methodology or data, which may have contributed to the wide range of results:

- most of these studies do not disaggregate the PRC into regions and ignore the substantial regional differences;
- most of these studies do not disaggregate the PRC's crop sector into different crops and ignore the significant differences among crops;
- some studies such as Wang *et al.* (2009), while addressing the regional and crop differences, use the Ricardian model that involves restrictive assumptions such as perfectly competitive land market[2]; and
- the agricultural production and social-economic data required for impact studies are difficult to obtain – only a few studies (Liu *et al.*, 2004; Wang *et al.*, 2009) were able to obtain a large national dataset but dated about ten years back.

While ignoring regional and crop differences prevents us from understanding the real impacts of climate change on PRC's grain production, using models with unrealistic underlying assumptions and dated dataset would mislead us from translating research findings into effective policies.

In this paper, we aim to address the above limitations by highlighting regional differences and crop varieties using the most recent nationwide rural household survey data available for the years 2003, 2005, and 2008, which contains over 9,000 households information. We focus on four major grain crops – wheat, rice, corn, and soybean. They account for 93 percent of the PRC's grain output (National Bureau of Statistics

of China (NBSC), 2010). Regressions were conducted to yield marginal impacts of climate change on different grain crops in different regions. In contrast to the current literature using Ricardian approach that involves perfect competitive land market assumption (which is obviously not the case in rural PRC), we stick to the traditional production function approach in investigating the impacts of climate change. Such approach does not depend on the assumption of perfect competitive land market.

Our results indicate pronounced regional differences and crop differences in the estimated impacts of climate changes. The overall impact on PRC's grain output is negative ranging from −0.31 to −2.69 percent in 2030 and from −1.93 to −3.07 percent in 2050 under different emission scenarios. Rice output is predicted to decrease by 15.62-24.26 percent in 2030 and 25.95-45.09 percent in 2050, whereas corn output will increase by 18.59-24.27 percent in 2030 and 32.77-49.58 percent in 2050. Climate change will impact soybean output positively with increases ranging from 0.48 to 5.53 percent in 2030 and from 3.96 to 6.48 percent in 2050. The impacts on wheat output are relatively small.

With respect to regional impacts, climate change in North PRC is expected to increase the country's grain output by 2.85-4.80 percent in 2030 and 5.30-8.49 percent in 2050, while for Central PRC, the increase is estimated to be 3.53-4.97 percent in 2030 and 8.91-13.43 percent in 2050. The impacts for South and Northwest PRC are very small though positive. However, the PRC's grain output is predicted to decrease in 2030 by 4.10-8.58 percent resulting from climate change in East PRC, by 2.29-4.05 percent from Southwest PRC, and by 2.58-2.66 percent from Northeast PRC.

The rest of the paper is structured as follows. Section II reviews the literature and Section III describes the methodologies and variables used to capture the impacts of climate changes on PRC's grain output. In Section IV, we describe the data and in Section V we present the empirical results. Further discussions using results from the econometric regression are provided in Section VI. Section VII summarizes the conclusions and policy implications.

II. Literature review

There is a growing literature on the impacts of the climate change on the agriculture sector (Parry *et al.*, 2004; Cline, 2007). Since the end of the last century, the focus of the research has increasingly focused on the developing countries (Mendelsohn and Dinar, 1999). In recent years, studies focusing on the agricultural impacts of the climate change in the PRC are emerging (Fischer *et al.*, 2001, 2002; Fischer *et al.*, 2005; Parry *et al.*, 2004; Cline, 2007; Zhai *et al.*, 2009; Wang *et al.*, 2009). However, despite these efforts, uncertainties and even controversies remain regarding analytical approaches and results related to the impacts of climate changes on the PRC agriculture.

Broadly speaking, there are four basic approaches that are commonly used in assessing the agricultural impacts of climate change: crop simulation models, agroeconomic zone (AEZ) models, Ricardian models, and general equilibrium models. Zhai *et al.* (2009) and ADB (2010) provide a discussion on the advantages and disadvantages of these models. Crop simulation models draw on controlled experiments where crops are grown in field or laboratory settings that simulate different climates and levels of CO_2 in order to estimate yield responses of a specific crop variety to certain climates and other variables. The estimates of these models do not include the effects of farmer adaptation to changing climate conditions. Consequently, their results tend to

overstate the damages of climate change to agricultural production (Mendelsohn and Dinar, 1999). These studies typically focus on only a few types of grain crops such as rice, maize, and wheat. General findings of crop simulation models suggest that crop yields will decrease with the increases in temperature and declines in rainfall.

One recent example of crop simulation modeling studies for the PRC is Tao *et al.* (2008), who assessed how rice production and water use would change with increasing global mean temperature (GMT) under various emission scenarios and projected regional climate changes. Their results show that a change in GMT will result in a wide range of climate changes across regions. Another recent study to apply the crop simulation model is Wu *et al.* (2006), who attempted to quantify the production potential of winter wheat in the North China Plain by taking into account climate change. The study demonstrated that low rainfall is a constraint for winter wheat in the northern part of the plain, while low radiation and high temperature restrict the crop growth in southern part.

The second approach, AEZ analysis, assign particular crops to certain agroecological zones, and then estimate yields for the different zones. Unlike crop simulation models, AEZ analysis incorporates land management decisions and captures the changes in agroclimatic resources (Darwin *et al.*, 1995; Fischer *et al.*, 2005). AEZ analysis categorizes existing lands by agroecological zones, which differ in the length of growing period and climate. The length of the growing period is defined based on temperature, precipitation, soil characteristics, and topography. The changes of the distribution of the crop zones along with climate change are tracked in AEZ models. Cline (2007) observed that AEZ studies tend to attribute excessive benefits to the warming of cold high-latitude regions, thereby overstating global gains from climate changes.

Albersen *et al.* (2000, 2002) assessed agricultural production in the PRC using the AEZ model. Albersen *et al.* (2000) argued that agricultural production in the northern PRC is constrained by water supply and improving water supply would increase yields to their potential levels. Similarly, Albersen *et al.* (2002) claimed that irrigated land tends to be more productive than rain-fed farms. Furthermore, their results revealed the scarcity of irrigated land, labor, and other inputs. The outputs of major crops such as rice, wheat, and maize are generally similar across regions and difference is only due to geographical conditions where the specific crop is best suited.

The Ricardian cross-sectional approach explores the relationship between agricultural capacity (measured by land value) and climate variables (usually temperature and precipitation) on the basis of statistical estimates from farm survey or country-level data. This approach automatically incorporates efficient climate change adaptations by farmers. Both crop simulation and agroecological zone models do not take into account economic considerations and human capital limitations, which are important factors for a farmer's decision (Mendelsohn and Dinar, 1999). The Ricardian approach has an advantage over the other two approaches in that it can incorporate farmers' adaptations in response to climate change (Mendelsohn and Dinar, 1999). The Ricardian approach assumes that each farmer has profit maximization characteristics subject to exogenous conditions to their farms (Wang *et al.*, 2009). The major criticisms of the Ricardian approach are that it does not account for price changes and that it fails to fully control for the impact of other variables that affect farm incomes (Mendelsohn and Dinar, 1999; Cline, 1996).

Although the Ricardian approach is widely used to assess agricultural impacts of climate change, the number of such studies for the PRC is limited. To the best of our knowledge, the first Ricardian analysis for the PRC was carried out by Liu *et al.* (2004), who provided regionally detailed estimates of impacts of climate change on agriculture in the PRC. The authors concluded that increases in both temperature and precipitation would have a positive impact on agriculture in the PRC, with variations across regions and seasons. One possible reason that the Ricardian approach is not widely used in the PRC context is that the approach relies on a restrictive assumption of competitive land market, which is clearly not true in today's PRC (see Zhang, 2010 for a discussion).

