Impact of Climate Change on Agricultural Economy and Role of International Trade in China

Abstract

1. Introduction

Agriculture is an important sector to China, feeding its over 1.3 billion populations, however, it is threatened by the production damage caused by climate change. Economic studies of the impact of climate change on agriculture have been included in. A limitation of these efforts was that they focused on domestic agricultural impacts and did not consider the effects of climate change on world production and markets. China has become net importer of agriculture products, importing more than 80 million tones maize in 2016. The fluctuation of international price and trade will significantly impact China's domestic balance of agriculture economy, and the impacts of climate change on agriculture.

Though previous studies have investigated the impacts of climate change in China, however, it is a vein of an integrated assessment of climate impacts on agricultural economy. Most previous studies solely examined one or two crops, mainly for cereal and soybean, and few of them concentrated on climate impacts on sugar, cotton and the indirect impacts on livestock productions. Few studies have investigated climate change impacts under different RCP scenarios from IPCC AR5 reports. Moreover, studies based on crop simulation models and econometric analysis seldom considered the mitigation capability of the economic system to climate change through adjusting price, demand, and trade. Though some global assessments based on PE or CGE models had examined climate change impacts on China's agriculture, unfortunately, their direct impacts of climate change on agriculture were usually arbitrary and lack of empirical research base.

Previous studies based on CGE or PE models always accepted a small country assumption, that export prices are fixed. However, the assumption is infeasible for China, a country with large agricultural trade. China's agricultural export and import have significantly affected global agricultural price, vice versa. Unfortunately, few of climate change studies have investigated the role of international trade on assessing climate change impacts on China's agricultural economy. Reilly and Hohmann (1993) initially using a comparative static analysis suggested interregional adjustments in production and consumption will serve to buffer the severity of climate change impacts on world agriculture. However, they simply used experiments assuming crop yield change without considering virtual situation.

Based on the discussion above, the overall goal of this paper is to assess climate change on China's agriculture economy (production, trade, and self-sufficiency), and role of international trade in assessing climate change. Specifically, three research issues will be addressed in this study. 1) How climate change impacts agricultural production, demand and trade under IPCC RCP scenarios in the future? 2) Whether the economic system has capacity to effectively mitigate crop loss caused by climate change through adjusting price, demand, and production? 3) How climate change impacts agricultural economy under international trade?

To address the issues mentioned above, the climate change impacts on China's agricultural economy without and with international trade are assessed based on a widely-used agricultural partial equilibrium model, CAPSiM, and its linkage model with GTAP model. The climate change impacts in this paper are examined during 2020-2050 under IPCC RCP scenarios. The results in this paper show that climate change only has slight adverse effects on agriculture production without consideration of international trade. Even under the most severe climate change scenario, RCP 8.5, wheat production will decline less than 13% by 2050, which is the biggest production loss among crops. Our results also suggest some evidence of the mitigation capability to climate change damage in the economic system by rising domestic price, increasing farming input, and adjusting production structure. International trade will provide some mitigation capability to climate change damage to China, reducing partly crop production loss due to climate change. Our results have important policy implications for future climate change assessment and making national mitigation plans.

Section 2 introduces climate change and its direct impacts on crop yield in China and the rest of world. Section 3 briefly describe the simulation methodology and reference scenario. Section 4 shows the results for climate change impacts on agriculture economy with and without international trade. Section 5 concludes this paper with some policy implications.

2. Impact of climate change on crop yield in China and the rest of world

The trend of temperature and precipitation is obtained from Yan et al. (2016), based on the RCP pathway of IPCC AR5 report (IPCC, 2014). The most and least severe scenario, RCP 8.5 and RCP 2.6 are respectively investigated in this paper. In Yan et al. (2016), global circulation models, provided by CMIP5, are applied to calculate in monthly temperature and precipitation from 2010-2100 in each province. Then for each crop, we calculated both annual average and deviation of temperature and precipitation respectively in its growth season. The plants studied in this paper includes rice, wheat, maize, soybean, cotton, rapeseed, peanut, cane and sugar beet. Consistent with crop sectors in the CAPSiM, oilseed is obtained by aggregating rapeseed and peanut by harvest area in 2015, and sugar is obtained by aggregating cane and sugar beet using the same method. In Figure 1, each crop's annual average temperature and precipitation are all projected to increase significantly in 2020-2050, compared to 2010, however, only annual precipitation deviation increase significantly for each crop.

