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Working Paper

Impacts of Climate Change on the People's Republic of China's Grain Output - Regional and Crop Perspective

ADB Economics Working Paper Series, No. 243

Provided in Cooperation with:
Asian Development Bank (ADB), Manila

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ADB Economics Working Paper Series

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No. 243 | January 2011

Asian Development Bank

ADB

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January 2011

Tun Lin is Natural Resources Economist, East Asia Department, Asian Development Bank. Xiaoyun Liu is Professor at the China Agricultural University. Guanghua Wan is Principal Economist in the Economics and Research Department, Asian Development Bank (ADB). Xian Xin is Professor at the China Agricultural University. Yongsheng Zhang is Professor at the Development Research Center, People's Republic of China. The authors thank Jing Cui and Yongwei Cui for their assistance in data processing, and the Research Center for the Rural Economy at the Ministry of Agriculture for providing the rural household survey data. Helpful comments from participants in various group discussions organized by the Asian Development Bank (ADB) are also fully appreciated. This paper is part of the research work funded by ADB (Project Number: 43068). The authors accept responsibility for any errors in the paper.

Asian Development Bank

Asian Development Bank
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org/economics

January 2011
ISSN 1655-5252
Publication Stock No. WPS113172

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Contents

Abstract

This paper investigates the impacts of climate change on the People's Republic of China's (PRC) grain output using rural household survey data. We highlight the regional differences of impacts by estimating output elasticities for different grain crops and different regions. Our results indicate that the overall negative climate impacts on the PRC's grain output range from –0.31% to –2.69% in 2030, and from –1.93% to –3.07% in 2050, under different emission scenarios. The impacts, however, differ substantially for different grain crops and different regions. From the perspective of grain crops, for example, modeling results suggest a decrease in rice output by 15.62%–24.26% in 2030 and by 25.95%–45.09% in 2050. Conversely, positive impacts of climate change are reported for both corn and soybean, with corn output increasing by 18.59%–24.27% in 2030 and 32.77%–49.58% in 2050, and soybean output increasing by 0.48%–5.53% in 2030 and 3.96%–6.48% in 2050. The impacts on wheat output are relatively small. Looking at the regional perspective, modeling results reveal that the impacts of climate change in the northern and central regions of the PRC are positive. Specifically, climate change in Northern PRC is calculated to increase the country's grain output by 2.85%–4.80% in 2030, and 5.30%–8.49% in 2050; while in Central PRC the increases will be 3.53%–4.97% in 2030, and 8.91%–13.43% in 2050. Climate change in South PRC and Northwest PRC is projected to have small positive impacts on the country's grain output. On the other hand, the impacts of climate change are negative in the remaining regions, with reductions in 2030 of 4.10%–8.58% in East PRC, 2.29%–4.05% in Southwest PRC, and 2.58%–2.66% in Northeast PRC.

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 to 5.0°C within the 21st century (Darwin et al. 1995). The China National Climate Center (CNCC 2009) projects that the People's Republic of China's (PRC) temperature will rise by less than 2.5°C by the end of the 21st 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%, wheat by 3.97%, and other grains by 1.39%. Tsigas et al. (1997) suggest that climate change will lead to a 3% increase in the country's crop production with carbon dioxide (CO_2) fertilization and a decrease by 17% 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%. Zhai et al. (2009) find that the PRC's rice output will fall by 0.5%, wheat will increase by 4.2%, and other grains will fall by 0.5%.[1]

Previous studies are limited in terms of methodology or data, which may have contributed to the wide range of results: (i) most of these studies do not disaggregate the PRC into regions and ignore the substantial regional differences; (ii) most of these studies do not disaggregate the PRC's crop sector into different crops and ignore the significant differences among crops; (iii) 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 (iv) the agricultural production and socioeconomic data required for impact studies are difficult to obtain—only a few studies (see Liu et al. 2004, Wang et al. 2009) were able to obtain a large national data set, but dated about 10 years back. While ignoring regional and crop