The last approach is general equilibrium models. Unlike the previous three approaches that only study the agricultural sector alone (i.e. "partial equilibrium models"), the general equilibrium models incorporate the interactions between different sectors. The argument is that the climate change may affect the agricultural sector either directly or indirectly through interactions between different sectors (Zhai *et al.*, 2009). Oftentimes the general equilibrium models are used in conjunction with the partial equilibrium models, while the latter examines the direct impacts and the former provides a framework to track interactions among sectors through trades, price changes, input factor substitution and other factors.

As far as the analytical results are concerned, there are a wide range of impact estimates of climate change on PRC's agriculture. Many of these estimates are different and some are of opposite signs, partly attributable to different models and datasets used in the studies. Four out of five AEZ models, for example, predict increases in cereal-production potential in the range of 5-23 percent (Fischer *et al.*, 2005). This is consistent with Cline (2007) who observed that AEZ studies tend to attribute excessive benefits to the warming of cold high-latitude regions, thereby overstating the impacts. Studies using Ricardian approaches seem to produce more modest results for the PRC. However, even studies using the same approaches do not produce consistent results. For example, both using the Ricardian approaches, while Liu *et al.* (2004) found that warming would have a positive impact on agricultural production, Wang *et al.* (2009) show the opposite. Their results suggest that a 1°C increase in temperature would reduce farm revenues per hectare by US$10. We suspect this has to do with the data used. Liu *et al.* (2004) used 1985-1991 data for 1,275 counties, while Wang *et al.* (2009) used the household level data from the Household Income and Expenditure Survey in 2001. Despite the differences in the approach and data used and the results obtained, all studies agree that the impacts of climate vary across crops, locations and seasons.

In this paper, we use production function to investigate the responses of grain output to climate variables as well as other traditional input variables. The use of production function approach allows us to do away with the competitive land market assumption as required in the Ricardian approach. Our results suggest that the impacts of climate changes significantly differ among regions and crops. These in turn imply substantial changes in inter-regional trade flows, which we will analyze using CGE model in another paper.

III. Methodology

We will use interaction terms of climate variables and regional dummies to capture the regional differences of climate change impact on grain crops. For this purpose, we group the PRC's provinces into seven regions, namely Northeast (including Heilonjiang,

Jilin, and Liaoning), North (including Beijing, Tianjin, Hebei, Shandong, Inner Mongolia), East (including Jiangsu, Shanghai, and Zhejiang), South (including Fujian, Guangdong, and Hainan), Central (including Shanxi, Henan, Anhui, Hubei, Hunan, and Jiangxi), Northwest (including Shannxi, Ningxia, Gansu, Qinghai, and Xinjiang), and Southwest (including Sichuan, Chongqing, Guangxi, Yunnan, Guizhou, and Tibet).

In our production function model, the dependent variable is rural household output (rice, wheat corn and soybean). Climate variables include seasonal mean temperature, annual accumulated precipitation, and annual accumulated sunshine hours. We also introduced squared climate variables into the model to capture possible nonlinear impacts of climate variables. Other independent variables include sown area, labor, fixed production assets, water resources, other inputs, as well as household head characteristics, community characteristics, regional dummies, interaction terms of climate variables and regional dummies[3]:

$$\begin{aligned} Output = f(&Climate\ variabels, Climate\ variabels\ squared\ \ Sown\ area, Labor,\\ &Fixed\ assets, Water\ resourse, Other\ inputs,\ Household\ head\ Characteristics,\\ &Household\ characteristics,\ Community\ characteristics,\\ &\mathrm{Re}gional\ dummies\ \ Interaction\ terms\ of\ climate\ variabels\ and\ regional\ dummies) \end{aligned}$$

The essential difference between our model and the Ricardian model of Wang *et al.* (2009) lies in that we use rural household crop output as the dependent variable while Wang *et al.* (2008) use crop net revenue per hectare as the dependent variable. In addition, our model differs from Wang *et al.* (2009) in that:

- we include one more climate indicator- sunshine accumulated hours, which is missing in Wang *et al.* (2009) and most existing literature;
- our model includes interaction terms of climate variables and regional dummies to catch the regional differences; and
- the use of crop output instead crop net revenue as dependent variable allows us to examine the impacts of climate changes on different crops.

The empirical model takes a similar linear form as in Wang *et al.* (2009).

IV. Data

Rural household survey data for the years 2003, 2005, and 2008 are used. These surveys were conducted by the Research Center for the Rural Economy (RCRE) at the PRC's Ministry of Agriculture. These surveys include information on rural village and rural household. The village questionnaire includes information on location, terrains, economy indicators, and other village variables. The rural household survey covers information on family members, land, fixed assets, crop production (inputs and outputs), livestock production, consumption, income and expenditure, and housing *et al.* our dataset cover over 9,000 rural households from each survey year. The number of observations used in the wheat model is 6,707, rice model 7,418, corn 10,264, and soybean 4,995.

Climate variables, which are obtained from the National Metrological Information Center, include seasonal mean temperature, annual accumulated precipitation, and annual accumulated sunshine days. We match the climate data to rural households.

The descriptive statistics are reported in Table I.

V. Regression results and elasticities associated with climate variables

The regression results of the impacts of climate change on grain crops production are provided in Table II. They suggest that all the three climate variables – temperature, rainfall, and sunshine – have significant impacts on wheat, rice, corn, and

	Wheat	Rice	Corn	Soybean
Grain output (kg)	1,301.437	2,054.410	1,992.502	417.301
Spring temperature (°C)	14.367	16.828	13.639	14.678
Spring precipitation (mm)	49.258	107.256	49.485	73.212
Spring sunshine (days)	196.330	146.456	196.706	176.896
Summer temperature (°C)	24.389	26.274	24.336	25.033
Summer precipitation (mm)	144.359	173.315	139.885	163.529
Summer sunshine (days)	180.672	173.917	185.483	174.915
Fall temperature (°C)	14.021	17.919	13.259	14.952
Fall precipitation (mm)	86.372	90.593	66.275	86.719
Fall sunshine (days)	152.457	144.821	163.073	154.518
Winter temperature (°C)	0.081	4.643	−1.951	0.350
Winter precipitation (mm)	14.810	38.331	13.211	23.192
Winter sunshine (days)	137.318	107.098	142.824	132.107
Sown area (μ)	4.121	4.947	4.577	3.324
Fertilizer (CNY)	364.551	445.818	334.894	89.577
Plastic film (CNY)	0.870	28.198	11.064	0.467
Pesticide (CNY)	24.463	139.650	28.420	23.370
Irrigation (CNY)	66.679	77.034	62.331	3.185
Animal power (CNY)	17.854	41.359	36.159	19.162
Machinery (CNY)	207.980	155.713	63.993	21.407
Labor (days)	51.947	93.120	59.454	114.600
Fixed productive assets (CNY)	6,346.782	4,746.642	7,773.242	6,279.467
Gender of household head (male – 1, female – 0)	0.860	0.834	0.845	0.838
Age of household head (years)	46.277	44.906	45.217	44.932
Education level of household head (years)	5.741	5.527	5.663	5.480
Agricultural training of household head (yes – 1, no – 0)	0.078	0.082	0.092	0.072
Village cadre (yes – 1, no – 0)	0.054	0.041	0.047	0.042
Terrain (plain – 1, otherwise – 0)	0.608	0.248	0.464	0.311
Terrain (hill – 1, otherwise – 0)	0.219	0.448	0.230	0.327
Region type (planting area – 1, otherwise – 0)	0.982	0.895	0.903	0.872
Region type (forestry area – 1, otherwise – 0)	0.013	0.073	0.091	0.092
Suburb (yes – 1, no – 0)	0.165	0.128	0.126	0.123
Economy rank within county (highest – 5, . . . , lowest – 1)	2.793	2.873	2.903	2.916
Share of paddy field in total (%)	0.154	0.654	0.154	0.276
Share of irrigated field in dry field (%)	0.398	0.059	0.308	0.088
Number of observations	6,707	7,418	10,264	4,995