Then annual yield change for each plant is calculated from a unique econometric estimation by Wang et al. (2016). Compared to crop simulation model, econometric estimation has theoretical advantages by examines the real change of farmers' production behavior in response to climate change. Wang et al. (2016) used a provincial panel data in China and estimated the impacts on different crop yield of annual temperature, precipitation and their deviation in growth period (Appendix Table 1-2). They finally captured a nonlinear correlation between climate variable and crop yield. Then we calculate annual yield change of each plant using projected climate variables from 2010-2050 and the equation (1) derived from the econometric model in Wang et al. (2016).

$$\ln(Y_t) = \widehat{\beta_1} * T_t + \widehat{\beta_2} * {T_t}^2 + \widehat{\beta_3} * P_t + \widehat{\beta_4} * {P_t}^2 + \widehat{\beta_5} * SDT_t + \widehat{\beta_6} * SDP_t \qquad (1)$$

Y is the annual yield of each harvest. T and P are annual temperature and precipitation in the growth period. SDT and SDP are annual standard deviation of temperature and precipitation in growth period respectively. $\hat{\beta}$s are estimated coefficients in Wang et al. (2016). Differentiated the equation (1), we will obtain the growth rate of crop yield in response to climate change.

Climate change impacts on yield are different among crops. Wheat, rice, sugar and cotton will experience more severe negative yield loss under RCP 8.5 than 2.6; other plants may benefit from climate change, with soybean gaining the most significant yield increase. Wheat has the most severe yield loss caused by climate change, and its yield will decline by more than 20% by 2050 even under the RCP 8.5; the yield loss will be about 13% by 2050 under the RCP 2.6. Rice, sugar, and cotton also will experience yield loss but smaller than wheat. On the other hand, under RCP 8.5, soybean will have a yield increase about 0.6% by 2030, and 1% by 2050.

The climate change impacts on crop yield are from the IFPRI assessment. The crops in IFPRI assessment included wheat, maize, rice and soybean, and 14 GT in Table 2. They estimated the yield change of these crops due to climate change in 2010-2050 with base year 2010. In Table 2, climate change was projected to bring different yield change for various crops in the rest of world under RCP 2.6 and 8.5. Most countries will have annual averaged yield loss in response to climate change for cereal and soybean. USA, Argentina and Brazil as the main exporters for maize and soybean will have yield loss by 2050, with annual average decrease of maize yield more than 0.4% for USA and Brazil and 0.2% for Argentina, and the soybean yield loss more than 0.3% for Brazil, and more than 0.15% for USA and Argentina. The supply of these crops, the biggest imports in China, will be threatened due to climate change, and their international price also will be effected significantly. We can also find that Canada will have yield benefit from climate change both for maize and soybean by 2050. For rice and wheat, most countries were found negative impacts of climate change on yield by 2050. Australia and New Zealand have the biggest wheat yield loss (-0.40% p.a.), and USA have the biggest rice yield loss (-0.27% p.a.). At the same time, Japan and European Union will benefit from climate change both for rice and wheat under RCP 8.5.

Though we could compare the climate change impacts on crop yield in China and the rest of world mentioned above, however, several important issues are still neglected as following: 1) autonomous mitigation capability to climate change loss in economy system through adjusting the price, trade, and demand; 2) concerns on agriculture price, trade, and food security; 3) how climate change impacts agricultural economy under international trade. It is necessary to use agriculture partial equilibrium model (PE) or computable general equilibrium model (CGE) to simulate climate change impacts on agricultural economy with and without considering international trade.

3. Simulation methodology

To meet our goals of tracking the effects of climate change on agricultural economy and their uncertainty, we have chosen to use a partial equilibrium model, CAPSiM (China's Agricultural Policy Simulation Model). CAPSiM was developed at the CCAP in the mid-1990s as a framework for analyzing policies affecting agricultural production, consumption, prices, and trade in China (Huang and Li, 2003). Since then, CAPSiM has been periodically updated and expanded. Recent versions of CAPSiM are designed to track changes in policies, including trade liberalization, on both national and households by region (Huang et al., 2009). In CAPSiM the component crops/commodities are more disaggregated and accounting for more than 90% of China’s agricultural output. The model can analyze 21 crops, livestock and fishery goods: including four main cereal sectors, sweet potato, potato, soybean, other edible oil crops, cotton, vegetables, fruit, other crops and six livestock products and three fishery sectors.