1 Zhang and Xin (2010) provide a comprehensive survey on climate change and the PRC's agriculture.

2 For a more detailed and comprehensive discussions about the limitations of applying the Ricardian model to the PRC's agricultural analysis, see Zhang (2010).

differences prevents us from understanding the real impacts of climate change on the PRC's grain production, using models with unrealistic underlying assumptions and dated data sets 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 household information. We focus on four major grain crops—wheat, rice, corn, and soybean—which all together account for 93% of the PRC's grain output (National Bureau of Statistics of China 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 the Ricardian approach that involves perfect competitive land market assumption (which is obviously not the case in rural areas of the 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 markets.

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 the 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 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 climate change in the PRC are emerging (see, for example, Fischer et al. 2001, 2002, 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's 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) 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 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 northern 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 crop growth in the southern part.

The second approach, AEZ analysis, assigns particular crops to certain agroecological zones, and then estimates 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 change.

Albersen et al. (2000 and 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 that 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 rainfed 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 adaptation by farmers. Both crop simulation and AEZ 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 the PRC today (see Zhang 2010 for a discussion).

The last approach is general equilibrium models. Unlike the previous three approaches that only study the agriculture sector alone (i.e., "partial equilibrium models"), the general equilibrium models incorporate the interactions between different sectors. The argument is that climate change may affect the agriculture 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, with the latter examining the direct impacts and the former providing 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 is a wide range of impact estimates of climate change on the PRC's agriculture. Many of these estimates are different and some are of opposite signs, partly attributable to different models and data sets used in the studies. Four out of five AEZ models, for example, predict increases in cereal production potential in the range of 5%–23% (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, using the Ricardian approaches, Liu et al. (2004) found that warming would have a positive impact on agricultural production, while Wang et al. (2009) show the opposite. The latter 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 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 a production function to investigate the responses of grain output to climate variables as well as other traditional input variables. The use of the 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 change significantly differ among regions and crops. These in turn imply substantial changes in interregional trade flows, which we will analyze using a computable general equilibrium model in another paper (Lin et al. 2011).

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, household head characteristics, community characteristics, regional dummies, interaction terms of climate variables, and regional dummies.[3]

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

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

[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.

model differs from Wang et al. (2009) in that (i) we include one more climate indicator, sunshine accumulated hours, which is missing in Wang et al. (2009) and most existing literature; (ii) our model includes interaction terms of climate variables and regional dummies to catch regional differences; (iii) we use crop output instead of crop net revenue as a dependent variable, which allows us to examine the impacts of climate change on different crops. The empirical model takes a similar linear form as in Wang et al. (2009).

IV. Data

Rural household survey data for 2003, 2005, and 2008 are used. These surveys were conducted by the Research Center for the Rural Economy at the Ministry of Agriculture. These surveys include information on rural villages and rural households. The village questionnaire includes information on location, terrain, 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, housing, etc. Our data set covers 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 1.

Table 1: Descriptive Statistics of Variables (Mean)

	Wheat	Rice	Corn	Soybean
Grain output (kg)	1301.437	2054.410	1992.502	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 (mu)	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)	6346.782	4746.642	7773.242	6279.467
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	6707	7418.	10264	4995

°C = degrees Celsius, kg = kilogram, mm = millimeter, mu = 1/15 hectare.

Sources: Results calculated using rural household survey data (2003, 2005, 2008) collected by the Research Center for the Rural Economy at the Ministry of Agriculture; and climate data from the National Metrological Information Center.

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 2. They suggest that all the three climate variables—temperature, rainfall, and sunshine—have significant impacts on wheat, rice, corn, and 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 the 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 systems could increase the output of wheat, rice, and soybean. More specifically, a CNY1 increase in irrigation could increase wheat output by 0.643 kilograms (kg), rice by 2.926 kg, and soybean by 1.286kg. 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.