Notes: °C – degrees Celsius; kg – kilogram, mm – millimeter, μ – 1/15 hectare
Source: Results calculated using rural household survey data (2003, 2005, 2008) collected by the RCRE at the PRC's Ministry of Agriculture and climate data from the National Metrological Information Center

Table I.
Descriptive statistics of variables (mean)

Table II.
Regression results of climate impacts on grain output (2003, 2005, 2008)

	Wheat		Rice		Corn		Soybean	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Sown area	230.903***	2.882	54.120***	1.967	186.927***	3.708	71.141***	2.047
Fertilizer	0.533***	0.023	1.026***	0.032	1.262***	0.042	0.563***	0.038
Plastic film	−0.001	0.337	0.009	0.017	−2.445***	0.297	0.335	0.499
Pesticide	3.149***	0.224	1.558***	0.077	4.067***	0.292	2.012***	0.130
Irrigation	0.643***	0.064	2.926***	0.058	−0.001	0.010	1.286***	0.199
Animal power	0.538***	0.090	0.539***	0.094	1.782***	0.170	0.037	0.131
Machinery	0.001	0.002	0.713***	0.046	2.420***	0.137	0.106	0.122
Labor	−0.592***	0.120	0.169***	0.039	0.037	0.027	0.001	0.001
Fixed productive assets	0.001	0.000	0.003***	0.001	0.005***	0.001	0.000	0.000
Spr. temp.*Northeast China			−946.302***	238.053	726.404***	127.797	−267.979***	68.613
Spr. temp.*North China	469.935***	88.280			340.262*	199.824	2,792.477	2,321.715
Spr. temp.*East China	1,034.242*	573.001	−1,721.516***	380.010	1,983.896	3,128.696	102.680	181.336
Spr. temp.*South China			−423.023	380.902			0.020	197.420
Spr. temp.*Central China	438.365***	90.394	−525.170*	306.048	−496.320***	198.292	30.311	140.245
Spr. temp.*Northwest China	230.344***	65.669	−261.963	1,449.498	−450.374***	154.996	142.259	104.032
Spr. temp.*Southwest China	563.326***	181.067	−657.518*	350.092	180.095	309.694	116.094	172.637
Spr. pre.*Northeast China			46.065***	8.030	−27.187***	6.323	−14.946***	3.101
Spr. Pre.*North China	−3.971	5.224	−210.288**	107.224	27.364***	7.626	−411.807***	132.988
Spr. pre.*East China	−67.010	62.431	−40.250*	23.675	−171.068	277.211	−14.087	17.094
Spr. pre.*South China	94.257***	15.673	−3.999	3.702	−111.440**	57.148	2.745	3.829
Spr. pre.*Central China	−2.939	2.458	−5.995**	2.771	7.755	5.834	2.350	1.787
Spr. pre.*Northwest China	−18.676***	3.206	−26.066	217.979	−3.078	9.212	27.062***	7.010
Spr. pre.*Southwest China	−0.911	3.368	−10.091***	2.384	10.603*	6.489	2.976	2.164
Spr. sunshine*Northeast China	4.746	5.423	67.654***	12.575	100.436***	11.565	−21.749***	5.483
Spr. Sunshine*North China	−3.004	4.830	−12.991	59.229	91.370***	11.161	66.511**	27.839
Spr. sunshine*East China	−70.513	72.787	91.412***	20.837	−92.749	276.275	0.384	10.183
Spr. sunshine*South China	68.485***	15.001	−5.260	8.439	−113.844*	64.003	3.386	7.227
Spr. sunshine*Central China	15.766***	4.546	−10.388	9.045	89.629***	9.603	3.447	5.099
Spr. sunshine*Northwest China	−18.281***	5.610	8.334	20.189	112.412***	12.919	1.134	6.156
Spr. sunshine*Southwest China	−11.940	7.551	−15.521**	6.619	49.293***	8.561	−2.134	3.540
Sum. temp.*Northeast China			−3,583.301***	611.495	1,812.015***	449.368	819.328***	224.907

(*continued*)

Table II.

	Wheat		Rice		Corn		Soybean	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Sum. temp.*North China	−966.136***	184.909			3,912.778***	490.577	−2,029.388	1,486.366
Sum. temp.*East China	−403.123	1,195.657	−3,541.273***	788.436	−1,234.281	1,741.104	7.909	478.566
Sum. temp.*South China			−1,789.542***	541.241			356.504	437.945
Sum. temp.*Central China	−815.389***	177.964	−1,671.724***	477.083	3,427.367***	503.668	194.549	251.130
Sum. temp.*Northwest China	−872.933***	134.322	−867.468	2,757.800	2,036.800***	412.511	277.957	190.282
Sum. temp.*Southwest China	−841.687***	162.738	−2,271.405***	420.154	2,530.673***	453.337	197.192	218.945
Sum. pre.*Northeast China			63.015***	4.796	−21.975***	3.878	−11.112***	1.551
Sum. pre.*North China	−3.329	2.122	105.377	107.580	0.695	4.363	204.259***	67.733
Sum. pre.*East China	10.696	11.888	−6.658	6.617	128.338	119.242	3.759	5.088
Sum. pre.*South China			−1.671	5.094	30.808*	17.073	0.067	4.846
Sum. pre.*Central China	5.287**	2.202	−7.404***	2.490	6.870	4.624	1.548	1.583
Sum. pre.*Northwest China	0.226	1.431	10.053	91.066	−18.182***	4.707	4.627*	2.731
Sum. pre.*Southwest China	1.902	2.466	−2.626	2.623	9.514**	4.898	2.005	1.782
Sum. sunshine*Northeast China			123.039***	13.996	−43.319***	11.556	−4.418	4.481
Sum. sunshine*North China	−24.394***	7.238			−79.405***	13.312	−89.419**	37.713
Sum. sunshine*East China	16.699	33.973	26.424	19.925	423.623	397.013	22.996*	14.107
Sum. sunshine*South China	−112.229***	20.375	31.654**	15.961	66.423	52.213	8.179	19.633
Sum. sunshine*Central China	−22.482***	4.687	9.162	9.655	−42.741***	9.994	9.043***	3.657
Sum. sunshine*Northwest China	−28.057***	8.280	21.221	40.872	−54.291***	15.707	14.950***	5.473
Sum. sunshine*Southwest China	−14.097***	4.828	37.108***	6.909	−24.767**	10.965	9.883***	3.923
Fall temp.*Northeast China			1,482.890***	369.723	−421.548***	153.460	−189.411**	89.972
Fall temp.*North China	540.199***	115.561			−1,500.803***	214.796	110.744	841.344
Fall temp.*East China	−920.621	1,889.283	−715.974	861.462			−485.082	540.004
Fall temp.*South China			1,187.217***	421.563			−185.449	296.731
Fall temp.*Central China	64.598	172.332	1,237.302***	325.456	−1,123.622***	294.128	−118.129	160.620
Fall temp.*Northwest China	561.457***	120.461	−908.565	1,362.229	−130.269	234.475	−244.656*	127.510
Fall temp.*Southwest China	66.116	233.785	1,554.027***	386.296	−1,679.508***	390.702	−210.936	198.481
Fall pre.*Northeast China			−32.101***	9.570	−24.712***	5.872	1.240	2.430
Fall pre.*North China	4.310***	1.258	−96.233	101.131	9.373***	2.562	−138.948***	43.856

(*continued*)