Then to understand the impacts of climate change on agricultural economy under the international trade, we use two models, the Global Trade Analysis Program (GTAP) and the Chinese Agricultural Policy Simulation and Projection Model (CAPSiM). GTAP is a well-known multi-country, multi-sector computable general equilibrium model and is often used for international trade analysis (see Hertel (1997) for details of the basic assumptions of the model). Compared with GTAP model, CAPSiM have detailed sector disaggregation, behavior parameter from econometric estimations, and elasticities of demand and supply changing over time. To map the sectors between CAPSiM and GTAP model, GTAP are firstly aggregated into 13 regions and XXX sectors listed in Appendix Table X.

Follow Horridge and Zhai (2005), we establish a soft linkage between CAPSiM and GTAP model to evaluate the climate change impacts under international trade. The mechanism of the soft linkage is to let the CAPSiM model determine agricultural export supply behavior, and to take world demand changes from GTAP. To do this, the global-level agricultural impacts of climate change are assessed with the GTAP model, using the yield change based econometric results for China, and IFPRI estimations for the rest of world. The simulated price changes of international agricultural products using GTAP model are then fed into CAPSiM in order to access the impacts of climate change on China's agricultural production, demand and trade.

Baseline scenario

For the purpose of analyzing the climate change impacts on agricultural economy, we firstly have built a baseline scenario. There are several key assumptions for the baseline scenario concerning on concerning economic growth, population growth rate, urbanization rate, urban and rural households' income growth rate and agricultural technology advancement (Appendix Table).

In the Baseline projection, China will keep its production growth to meet the domestic demand for most crops.

Transmission of climate change into simulation models

Crop yield change are generally modeled as a shock to total factor productivity of crop sectors in assessing climate change impacts. In CAPSiM, crop yield change is a linear function of crop price, input price, including fertilizer, land, and labor, and three shift variables representing irrigation, policy and climate change condition respectively. The impacts of climate change on crop yield calculated above could be transmitted into the crop production module in CAPSiM through shifting the crop yield change. Crop yield change is introduced into GTAP model as the shift of total factor productivity of these crop sectors.

4. Results for climate change impacts with and without international trade

The following section describes results for climate change impacts on agricultural economy (production, demand, and trade) based on the CAPSiM simulation in 2015-2050. Then the assessment on climate change impacts with international trade will be discussed on the basis of simulation results from CAPSiM-GTAP linkage model. To this end, percentage changes indicated in the text refer to comparisons of agriculture results without and with climate change.

4.1 The climate change impacts on agricultural production

Climate change will significantly impact crop production in China. Rice, wheat and sugar will have production loss due to climate change both under the RCP 2.6 and 8.5 (Row 1-2), and wheat is projected to have moderate production reduction by 2050 (1.61% for RCP 2.6 and 4.28% for RCP 8.5). Maize will have slight production increase under RCP 2.6, however, its production is projected to decrease slightly under RCP 8.5. Soybean and oilseed have slightly positive climate change impacts except in 2050 under RCP 8.5. Cotton will benefit from climate change by 2050 both under RCP 2.6 (0.74%) and RCP 8.5 (3.57%).

The climate change impacts on crop production is less than the yield loss estimated by GCMs and econometric model. Among crops, wheat has the biggest production in 2050 under RCP 8.5 (4.28%), less than half of the yield loss due to climate change (10.63%). If crops occur to yield loss due to climate change, their production loss will be mitigated at least partly, through raising domestic price and increasing harvest area and other input. Interestingly, some crops with positive yield change will finally have production reduction in Table 3. The crops with positive yield change due to climate change will have lower price, and reduce harvest land to expand the crops with negative yield change.

If considering climate change impacts on other countries, causing international price changing, the impacts of climate change on China's agricultural will be further mitigated. While soybean production has slight decrease by 2050 under RCP 8.5 (-1.47%) without international trade, soybean production is projected to significantly increase (16.75%) with international trade. The case could be attributed to the different yield shock due to climate change in China and the rest of world: soybean yield is projected to have slight increase in China (Table 3), and the main exporter, such as Brazil, Argentina and USA, are all projected to decrease (Table 2). We could also observe that international trade for other crops have similar role on climate change impacts to soybean. If taking the international trade into climate change assessment, the climate change impacts on crop production will be reduced at least partly.