Table 2: Regression Results of Climate Impacts on Grain Output (2003, 2005, 2008)

	Wheat		Rice		Corn		Soybean	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
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
Spring temperature *Northeast PRC			-946.302***	238.053	726.404***	127.797	-267.979***	68.613
Spring temperature *North PRC	469.935***	88.280			340.262*	199.824	2792.477	2321.715
Spring temperature *East PRC	1034.242*	573.001	-1721.516***	380.010	1983.896	3128.696	102.680	181.336
Spring temperature *South PRC			-423.023	380.902			0.020	197.420
Spring temperature *Central PRC	438.365***	90.394	-525.170*	306.048	-496.320***	198.292	30.311	140.245
Spring temperature *Northwest PRC	230.344***	65.669	-261.963	1449.498	-450.374***	154.996	142.259	104.032
Spring temperature *Southwest PRC	563.326***	181.067	-657.518*	350.092	180.095	309.694	116.094	172.637
Spring precipitation *Northeast PRC			46.065***	8.030	-27.187***	6.323	-14.946***	3.101
Spring precipitation *North PRC	-3.971	5.224	-210.288**	107.224	27.364***	7.626	-411.807***	132.988
Spring precipitation *East PRC	-67.010	62.431	-40.250*	23.675	-171.068	277.211	-14.087	17.094
Spring precipitation *South PRC	94.257***	15.673	-3.999	3.702	-111.440**	57.148	2.745	3.829
Spring precipitation *Central PRC	-2.939	2.458	-5.995**	2.771	7.755	5.834	2.350	1.787
Spring precipitation *Northwest PRC	-18.676***	3.206	-26.066	217.979	-3.078	9.212	27.062***	7.010
Spring precipitation *Southwest PRC	-0.911	3.368	-10.091***	2.384	10.603*	6.489	2.976	2.164
Spring sunshine *Northeast PRC	4.746	5.423	67.654***	12.575	100.436***	11.565	-21.749***	5.483
Spring sunshine *North PRC	-3.004	4.830	-12.991	59.229	91.370***	11.161	66.511**	27.839
Spring sunshine *East PRC	-70.513	72.787	91.412***	20.837	-92.749	276.275	0.384	10.183
Spring sunshine *South PRC	68.485***	15.001	-5.260	8.439	-113.844*	64.003	3.386	7.227
Spring sunshine *Central PRC	15.766***	4.546	-10.388	9.045	89.629***	9.603	3.447	5.099
Spring sunshine *Northwest PRC	-18.281***	5.610	8.334	20.189	112.412***	12.919	1.134	6.156
Spring sunshine *Southwest PRC	-11.940	7.551	-15.521**	6.619	49.293***	8.561	-2.134	3.540
Summer temperature *Northeast PRC			-3583.301***	611.495	1812.015***	449.368	819.328***	224.907
Summer temperature *North PRC	-966.136***	184.909			3912.778***	490.577	-2029.388	1486.366
Summer temperature *East PRC	-403.123	1195.657	-3541.273***	788.436	-1234.281	1741.104	7.909	478.566
Summer temperature *South PRC			-1789.542***	541.241			356.504	437.945
Summer temperature *Central PRC	-815.389***	177.964	-1671.724***	477.083	3427.367***	503.668	194.549	251.130
Summer temperature *Northwest PRC	-872.933***	134.322	-867.468	2757.800	2036.800***	412.511	277.957	190.282
Summer temperature *Southwest PRC	-841.687***	162.738	-2271.405***	420.154	2530.673***	453.337	197.192	218.945
Summer precipitation *Northeast PRC			63.015***	4.796	-21.975***	3.878	-11.112***	1.551
Summer precipitation *North PRC	-3.329	2.122	105.377	107.580	0.695	4.363	204.259***	67.733
Summer precipitation *East PRC	10.696	11.888	-6.658	6.617	128.338	119.242	3.759	5.088
Summer precipitation *South PRC			-1.671	5.094	30.808*	17.073	0.067	4.846
Summer precipitation *Central PRC	5.287**	2.202	-7.404***	2.490	6.870	4.624	1.548	1.583
Summer precipitation *Northwest PRC	0.226	1.431	10.053	91.066	-18.182***	4.707	4.627*	2.731
Summer precipitation *Southwest PRC	1.902	2.466	-2.626	2.623	9.514**	4.898	2.005	1.782

continued.