	Wheat		Rice		Corn		Soybean	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Fall pre.*East China	−6.793	8.262	−16.124*	8.911	−178.818	186.016	−4.510	5.431
Fall pre.*South China	31.327***	4.516	3.583	2.361	−72.133***	21.352	0.184	3.814
Fall pre.*Central China	−0.030	0.247	−0.568	0.777	−0.270	0.840	0.029	0.268
Fall pre.*Northwest China	−3.613***	1.262	−2.719	36.724	20.081***	4.567	−2.475	2.204
Fall pre.*Southwest China	1.499	1.296	−2.305*	1.349	−0.859	2.748	0.099	0.920
Fall sunshine*Northeast China			−30.949*	16.417	−40.664***	15.148	−34.635***	7.739
Fall sunshine*North China	2.413	7.203	49.818	114.227	−34.182**	15.802	−83.188**	35.192
Fall sunshine*East China	−44.528	78.913	80.771***	29.410	−54.187	160.349	−12.129	16.221
Fall sunshine*South China			8.372	9.469	71.179	116.482	−16.287	11.948
Fall sunshine*Central China	1.806	4.857	19.450***	7.505	−40.392***	11.457	−14.904**	6.207
Fall sunshine*Northwest China	4.798	6.252	49.252	72.972	−38.983***	14.403	−17.551**	7.513
Fall sunshine*Southwest China	6.962	4.361	0.759	5.128	−20.150**	8.325	−11.674***	4.260
Winter temp.*Northeast China			25.858	225.988	131.735	83.403	47.891	45.580
Winter temp.*North China	−201.214***	57.847			−525.785***	121.667	−1,550.905	1,244.342
Winter temp.*East China	−594.606	1,026.965	2,674.854***	632.036	264.684	3,751.658	240.159	414.006
Winter temp.*South China			−289.174*	174.373			−17.892	203.598
Winter temp.*Central China	159.820***	44.094	−404.898***	106.512	168.099***	65.403	94.732***	34.876
Winter temp.*Northwest China	−189.388***	27.596	1,003.705	917.979	207.245***	70.768	−6.752	43.437
Winter temp.*Southwest China	−2.825	57.431	−80.298	73.080	−237.912***	63.894	−24.757	30.862
Winter pre.*Northeast China			−269.813***	45.722	233.221***	46.200	109.281***	21.021
Winter pre.*North China	49.236***	16.511			236.325***	38.363	70.040	362.555
Winter pre.*East China	54.236	85.026	−80.783**	40.001	−322.923	319.923	−13.677	19.348
Winter pre.*South China			1.080	11.481	303.423***	104.636	−6.201	11.356
Winter pre.*Central China	−7.109*	4.223	8.052	7.013	−51.139***	10.027	−8.148**	4.019
Winter pre.*Northwest China	−11.639	7.434	277.012	663.888	−53.741***	20.877	8.077	14.974
Winter pre.*Southwest China	−8.172	7.174	−8.577	6.727	−21.866**	9.853	−4.519	3.804
Winter sunshine*Northeast China			43.401**	19.026	−46.031***	14.353	34.919***	5.928
Winter sunshine*North China	−20.686***	3.641	−26.626	30.555	4.453	10.762	−76.828*	40.109
Winter sunshine*East China	21.547	50.876	−181.116***	45.743	−149.703	200.952	−22.284	25.933
Winter sunshine*South China			24.072***	8.209	−65.677	72.816	−7.091	6.792

(continued)

Table II.

Table II.

	Wheat		Rice		Corn		Soybean	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Winter sunshine*Central China	−29.235***	3.258	14.792*	7.709	−6.626	8.825	−5.564	3.903
Winter sunshine*Northwest China	−26.789***	3.636	50.421*	21.557	−1.448	11.226	−6.997	5.476
Winter sunshine*Southwest China	−14.455**	5.952	11.104*	4.612	−25.743***	5.673	−2.174	3.107
Spr. temp. squared	−10.729***	2.754	12.018	8.939	11.115*	6.227	−1.857	4.168
Spr. prec. squared	0.031***	0.013	0.035***	0.007	−0.026	0.029	−0.012	0.008
Spr. sun. squared	−0.010	0.011	0.036	0.023	−0.223***	0.024	−0.001	0.011
Sum. temp. squared	15.144***	3.244	41.011***	8.154	−52.901***	9.565	−4.677	4.586
Sum. prec. squared	−0.004	0.006	0.011*	0.006	−0.021*	0.012	−0.005	0.004
Sum. sun. squared	0.068***	0.016	−0.080***	0.021	0.103***	0.029	−0.029***	0.011
Fall temp. squared	−8.255*	4.867	−34.571***	9.003	24.036***	8.000	4.193	4.533
Fall prec. squared	0.000	0.000	0.000	0.001	0.000	0.001	−0.000	0.000
Fall sun. squared	−0.014	0.016	−0.036**	0.018	0.139***	0.036	0.058***	0.020
Winter temp. squared	−2.606**	1.198	10.536**	4.903	16.197***	2.788	1.151	1.606
Winter prec. squared	0.066	0.047	0.009	0.059	0.535***	0.110	0.067*	0.039
Winter sun. squared	0.094***	0.011	−0.059***	0.022	0.028	0.033	0.014	0.015
Gender of household head	−36.066	26.389	55.089	55.574	31.571	70.025	7.155	27.511
Age of household head	−0.797*	0.438	−1.560	0.996	−4.223***	1.168	0.076	0.470
Education level of HH	1.396	1.941	−0.772	4.727	−23.008***	5.587	1.648	2.136
Agri. training of HH	40.676*	23.357	23.387	48.229	18.423	57.786	−54.166**	24.111
Village cadre	38.983*	23.746	−6.637	60.886	19.831	68.520	27.697	27.591

(continued)

Table II.

	Wheat		Rice		Corn		Soybean	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Terrain (plain)	207.523***	35.516	156.567**	77.734	−47.688	77.741	−71.878	47.279
Terrain (hill)	251.561***	33.779	393.956***	53.943	102.586	69.314	−57.843*	33.379
Region type (planting)	−471.152***	90.424	84.679	160.116	907.873***	275.909	−268.233***	74.938
Region type (forestry)	−488.889***	114.404	219.240	195.641	1,543.548***	281.928	−276.960***	82.223
Suburb.	2.305	25.221	404.835***	63.689	−321.126***	72.633	−9.192	32.268
Economy rank within county	−7.404	10.685	136.126***	33.623	−195.301***	23.423	−7.659	11.392
Share of paddy field in total	−75.269**	31.245	392.780***	50.847	132.145*	80.429	−33.072	27.712
Share of irri. field in dry field	114.098***	17.636	−19.915	69.359	−18.978	53.637	29.999	26.012
Northeast China			32,857.170***	11,043.200	−34,785.400***	10,626.390	−7,818.184*	4,579.159
North China	17,732.240***	3,671.695			−79,137.540***	11,416.320	31,138.010*	17,377.620
East China	29,131.580	72,927.600	127,554.000***	34,087.300			7,896.535	21,338.690
South China			28,678.710*	16,999.620			−5,037.681	13,175.740
Central China	17,753.760***	3,239.552	30,822.150**	12,761.460	−60,592.870***	11,319.150	−3,725.352	5,059.124
Northwest China	23,779.330***	2,751.485	17,833.490	40,004.980	−42,545.390***	9,976.377	−6,741.694	4,416.977
Southwest China	17,521.240***	2,893.737	41,434.110***	12,075.930	−37,156.370***	10,412.080	−3,691.609	4,608.416
Constant	−8,969.009***	1,641.108	−20,989.740***	6,525.081	22,287.360***	6,261.563	2,871.019	2,702.164
Number of observations	6,707		7,418		10,264		4,995	
Adjusted R^2	0.876		0.842		0.757		0.749	

Note: Significant at: *10, **5 and ***10 percent

soybean output. Moreover, the climate variables squared are also significant in regressions which, in turn, indicate that climate change impacts grain output nonlinearly.