4.2 The climate change impacts on agricultural price

The crops with adverse yield shocks due to climate change will have a national price increase by 2030 and 2050 both for RCP 2.6 and RCP 8.5. Rice, wheat, and sugar experienced some increase of local price in response to yield loss caused by climate change. Wheat has the largest price increase by 2050 around 6.83% for RCP 2.6 and 17.53% for RCP 8.5, as it also experiences most severe yield loss. Rice price have moderate increase by 2050 around 5% for RCP 8.5 and 2.7% for RCP 2.6. When the climate change causes yield loss to these crops, their domestic production will decrease, and consequently, the inadequate domestic supply will raise the local price. Consistent with positive yield shock due to climate change, cotton has a lower local price, by 0.27% in 2030 and 1.37% in 2050 compared to in 2010. Maize will occur some yield increase under either RCP 2.6 or RCP 8.6, and its local price will have a slight increase.

The domestic price is higher for all crops with consideration of international trade. Climate change have impacts on agricultural production not only for China, but also for the rest of world. The global demand will increase significantly for crops with negative yield change due to climate change. As a result, the increasing export demand will lead to raise China's crop domestic price. Wheat and soybean domestic price will increase by more than 20%, resulting from that China has less yield loss than the rest of world for these crops.

4.3 The climate change impacts on agricultural trade

The crop yield shock also will impact significantly on net import of agriculture products (Table 4). The plants with negative yield shock will increase their net import in 2030 and 2050, especially for rice and wheat. Wheat is projected to have most significant net import increase both under the scenario RCP 2.6 and 8.5. Under RCP 8.5, by 2050, net import of wheat will increase by more than 50%, as wheat will have yield loss by around 10%. On the other hand, some crops will have slight net import decrease including cotton, oil and soybean, as these crops only have slight yield increase.

4.4 The climate change impacts on agricultural self-sufficiency

Compared to the baseline scenario, crops experienced negative yield shock will have a lower self-sufficient rate (Table 5), and among them, wheat has the biggest self-sufficient rate loss. Under RCP 8.5 scenario, all crops will have lower self-sufficient rate by 2050 compared to 2010, except for cotton which benefits most from climate change. On the other hand, by 2030, only rice, wheat and sugar will have self-sufficient rate loss under RCP 2.6 scenario consistent with crop production loss.

5. Conclusion

Agriculture is an important sector to China, feeding its over 1.3 billion populations, however, it is threatened by the production damage caused by climate change. A limitation of previous studies was that they focused on domestic agricultural impacts and did not consider the effects of climate change on world production and markets. China has become net importer of agriculture products, importing more than 80 million tones maize in 2016. The fluctuation of international price and trade will significantly impact China's domestic balance of agriculture economy, and the impacts of climate change on agriculture.

To address the issues mentioned above, the climate change impacts on China's agricultural economy without and with international trade are assessed based on a widely-used agricultural partial equilibrium model, CAPSiM, and its linkage model with GTAP model. The climate change impacts in this paper are examined during 2020-

2050 under IPCC RCP scenarios. The results in this paper show that climate change only has slight adverse effects on agriculture production without consideration of international trade. Even under the most severe climate change scenario, RCP 8.5, wheat production will decline less than 13% by 2050, which is the biggest production loss among crops. Our results also suggest some evidence of the mitigation capability to climate change damage in the economic system by rising domestic price, increasing farming input, and adjusting production structure. International trade will provide some mitigation capability to climate change damage to China, reducing partly crop production loss due to climate change. Our results have important policy implications for future climate change assessment and making national mitigation plans.

The moderate adaptation must be needed in China to climate change. Though climate change has gained much attention, China's agriculture will experience slight loss attributed to climate change by 2050s. Previous studies mostly suggested investment in agricultural infrastructure to mitigate climate change impacts, and the government has implemented some programs to raise farmers' capacity to resist climate change risk. However, these mitigation programs generally cost so much, possibly beyond the mitigation benefit to agriculture. Therefore, climate change adaptation should avoid over-investment.

Reducing trade barrier may help to mitigate climate change impacts. Compared to assessment without international trade, climate change impacts will be mitigated at least partly due to international trade. International trade could reallocate resource and commodities according to countries' comparative advantage. In addition to investment in agricultural infrastructure, reduce import tariff, import quota and other trade barrier is recommended to reduce production loss due to climate change.