Table 2: *continued.*

	Wheat		Rice		Corn		Soybean	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Summer sunshine *Northeast PRC			123.039***	13.996	-43.319***	11.556	-4.418	4.481
Summer sunshine *North PRC	-24.394***	7.238			-79.405***	13.312	-89.419**	37.713
Summer sunshine *East PRC	16.699	33.973	26.424	19.925	423.623	397.013	22.996*	14.107
Summer sunshine *South PRC	-112.229***	20.375	31.654**	15.961	66.423	52.213	8.179	19.633
Summer sunshine *Central PRC	-22.482***	4.687	9.162	9.655	-42.741***	9.994	9.043***	3.657
Summer sunshine *Northwest PRC	-28.057***	8.280	21.221	40.872	-54.291***	15.707	14.950***	5.473
Summer sunshine *Southwest PRC	-14.097***	4.828	37.108***	6.909	-24.767**	10.965	9.883***	3.923
Fall temperature *Northeast PRC			1482.890***	369.723	-421.548***	153.460	-189.411**	89.972
Fall temperature *North PRC	540.199***	115.561			-1500.803***	214.796	110.744	841.344
Fall temperature *East PRC	-920.621	1889.283	-715.974	861.462			-485.082	540.004
Fall temperature *South PRC			1187.217***	421.563			-185.449	296.731
Fall temperature *Central PRC	64.598	172.332	1237.302***	325.456	-1123.622***	294.128	-118.129	160.620
Fall temperature *Northwest PRC	561.457***	120.461	-908.565	1362.229	-130.269	234.475	-244.656*	127.510
Fall temperature *Southwest PRC	66.116	233.785	1554.027***	386.296	-1679.508***	390.702	-210.936	198.481
Fall precipitation *Northeast PRC			-32.101***	9.570	-24.712***	5.872	1.240	2.430
Fall precipitation *North PRC	4.310***	1.258	-96.233	101.131	9.373***	2.562	-138.948***	43.856
Fall precipitation *East PRC	-6.793	8.262	-16.124*	8.911	-178.818	186.016	-4.510	5.431
Fall precipitation *South PRC	31.327***	4.516	3.583	2.361	-72.133***	21.352	0.184	3.814
Fall precipitation *Central PRC	-0.030	0.247	-0.568	0.777	-0.270	0.840	0.029	0.268
Fall precipitation *Northwest PRC	-3.613***	1.262	-2.719	36.724	20.081***	4.567	-2.475	2.204
Fall precipitation *Southwest PRC	1.499	1.296	-2.305*	1.349	-0.859	2.748	0.099	0.920
Fall sunshine *Northeast PRC			-30.949*	16.417	-40.664***	15.148	-34.635***	7.739
Fall sunshine *North PRC	2.413	7.203	49.818	114.227	-34.182**	15.802	-83.188**	35.192
Fall sunshine *East PRC	-44.528	78.913	80.771***	29.410	-54.187	160.349	-12.129	16.221
Fall sunshine *South PRC			8.372	9.469	71.179	116.482	-16.287	11.948
Fall sunshine *Central PRC	1.806	4.857	19.450***	7.505	-40.392***	11.457	-14.904**	6.207
Fall sunshine *Northwest PRC	4.798	6.252	49.252	72.972	-38.983***	14.403	-17.551**	7.513
Fall sunshine *Southwest PRC	6.962	4.361	0.759	5.128	-20.150**	8.325	-11.674***	4.260
Winter temperature *Northeast PRC			25.858	225.988	131.735	83.403	47.891	45.580
Winter temperature *North PRC	-201.214***	57.847			-525.785***	121.667	-1550.905	1244.342
Winter temperature *East PRC	-594.606	1026.965	2674.854***	632.036	264.684	3751.658	240.159	414.006
Winter temperature *South PRC			-289.174*	174.373			-17.892	203.598
Winter temperature *Central PRC	159.820***	44.094	-404.898***	106.512	168.099***	65.403	94.732***	34.876
Winter temperature *Northwest PRC	-189.388***	27.596	1003.705	917.979	207.245***	70.768	-6.752	43.437
Winter temperature *Southwest PRC	-2.825	57.431	-80.298	73.080	-237.912***	63.894	-24.757	30.862
Winter precipitation *Northeast PRC			-269.813***	45.722	233.221***	46.200	109.281***	21.021
Winter precipitation *North PRC	49.236***	16.511			236.325***	38.363	70.040	362.555
Winter precipitation *East PRC	54.236	85.026	-80.783**	40.001	-322.923	319.923	-13.677	19.348
Winter precipitation *South PRC			1.080	11.481	303.423***	104.636	-6.201	11.356
Winter precipitation *Central PRC	-7.109*	4.223	8.052	7.013	-51.139***	10.027	-8.148**	4.019
Winter precipitation *Northwest PRC	-11.639	7.434	277.012	663.888	-53.741***	20.877	8.077	14.974
Winter precipitation *Southwest PRC	-8.172	7.174	-8.577	6.727	-21.866**	9.853	-4.519	3.804
Winter sunshine *Northeast PRC			43.401**	19.026	-46.031***	14.353	34.919***	5.928
Winter sunshine *North PRC	-20.686***	3.641	-26.626	30.555	4.453	10.762	-76.828*	40.109
Winter sunshine *East PRC	21.547	50.876	-181.116***	45.743	-149.703	200.952	-22.284	25.933