The significance of interaction terms of climate variables and regional dummies indicates that climate change impacts crops output differently in different regions. The impacts of climate change on grain output also differ among different crops. Clearly, models assuming the PRC as a single region (as in GTAP model) or using total grain as a single commodity (as in some econometric models) may have produced biased estimates, yielding incorrect impact assessment and misleading policy recommendations.

The significance of irrigation variables indicates that improving water irrigation system could increase the output of wheat, rice, and soybean. More specifically, one CNY increase in irrigation could increase wheat output by 0.643 kg, rice 2.926 kg, and soybean 1.286 kg. The output elasticities associated with wheat, rice, and soybean are 0.03, 0.09, and 0.01, respectively, measured at the mean value of variables.

The elasticities of climate change with respect to grain outputs by crops, regions, and seasons can also be obtained. Since the climate variables enter into production functions nonlinearly, their elasticities are evaluated at the regional mean values of relevant variables. The regional elasticities can be added up using regional output shares in national grain output as weights, giving rise to the weighted elasticity for each crop at the national level. The higher the weighted elasticity is, the larger the impacts of climate change on national output. The regional shares are calculated with data from the NBSC (2010). The elasticities associated with climate change for the different grain crops across different regions during different seasons are reported in Table III.

(A) Elasticities associated with climate variables in wheat production

Temperature. The elasticity of wheat output with respect to temperature changes is −0.76 at the national level, and ranges from −7.20 to 2.15 across different regions.

Climate warming in East and Southwest PRC is calculated to have larger negative impacts on the country's wheat production, with associated elasticities of −7.20 in East PRC and −6.93 in Southwest PRC. These two regions produce approximately 9 and 6 percent of the country's wheat, respectively. The weighted elasticities for these two regions are −0.66 and −0.43, respectively, indicating that the negative impacts of climate warming on the PRC's overall wheat production come from these two regions.

With a small elasticity of −0.02, climate warming in Northwest PRC will also have negative impacts on wheat production. This region produces 10 percent of the PRC's wheat, so climate warming impacts in this region will have almost no effect on the country's overall wheat production.

Wheat production in Northeast, North, South, and Central PRC will benefit from climate warming. Northeast and South PRC are the two regions that will benefit largely from climate warming, with elasticities of 2.01 and 2.15, respectively. These two regions, however, only produce around 1 percent of the country's wheat, hence the weighted national elasticities for these two regions are very small. As such, the impacts of climate warming on wheat production in these two regions will not affect PRC's overall wheat production.

Collectively producing 74 percent of the PRC's wheat, North PRC and Central PRC are the country's major wheat producing regions. The weighted elasticities associated

Table III. Elasticity of output with respect to climate variables

	Wheat						Rice					
	Spr.	Summer	Fall	Winter	Region	Weighted	Spr.	Summer	Fall	Winter	Region	Weighted
Temperature												
Northeast PRC	−3.40	13.83	−2.49	−0.00	2.01	0.01	−1.79	−9.01	1.84	0.16	−4.07	−0.53
North PRC	1.58	−3.35	2.89	0.23	0.79	0.25	1.92	27.07	−5.50	0.29	8.16	0.10
East PRC	7.41	6.97	−13.05	−0.83	−7.20	−0.66	−12.55	−19.66	−20.30	6.86	−16.95	−2.26
South PRC	−2.86	13.11	−2.11	−0.01	2.15	0.00	1.16	8.51	−5.63	−0.09	2.30	0.21
Central PRC	1.81	−0.06	−4.73	0.53	0.18	0.08	−1.61	10.57	−1.27	−0.94	0.10	0.04
Northwest PRC	−0.17	−3.20	2.68	0.52	−0.02	−0.00	0.17	12.04	−8.05	−2.69	1.66	0.02
Southwest PRC	8.17	−6.57	−8.84	−0.75	−6.93	−0.43	−3.10	−3.95	3.85	0.57	−0.87	−0.19
Overall PRC	2.42	−1.06	−2.62	0.23	−0.76	−0.76	−3.11	0.85	−2.81	0.65	−2.61	−2.61
Precipitation												
Northeast PRC	0.12	−0.13	0.00	0.02	0.22	0.00	1.07	2.19	−0.45	−1.76	−3.39	−0.44
North PRC	−0.04	−0.41	0.17	0.18	1.85	0.58	−2.86	7.10	−2.67	0.00	−5.41	−0.07
East PRC	−2.84	1.21	−0.72	0.86	−0.25	−0.02	−2.25	−0.27	−1.33	−2.42	−9.16	−1.22
South PRC	1.97	−0.10	1.24	0.00	4.92	0.00	0.50	0.27	0.21	0.04	0.95	0.09
Central PRC	0.09	0.78	−0.00	−0.05	0.38	0.16	−0.05	−0.42	−0.02	0.34	0.23	0.09
Northwest PRC	−0.28	−0.02	−0.10	−0.03	−0.75	−0.07	−0.15	0.21	−0.03	0.21	2.40	0.03
Southwest PRC	0.85	0.16	0.26	−0.26	0.10	0.01	−0.23	0.26	−0.12	−0.17	−0.88	−0.19
Overall PRC	−0.21	0.33	−0.01	0.09	0.66	0.66	−0.23	0.26	−0.29	−0.45	−1.72	−1.72
Sunshine												
Northeast PRC	0.14	3.39	−0.50	2.73	6.01	0.04	3.57	4.19	−1.88	0.91	6.47	0.84
North PRC	−1.08	0.08	−0.27	1.03	0.07	0.02	0.62	−3.84	3.82	−4.85	−2.67	−0.03
East PRC	−9.20	3.87	−4.62	4.01	−5.02	−0.46	8.20	−0.16	5.48	−10.99	−1.44	−0.19
South PRC	9.45	−10.84	−0.54	3.25	0.32	0.00	0.32	−0.10	−0.30	0.66	0.71	0.06
Central PRC	2.36	−0.24	−0.35	−0.48	0.66	0.28	0.17	−1.92	0.89	0.00	−0.44	−0.18
Northwest PRC	−3.57	0.47	−0.03	0.45	−2.04	−0.20	3.24	−2.69	3.61	2.66	4.49	0.05
Southwest PRC	−4.36	1.18	0.99	−0.36	−1.10	−0.07	−0.65	1.58	−0.62	0.17	0.19	0.04
Overall PRC	−0.79	0.42	−0.60	0.53	−0.38	−0.38	1.56	0.01	0.77	−1.29	0.59	0.59

(*continued*)

Table III.