Reference

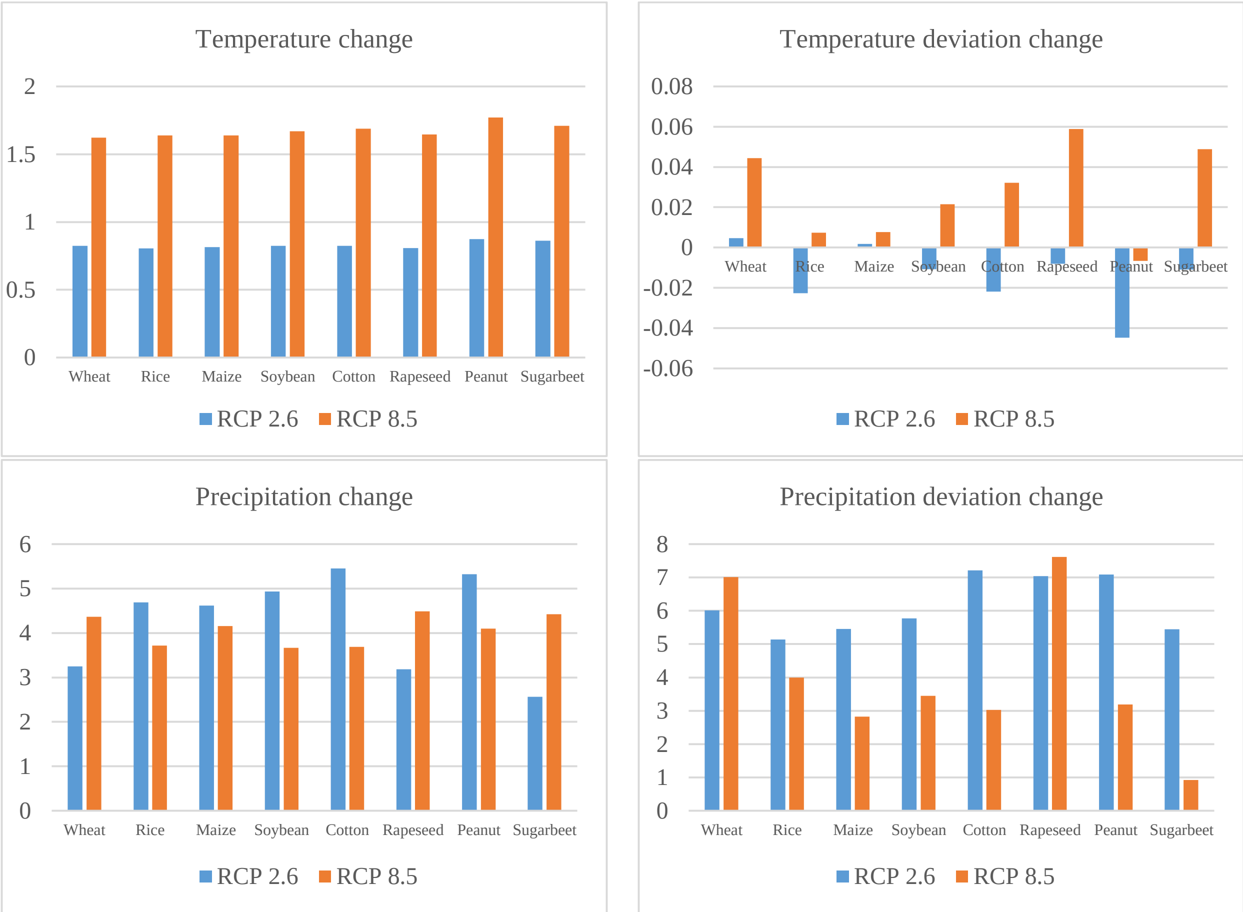

Figure 1. Average and deviation change of temperature and precipitation for different crops during their growing season by 2050 (Base year: 2010)

Table 1. Impact of climate change on crop yield under RCP 2.6 and 8.5 based on econometric estimation