continued.

Table 2: *continued.*

	Wheat		Rice		Corn		Soybean	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Winter sunshine *South PRC			24.072***	8.209	-65.677	72.816	-7.091	6.792
Winter sunshine *Central PRC	-29.235***	3.258	14.792*	7.709	-6.626	8.825	-5.564	3.903
Winter sunshine *Northwest PRC	-26.789***	3.636	50.421*	21.557	-1.448	11.226	-6.997	5.476
Winter sunshine *Southwest PRC	-14.455**	5.952	11.104*	4.612	-25.743***	5.673	-2.174	3.107
Spring temperature squared	-10.729***	2.754	12.018	8.939	11.115*	6.227	-1.857	4.168
Spring precipitation squared	0.031***	0.013	0.035***	0.007	-0.026	0.029	-0.012	0.008
Spring sunshine squared	-0.010	0.011	0.036	0.023	-0.223***	0.024	-0.001	0.011
Summer temperature squared	15.144***	3.244	41.011***	8.154	-52.901***	9.565	-4.677	4.586
Summer precipitation squared	-0.004	0.006	0.011*	0.006	-0.021*	0.012	-0.005	0.004
Summer sunshine squared	0.068***	0.016	-0.080***	0.021	0.103***	0.029	-0.029***	0.011
Fall temperature squared	-8.255*	4.867	-34.571***	9.003	24.036***	8.000	4.193	4.533
Fall precipitation squared	0.000	0.000	0.000	0.001	0.000	0.001	-0.000	0.000
Fall sunshine squared	-0.014	0.016	-0.036**	0.018	0.139***	0.036	0.058***	0.020
Winter temperature squared	-2.606**	1.198	10.536**	4.903	16.197***	2.788	1.151	1.606
Winter precipitation squared	0.066	0.047	0.009	0.059	0.535***	0.110	0.067*	0.039
Winter sunshine 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 household head	1.396	1.941	-0.772	4.727	-23.008***	5.587	1.648	2.136
Agricultural training of household head	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
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	1543.548***	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 irrigated field in dry field	114.098***	17.636	-19.915	69.359	-18.978	53.637	29.999	26.012
Northeast PRC			32857.170***	11043.200	-34785.400***	10626.390	-7818.184*	4579.159
North PRC	17732.240***	3671.695			-79137.540***	11416.320	31138.010*	17377.620
East PRC	29131.580	72927.600	127554.000***	34087.300			7896.535	21338.690
South PRC			28678.710*	16999.620			-5037.681	13175.740
Central PRC	17753.760***	3239.552	30822.150**	12761.460	-60592.870***	11319.150	-3725.352	5059.124
Northwest PRC	23779.330***	2751.485	17833.490	40004.980	-42545.390***	9976.377	-6741.694	4416.977
Southwest PRC	17521.240***	2893.737	41434.110***	12075.930	-37156.370***	10412.080	-3691.609	4608.416
Constant	-8969.009***	1641.108	-20989.740***	6525.081	22287.360***	6261.563	2871.019	2702.164
Number of observations	6707		7418.		10264		4995	
Adjusted R-squared	0.876		0.842		0.757		0.749	