	Corn						Soybean					
Temperature												
Northeast PRC	1.51	−2.32	−0.11	0.78	0.04	0.01	−1.84	10.47	−0.73	−0.18	0.99	0.33
North PRC	3.20	12.22	−4.34	0.80	1.84	0.55	−1.84	10.47	−0.73	−0.18	0.99	0.14
East PRC	33.83	−98.03	10.27	0.07	−8.57	−0.12	2.91	−25.67	−23.31	1.74	−18.52	−1.21
South PRC	22.09	−153.79	51.94	15.53	−32.45	−0.17	−20.96	30.48	2.58	1.68	7.31	0.14
Central PRC	−6.52	43.77	−12.29	2.12	18.96	3.49	−2.25	−8.82	3.95	2.20	5.47	1.15
Northwest PRC	−4.76	−52.06	34.15	2.43	6.33	0.53	2.60	3.35	−3.56	0.15	−0.20	−0.01
Southwest PRC	17.11	−4.83	−24.02	0.17	−9.28	−1.16	7.11	−10.06	−7.60	−0.35	−8.07	−1.33
Overall PRC	2.51	3.92	−3.31	1.16	3.14	3.14	−0.22	0.61	−2.48	0.47	−0.79	−0.79
Precipitation												
Northeast PRC	−0.20	−0.73	−0.15	0.20	1.58	0.46	−0.52	−1.34	0.03	0.54	3.52	1.17
North PRC	0.29	−0.23	0.18	0.41	5.48	1.64	−0.52	−1.34	0.03	0.54	3.52	0.50
East PRC	−9.59	19.00	−20.39	−5.22	−45.82	−0.63	−5.02	1.53	−2.85	−1.13	−12.82	−0.83
South PRC	−18.59	7.76	−16.47	13.70	31.58	0.16	−2.04	−3.89	0.18	−0.36	−4.72	−0.09
Central PRC	0.75	−1.12	−0.04	−0.94	−1.76	−0.32	0.25	−0.40	0.01	−0.56	−1.01	−0.21
Northwest PRC	−1.16	−15.07	2.93	−1.20	−6.21	−0.52	1.46	0.65	−0.26	0.07	3.05	0.21
Southwest PRC	0.89	0.47	−0.10	0.20	1.78	0.22	0.16	0.14	0.06	−0.15	−0.22	−0.04
Overall PRC	−0.05	−1.39	−0.13	−0.07	1.00	1.00	−0.43	−0.63	−0.17	0.04	0.70	0.70
Sunshine												
Northeast PRC	−0.04	−0.08	0.61	−1.35	−0.99	−0.29	−3.83	−2.40	−1.83	5.66	−1.52	−0.50
North PRC	−0.78	−2.93	1.19	0.94	−1.49	−0.45	−3.83	−2.40	−1.83	5.66	−1.52	−0.22
East PRC	−33.43	75.30	−1.81	−19.01	10.85	0.15	−0.03	9.11	2.49	−9.99	−0.34	−0.02
South PRC	−59.67	43.97	39.83	−14.01	−1.33	−0.01	5.00	−9.80	7.11	−5.23	−0.40	−0.01
Central PRC	3.26	−4.61	0.83	0.73	−0.09	−0.02	3.15	−0.11	2.34	−1.25	1.53	0.32
Northwest PRC	14.31	−9.15	1.39	2.76	1.45	0.12	0.30	0.87	1.05	−0.80	1.10	0.08
Southwest PRC	−0.03	0.84	1.39	−2.17	−0.91	−0.11	−2.00	1.81	0.88	−0.23	−0.12	−0.02
Overall PRC	0.78	−1.15	1.16	−0.35	−0.60	−0.60	−1.37	−0.40	0.14	1.58	−0.37	−0.37

Notes: Spr. – spring; national elasticities are calculated using regional mean, and overall PRC impacts are weighted by regional share

with these two regions are 0.25 and 0.08, respectively. These two regions will help reduce the overall negative impacts of climate warming on the PRC's wheat production.

Precipitation. As expected, increase in precipitation will benefit the PRC's wheat production. The national elasticity of wheat output with respect to precipitation is 0.66, which means that a 1 percent increase in precipitation will increase the country's wheat production by 0.66 percent.

South PRC and North PRC are the two regions that will benefit the most from increases in precipitation. The regional elasticities associated with these two regions are 4.92 and 1.85, respectively. South PRC only produces less than 0.5 percent of the country's wheat, so precipitation changes occurring in this region will have almost no impact on the PRC's overall wheat production. North PRC, on the other hand, produces 31 percent of the country's wheat, and its weighted elasticity reached 0.58. This means that North PRC accounts for 90 percent of precipitation impacts on the country's overall wheat production.

Wheat production in Central PRC will also benefit from increases in precipitation. Its regional elasticity is 0.38. This region produces 43 percent of the PRC's wheat, so the weighted national elasticity is 0.16. Central PRC is, thus, ranked second, after North PRC, among the regions that will contribute to wheat production increase due to precipitation increases.

Northeast and Southwest PRC will also benefit from increases in precipitation. However, wheat production in East China and Northwest China will decrease once precipitation increases. Yet, the impacts of precipitation changes in these four regions will only have very small impacts on the PRC's overall wheat production.

Sunshine hours. Increases in duration of sunshine will have negative impacts on the country's wheat production. The elasticity of wheat output with respect to duration of sunshine is −0.38, which means that a 1 percent increase of duration of sunshine will result in 0.38 percent decrease in wheat production.

Given a 1 percent increase of sunshine hours, regional wheat output will decrease by 5.02 percent in East PRC, 2.04 percent in Northwest PRC, and 1.1 percent in Southwest PRC. But regional wheat output in Northeast, North, South, and Central PRC will increase, with regional elasticities of 6.01, 0.07, 0.32, and 0.66, respectively.

The negative impacts of an increase in the duration of sunshine on the PRC's overall wheat production predominantly originate from East and Northwest PRC, while the positive impacts mainly come from Central PRC.

(B) Elasticities associated with climate variables in rice production

Temperature. Temperature changes will have much larger impacts on the PRC's rice production than on wheat production. The elasticity of rice output with respect to temperature changes reaches −2.61, or three times that of wheat.

Rice production in East PRC is relatively sensitive to temperature changes, with elasticity reaching −16.95. This region produces only 13 percent of the country's rice, yet its weighted elasticity still reaches −2.26. This region accounts for a dominant share of the negative impacts of temperature changes on the PRC's overall rice production.

Northeast and Southwest PRC rank second and third, respectively, in their contribution to reduction in the country's rice production as a result of rising temperature. Their regional elasticities are −4.07 and −0.87, respectively, and their associated weighted elasticities are −0.53 and −0.19, respectively.

Nonetheless, not all regions are adversely affected by temperature changes, as rice production in North, South, Central, and Northwest PRC will benefit from climate warming.

Precipitation. Generally, increases in precipitation will negatively affect the PRC's rice production, with calculated elasticity of −1.72. Most of the negative impacts come from East and Northeast PRC. North and Southwest PRC will also suffer from increases in precipitation, but the impacts are relatively small.

Rice production in South, Central, and Northwest PRC will increase with rising precipitation, but their overall impacts on the country's rice production are somewhat insignificant.

Sunshine hours. Increases in the duration of sunshine will help increase the PRC's rice production. The elasticity of rice output with respect to the duration of sunshine is 0.59, which means that a 1 percent increase of sunshine duration will increase the country's rice output by 0.59 percent.

Northeast PRC will see the largest percentage increase in rice production when the duration of sunshine increases. The regional elasticity is 6.47, and its weighted elasticity is 0.84. Rice output in Northwest PRC will also increase when the duration of sunshine increases, with regional elasticity of 4.49. But this region's transmitted impacts to the PRC's overall rice production are small. South and Southwest PRC will also benefit from rising duration of sunshine, while North, East, and Central PRC will suffer; but their combined impacts are small.

(C) Elasticities associated with climate variables in corn production

Temperature. Corn production in the PRC will generally benefit from climate warming. The elasticity of corn output with respect to temperature changes is 3.14, indicating that a 1 percent change in temperature will result in a 3.14 percent increase in the country's corn output.

Central PRC, producing 18 percent of the country's corn, will benefit the most from rising temperature. The elasticity associated with this region is 18.96, and its weighted elasticity is 3.49.

Corn production in North PRC, the major corn producing region accounting for 30 percent of the PRC's corn output, will also increase when temperature rises. The regional elasticity is 1.84, and its weighted elasticity is 0.55. Northwest PRC (producing 8 percent of the PRC's corn) also has a weighted elasticity of 0.53.

The impacts of climate warming on corn production in Northeast PRC (producing 29 percent of the PRC's corn) are quite small, with a regional elasticity of 0.04 and weighted elasticity of 0.01.