*** significant at 1%; ** significant at 5%; * significant at 10%.
Source: Authors' regression results.

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, 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 3.

Table 3: Elasticity of Output with Respect to Climate Variables

	Wheat						Rice					
	Spring	Summer	Fall	Winter	Region	Weighted	Spring	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 3: *continued.*

	Corn						Soybean					
	Spring	**Summer**	**Fall**	**Winter**	**Region**	**Weighted**	**Spring**	**Summer**	**Fall**	**Winter**	**Region**	**Weighted**
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

Note: National elasticities are calculated using regional mean, and overall PRC impacts are weighted by regional share.
Source: Authors' regression results.

A. Elasticities Associated with Climate Variables in Wheat Production

1. 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 PRC 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% 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% 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 PRC 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% 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 the PRC's overall wheat production.

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

2. 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% increase in precipitation will increase the country's wheat production by 0.66%.

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% 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% of the country's wheat, and its weighted elasticity reached 0.58. This means that North PRC accounts for 90% 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% 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 PRC and Northwest PRC 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.

3. 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% increase of duration of sunshine will result in 0.38% decrease in wheat production.

Given a 1% increase of sunshine hours, regional wheat output will decrease by 5.02% in East PRC, 2.04% in Northwest PRC, and 1.1% 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

1. 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% 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.

2. 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.

3. 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% increase of sunshine duration will increase the country's rice output by 0.59%.

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, although their combined impacts are small.

C. Elasticities Associated with Climate Variables in Corn Production

1. 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% change in temperature will result in a 3.14% increase in the country's corn output.

Central PRC, producing 18% 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% 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% 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% 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% of the country's corn, and their impacts on the country's overall corn output are small. Southwest PRC, though, produces 12% of the PRC's corn, and its weighted elasticity is estimated at –1.16.

2. 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.

3. 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 PRC 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

1. 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 PRC and Southwest PRC, respectively accounting for 7% and 12% 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 two major soybean-producing regions—Northeast PRC and Central PRC, producing 33% and 21% of the country's soybean output, respectively—will benefit from climate warming. Regional elasticities associated with Northeast PRC 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 PRC and South PRC will also benefit from rising temperatures. The weighted elasticity associated with these two regions is 0.14, which means that climate warming in these regions will have small impacts on the country's overall soybean output.

2. 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 PRC 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.

3. 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 PRC 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 China National Climate Center (CNCC 2009), we can simulate the impacts of climate change on the 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 4.