Conversely, corn output in East, South, and Southwest PRC will decline substantially when temperature rises. Elasticities of corn output with respect to temperature for these three regions are −8.57, −32.45, and −9.28, respectively. Both East and South PRC, however, produce only 1 percent of the country's corn, and their impacts on the country's overall corn output are small. Southwest PRC, though, produces 12 percent of the PRC's corn, and its weighted elasticity is estimated at −1.16.

Precipitation. Increases in precipitation will generally favor the PRC's corn production, with a calculated elasticity of 1. Regions that will benefit from increases in precipitation include Northeast, North, South, and Southwest PRC. Among these four regions, North PRC has the largest weighted elasticity at 1.64.

Rising temperatures will have negative impacts on corn production in East, Central, and Northwest PRC. The regional elasticities associated with these regions range from −1.76 to −45.82, but their weighted elasticities range from −0.32 to −0.63.

Sunshine hours. Increases in duration of sunshine will generally decrease the PRC's corn production. The elasticity of corn output with respect to the duration of sunshine is −0.60. Corn production in only two regions, East and Northwest PRC, will benefit from rising duration of sunshine, but their weighted elasticities are only 0.15 and 0.12, respectively. Corn production of the other five regions will suffer from rising duration of sunshine. The weighted elasticities associated with these five regions are also relatively small and range from −0.01 to 0.45.

(D) Elasticities associated with climate variables in soybean production

Temperature. Soybean production in the PRC will be negatively affected by climate warming. The elasticity of soybean output with respect to temperature is −0.79.

Soybean production in East and Southwest PRC, respectively, accounting for 7 and 12 percent of the PRC's soybean production, is relatively sensitive to climate warming, with elasticities of −18.52 and −8.07, respectively. These two regions have relatively large negative impacts on the country's overall soybean output, and their weighted elasticities are −1.21 and −1.33, respectively. Northwest PRC will have relatively small negative impacts on the PRC's overall soybean output, with a weighted elasticity −0.01.

Soybean production in the PRC's two major soybean producing regions, Northeast and Central PRC (producing 33 and 21 percent of the country's soybean output, respectively) will benefit from climate warming. Regional elasticities associated with Northeast and Central PRC are 0.99 and 5.47, respectively, and their corresponding weighted elasticities are 0.33 and 1.54, respectively.

Soybean production in North and South PRC will also benefit from rising temperature. The weighted elasticities associated with these two regions are 0.14, which means that climate warming in these regions will have small impacts on the country's overall soybean output.

Precipitation. The PRC's soybean production will generally benefit from increases in precipitation, with an elasticity of 0.70.

Northeast PRC will have a relatively larger impact on the PRC's overall soybean output when precipitation increases. The weighted elasticity associated with Northeast PRC is 1.17. North and Northwest PRC will also benefit from increases in precipitation, and the weighted elasticities associated with these two regions are 0.50 and 0.21, respectively.

Regions that will suffer from increases in precipitation include East, South, Central, and Southwest PRC. Soybean production in East PRC is relatively sensitive to precipitation changes with an elasticity of −12.82, and this region also has a relatively large negative impact on the PRC's overall soybean output when precipitation rises. The other three regions have relatively small negative impacts on the country's soybean output if precipitation increases, and the associated weighted elasticities are −0.09 for South PRC, −0.21 for Central PRC, and −0.04 for Southwest PRC.

Sunshine hours. Increases in duration of sunshine will generally reduce the PRC's soybean output. The elasticity of soybean output to duration of sunshine is −0.37. Soybean production in only two regions, Central and Northwest PRC, will benefit from increases in sunshine hours. Their impacts on the country's soybean output, however, are small. All the other five regions will see declines in soybean output when duration

of sunshine increases. Northeast PRC will have relatively larger negative impacts on the PRC's overall soybean output when duration of sunshine increases. The elasticity associated with Northwest PRC is −0.50, and −0.22 for North PRC, −0.02 for East PRC, −0.01 for South PRC, and −0.02 for Southwest PRC.

VI. Simulation results

Using the estimated elasticities, data on sunshine from Ding *et al.* (2006), and temperature and precipitation data from the CNCC (2009), we can simulate the impacts of climate change on PRC's grain output under three scenarios, namely A2, B1, and A1B emission scenarios[4]. The simulation is based on a model provided by CNCC and results for both 2030 and 2050 are reported in Table IV.

Whereas rice output will decrease by 15.62-24.26 percent in 2030 and 25.95-45.09 percent in 2050, corn output, on the other hand, will increase by 18.59-24.27 percent in 2030 and 32.77-49.58 percent in 2050. Climate change also yield positive impacts on soybean output, ranging from 0.48 to 5.53 percent in 2030 and from 3.96 to 6.48 percent in 2050. The impacts on wheat output, however, are relatively small.

Climate change in North PRC will lead to an increase in the PRC's grain output by 2.85-4.80 percent in 2030 and 5.30-8.49 percent in 2050. Likewise, climate change in Central PRC will increase the country's grain output by 3.53-4.97 percent in 2030 and 8.91-13.43 percent in 2050. The PRC's grain output in 2030 is projected to decrease by 4.10-8.58 percent as a result of climate change in East PRC, by 2.29-4.05 percent in Southwest PRC, and 2.58-2.66 percent in Northeast PRC. Moreover, the impacts of climate change in South and Northwest PRC will have small positive impacts on the country's grain output.

In the following analysis, we will focus on the simulation results of climate change under A2 scenario.

(A) Predicted impact in 2030

The PRC's grain output will decrease by 0.31, 0.32, and 2.69 percent under A2, B1, and A1B emission scenarios, respectively. The simulation results indicate that the impacts of climate change substantially vary among regions and crops. Climate impacts on the PRC's grain output under A2 and B1 scenarios are similar. The following explanations are based on the simulations results under A2 scenario.

Under A2 emission scenario, grain production in North, South, Central, and Northwest PRC will generally benefit from climate change. Climate change in Central and North PRC will increase the country's grain output by 5.06 and 4.8 percent, respectively. The PRC's grain output will also increase as a result of climate change in Northwest and South PRC by 0.89 and 0.26 percent, respectively. However, the country's grain output will fall by 6.43 percent from climate change in East PRC, 2.58 percent from Northwest PRC, and 2.30 percent from Southwest PRC.

Under A2 emission scenario, the PRC's output of wheat will increase by 0.55 percent. Climate change in East and Southwest PRC, however, will lead to reductions in the PRC's wheat production by 1.95 and 1.59 percent, respectively. But climate change in North PRC is projected to increase the country's wheat output by 3.71 percent. The impacts of climate change in the other three regions have small positive impacts on the country's wheat production, ranging from 0.003 to 0.23 percent.