Whereas rice output will decrease by 15.62%–24.26% in 2030 and 25.95%–45.09% in 2050, corn output, on the other hand, will increase by 18.59%–24.27% in 2030 and 32.77%–49.58% in 2050. Climate change also yields positive impacts on soybean output, ranging from 0.48% to 5.53% in 2030, and from 3.96% to 6.48% 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% in 2030 and 5.30%–8.49% in 2050. Likewise, climate change in Central PRC will increase the country's grain output by 3.53%–4.97% in 2030 and 8.91%–13.43% in 2050. The PRC's grain output in 2030 is projected to decrease by 4.10%–8.58% as a result of climate change in East PRC, by 2.29%–4.05% in Southwest PRC, and 2.58%–2.66% 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 Impacts in 2030

The PRC's grain output will decrease by 0.31%, 0.32%, and 2.69% 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

[4] The Intergovernmental Panel on Climate Change 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 midcentury and declines thereafter, and rapid introduction of new and more efficient technologies. The three A1 groups are distinguished by their technological emphasis: fossil-intensive (A1FI), nonfossil 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). See IPCC (2010) for details.

PRC will increase the country's grain output by 5.06% and 4.8%, respectively. The PRC's grain output will also increase as a result of climate change in Northwest PRC and South PRC by 0.89% and 0.26%, respectively. However, the country's grain output will fall by 6.43% from climate change in East PRC, 2.58% in Northwest PRC, and 2.30% in Southwest PRC.

Under A2 emission scenario, the PRC's output of wheat will increase by 0.55%. Climate change in East and Southwest PRC, however, will lead to reductions in the PRC's wheat production by 1.95% and 1.59%, respectively. But climate change in North PRC is projected to increase the country's wheat output by 3.71%. 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%.

The PRC's rice output will, on average, fall by 19.65%. Climate change in East PRC and Northeast PRC will decrease the country's rice output by 11.72% and 9.15%, respectively. Climate change in Southwest PRC will also result in a 1.32% 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%, respectively.

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

The country's soybean output will increase by 5.17% under A2 emission scenario. Climate change in Northeast PRC will increase the PRC's soybean output by 10.51%, in North PRC by 3.30%, and in Central PRC by 3.53%. Climate change in East and Southwest PRC will, however, decrease the PRC's soybean output by 7.56% and 4.90%, 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%, respectively, while the output of corn and soybean will increase by 24.27% and 0.48%, respectively.

B. Predicted Impacts in 2050

The PRC's grain output will fall by 3.09% under the A2 emission scenario. Under the 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%, respectively. Climate changes in Central and North PRC will respectively result in 10.74% and 8.49% increase in the PRC's grain output.

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

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

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

Table 4: Simulation Results of Climate Change Impacts on the PRC's Grain Output

	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.
Source: Authors' regression results.

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. Econometric 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% in 2030 and from –1.93% to –3.07% 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% in 2030 and 25.95%–45.09% in 2050. Corn output will increase by 18.59%–24.27% in 2030 and 32.77%–49.58% in 2050. The positive impacts of climate change on soybean output range from 0.48% to 5.53% in 2030, and from 3.96% to 6.48% 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% in 2030 and 5.30%–8.49% in 2050. Climate change in Central PRC will increase the PRC's grain output by 3.53%–4.97% in 2030 and 8.91%–13.43% in 2050. The country's grain output in 2030 is predicted to decrease by 4.10%–8.58% as a result of climate change in East PRC, by 2.29%–4.05% in Southwest PRC, and 2.58%–2.66% in Northeast PRC. The impacts of climate change in South PRC and Northwest PRC have small positive effects on the PRC's grain output.

The 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 interregional 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. Nonagriculture sectors will also be negatively affected since the linkages between agriculture and nonagriculture sectors are becoming much closer.

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About the Paper

Tun Lin, Xiaoyun Liu, Guanghua Wan, Xian Xin, and Yongsheng Zhang investigate the impacts of climate change on the People's Republic of China's (PRC) grain output using rural household survey data. The results indicate that the overall negative climate impacts on the PRC's grain output range from –0.31% to –2.69% in 2030, and from –1.93% to –3.07% in 2050, under different emission scenarios. The impacts, however, differ substantially for different grain crops and different regions.

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Asian Development Bank
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org/economics
ISSN: 1655-5252
Publication Stock No. WPS113172

<0113 1727>

Printed in the Philippines