			2030					2050		
	Wheat	Rice	Corn	Soybean	Sum	Wheat	Rice	Corn	Soybean	Sum
Climate scenario for A2 emissions										
Northeast PRC	0.03	−9.15	2.07	10.51	−2.58	0.04	−16.89	4.09	19.55	−4.68
North PRC	3.71	1.02	10.70	3.30	4.80	6.51	1.59	19.21	5.99	8.49
East PRC	−1.95	−11.72	−2.55	−7.56	−6.43	−4.91	−26.51	−5.30	−17.00	−14.51
South PRC	0.00	0.53	0.10	0.09	0.26	0.01	1.08	0.19	0.20	0.52
Central PRC	0.10	0.81	14.27	3.53	5.06	0.25	1.64	30.34	7.64	10.74
Northwest PRC	0.23	0.17	2.38	0.22	0.89	0.48	0.25	3.15	0.49	1.23
Southwest PRC	−1.59	−1.32	−3.66	−4.90	−2.30	−3.38	−2.72	−7.85	−10.39	−4.87
PRC	0.55	−19.65	23.31	5.17	−0.31	−1.01	−41.55	43.83	6.48	−3.09
Climate scenario for B1 emissions										
Northeast PRC	0.03	−8.77	1.53	9.27	−2.66	−0.03	−12.71	2.88	13.51	−3.66
North PRC	2.05	0.62	6.41	2.05	2.85	3.77	1.08	12.04	3.89	5.30
East PRC	−1.04	−7.57	−1.62	−4.94	−4.10	−3.10	−18.22	−3.44	−11.74	−9.85
South PRC	0.00	0.42	−0.09	0.20	0.16	0.00	0.83	−0.17	0.38	0.31
Central PRC	−0.09	0.70	14.66	3.79	5.11	−0.26	1.36	25.49	6.35	8.91
Northwest PRC	0.33	0.07	1.63	0.02	0.62	0.66	0.10	2.68	0.06	1.04
Southwest PRC	−1.59	−1.09	−3.92	−4.86	−2.29	−2.74	−1.99	−6.71	−8.49	−3.97
PRC	−0.31	−15.62	18.59	5.53	−0.32	−1.69	−29.55	32.77	3.96	−1.93
Climate scenario for A1B emissions										
Northeast PRC	0.03	−9.15	2.07	10.51	−2.58	0.05	−17.41	4.11	20.09	−4.86
North PRC	3.71	1.02	10.70	3.30	4.80	6.61	1.64	19.45	6.05	8.61
East PRC	−3.27	−15.73	−2.81	−10.00	−8.58	−5.78	−29.19	−5.47	−18.62	−15.94
South PRC	0.00	0.43	0.17	0.02	0.24	0.01	0.99	0.26	0.13	0.50
Central PRC	0.20	0.86	18.77	4.97	6.60	0.42	1.73	38.21	10.16	13.43
Northwest PRC	0.23	0.17	2.38	0.22	0.89	0.47	0.26	3.32	0.49	1.29
Southwest PRC	−2.90	−1.86	−7.01	−8.53	−4.05	−4.30	−3.10	−10.20	−12.93	−6.10
PRC	−1.98	−24.26	24.27	0.48	−2.69	−2.53	−45.09	49.68	5.37	−3.07

Note: The base year is 2005

Table IV. Simulation results of climate change impacts on the PRC's grain output

The PRC's rice output will, on average, fall by 19.65 percent. Climate change in East PRC and Northeast PRC will decrease the country's rice output by 11.72 and 9.15 percent, respectively. Climate change in Southwest PRC will also result in a 1.32 percent decrease in the PRC's rice output. Again, climate change in North, South, Central, and Northwest PRC will increase the country's rice output by 1.02, 0.53, 0.81, and 0.17 percent, respectively.

The PRC will see an increase of 23.31 percent in corn production under A2 emission scenario. The most significant increase is from Central (14.27 percent) and North PRC (10.70 percent). Climate change in East and Southwest PRC will lead to a decrease in the PRC's corn output by 2.55 and 3.66 percent, respectively.

The country's soybean output will increase by 5.17 percent under A2 emission scenario. Climate change in Northeast PRC will increase the PRC's soybean output by 10.51 percent, in North PRC by 3.30 percent, and in Central PRC by 3.53 percent. Climate change in East and Southwest PRC will, however, decrease the PRC's soybean output by 7.56 and 4.90 percent, respectively.

Under A1B emission scenario, the negative impacts of climate change on the PRC's grain output are larger than those under the other two scenarios. The output of wheat and rice will decrease by 1.98 and 24.26 percent, respectively, while the output of corn and soybean will increase by 24.27 and 0.48 percent, respectively.

(B) Predicted impacts in 2050

The PRC's grain output will fall by 3.09 percent under A2 emission scenario. Under A2 emission scenario, climate change in East, Northeast, and Southwest PRC will decrease the country's grain output by 14.51, 4.68, and 4.87 percent, respectively. Climate changes in Central and North PRC will, respectively, result in 10.74 and 8.49 percent increase in the PRC's grain output.

The country's rice output will fall by 41.55 percent. A decline of 26.52 and 16.89 percent will be due to climate change in East PRC and Northeast PRC, respectively. Wheat output will also decrease by 1.01 percent. Climate change in East and South PRC will decrease the PRC's wheat output by 4.91 and 3.38 percent, respectively, while climate change in North PRC will increase wheat output by 6.51 percent.

Climate change will positively impact on both corn and soybean output. Corn output will increase by 43.83 percent, and the most significant increases will be from Central and North PRC. Northeast and Northwest PRC will likewise contribute to the PRC's corn output increase. However, climate change in East and Southwest PRC will decrease the country's corn output by 5.30 and 7.85 percent, respectively. Furthermore, the PRC's soybean output will increase by 6.48 percent. Soybean production in Northeast, Central, and North PRC will benefit from climate change, resulting in increases in the country's soybean output by 19.55, 7.64, and 5.99 percent, respectively. Climate change in East and Southwest PRC will decrease the PRC's soybean output by 17.00 and 10.39 percent, respectively.

Climate change will decrease the PRC's grain output by 1.93 percent under B1 emission scenario and by 3.07 percent under A1B emission scenario.

VII. Concluding remarks

In this paper, we investigate the impacts of climate change on the PRC's grain output using rural household survey data. We highlight the regional differences of climate change impacts on different grain crops. Econometrical models were estimated to obtain elasticities (with respect to climate change) associated with different grain crops across different regions. Our results indicate that the overall negative climate change impacts on the PRC's grain output range from −0.31 to −2.69 percent in 2030 and from −1.93 to −3.07 percent in 2050 under different emission scenarios. However, climate change has substantially varying impacts on different grain crops in different regions.

Rice output will decrease by 15.62-24.26 percent in 2030 and 25.95-45.09 percent in 2050. Corn output will increase by 18.59-24.27 percent in 2030 and 32.77-49.58 percent in 2050. The positive impacts of climate change on soybean output range from 0.48 to 5.53 percent in 2030, and from 3.96 to 6.48 percent in 2050. The impacts on wheat output are relatively small.

Climate change in North PRC will lead to an increase in the country's grain output by 2.85-4.80 percent in 2030 and 5.30-8.49 percent in 2050. Climate change in Central PRC will increase the PRC's grain output by 3.53-4.97 percent in 2030 and 8.91-13.43 percent in 2050. The country's grain output in 2030 is predicted to decrease by 4.10-8.58 percent as a result of climate change in East PRC, by 2.29-4.05 percent from Southwest PRC, and 2.58-2.66 percent from Northeast PRC. The impacts of climate change in South and Northwest PRC have small positive effects on the PRC's grain output.

The Chinese national and provincial governments, therefore, need to fight the adverse impacts of climate change in heavily affected regions and grain crops. Moreover, the substantial regional differences imply further changes in agricultural inter-regional trade patterns. This will in turn generate demand for changes in transportation arrangements and related infrastructure. If grain transportation, storage and handling facilities could not be adjusted to meet these changes, agricultural prices may rise sharply in those regions with significant decline in agricultural output and fall sharply in those regions with significant increases in agricultural output. These will have negative impacts on local food security and social welfare and may very likely affect millions of farmers and consumers livelihood. Non-agricultural sectors will also be negatively affected since the linkages between agricultural and non-agricultural sectors are becoming much closer.

Notes

1. Please refer to Zhang and Xin (2010) for a comprehensive survey on climate change and China's agriculture.
2. For a more detailed and comprehensive discussions about the limitations of applying the Ricardian model to PRC's agricultural analysis please refer to Zhang (2010).
3. Grain prices are not explicitly included into the production functions. The impacts of grain prices on production are implicitly captured via production input factors.
4. The IPCC developed four different narrative storylines to cover a wide range of the main demographic, economic and technological driving forces of future greenhouse gas and sulphur emissions. The A2 storyline and scenario family describes a very heterogeneous world while the B1 storyline and scenario family describes a convergent world. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies). Please refer to IPCC (2010) for details.

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