	2030		2050	
	RCP2.6	RCP8.5	RCP2.6	RCP8.5
Rice	-0.59	-0.75	-1.51	-2.62
Wheat	-2.62	-3.68	-5.79	-10.63
Maize	0.28	-0.09	0.1	0.13
Soybean	0.23	0.08	0.49	0.47
Cotton	0.52	1.29	1.79	4.05
Oil seeds	-0.13	0.03	-0.05	0.18
Sugar	-0.04	0.00	-0.05	-0.02

Note: The base year is 2010. Oil seed is from aggregating peanut and rapeseed using each crop's areas in 2010 as share; sugar is from aggregating sugarcane and sugar beet using each crop's areas in 2010 as share.
Source: authors' calculation based on CCAP estimation (2014)

Table 2. The annual impacts (%) of climate change on crop yield in the rest of the world to 2050 (Base year:2010)

	RCP 2.6				RCP 8.5			
	Rice	Wheat	Maize	Soybean	Rice	Wheat	Maize	Soybean
Australia & New Zealand	-0.02	-0.27	-0.12	-0.09	-0.19	-0.40	-0.28	-0.28
Japan	0.15	-0.09	-0.04	0.01	0.16	0.09	-0.18	-0.01
Korea	-0.01	0.23	-0.35	-0.03	-0.06	0.24	-0.66	-0.07
Indonesia	-0.01	0.00	-0.17	-0.08	0.00	0.00	-0.33	-0.13
Malaysia	-0.04	0.00	-0.17	0.12	-0.08	0.00	-0.42	-0.05
Philippine	-0.03	0.00	-0.18	-0.11	-0.05	0.00	-0.38	-0.24
Thailand	-0.05	0.05	-0.38	-0.23	-0.14	-0.00	-0.79	-0.31
Vietnam	-0.09	0.03	-0.22	-0.12	-0.18	0.03	-0.57	-0.26
Canada	0.00	0.05	0.15	0.17	0.00	-0.03	0.05	0.14
USA	-0.09	0.06	-0.22	-0.03	-0.27	0.07	-0.63	-0.21
Argentina	-0.03	-0.10	-0.05	-0.01	-0.12	-0.15	-0.25	-0.15
Brazil	-0.07	-0.04	-0.14	-0.13	-0.18	-0.18	-0.41	-0.34
EU_28	0.07	0.13	-0.03	0.08	0.04	0.06	-0.20	0.00
Rest of World	-0.07	0.05	-0.13	-0.15	-0.20	-0.01	-0.37	-0.37

Source: IFPRI, 2015

Table 3. The impacts of climate change on crop production in China under RCP 2.6 and 8.5

	RCP 2.6				RCP 8.5			
	CAPSiM		CAPSiM+GTAP		CAPSiM		CAPSiM+GTAP	
	2030	2050	2030	2050	2030	2050	2030	2050
Rice	-0.27	-0.46	-0.28	-0.55	-0.30	-0.67	-0.21	-0.22
Wheat	-0.92	-1.61	-0.97	-2.21	-1.95	-4.28	-1.92	-4.03
Maize	0.24	0.20	0.40	3.58	-0.11	-0.64	1.01	1.93
Soybean	0.38	0.29	1.48	2.98	0.00	-1.47	4.26	16.75
Cotton	-0.48	0.74	-0.10	2.35	2.07	3.57	2.49	9.30
Oil seeds	0.06	0.17	0.11	0.23	0.19	-0.10	0.41	0.72
Sugar	-0.11	-0.21	-0.15	-0.45	-0.32	-0.66	-0.53	-1.53

Note: The base period is 2012.

Source: CAPSiM and CAPSiM+GTAP simulations

Table 4. The impacts of climate change on crop price in China under RCP 2.6 and 8.5

	RCP 2.6				RCP 8.5			
	CAPSiM		CAPSiM+GTAP		CAPSiM		CAPSiM+GTAP	
	2030	2050	2030	2050	2030	2050	2030	2050
Rice	1.75	2.92	1.52	2.91	1.61	4.55	2.81	7.41
Wheat	3.85	6.83	3.71	7.17	5.49	15.47	8.56	22.91
Maize	0.16	0.31	0.23	6.35	0.00	0.23	2.95	8.86
Soybean	-0.02	-0.02	1.64	6.73	-0.03	0.10	7.06	30.27
Cotton	0.28	-0.27	1.02	3.82	-0.58	-0.77	0.54	10.42
Oil seeds	-0.05	-0.15	0.11	0.42	-0.27	0.10	0.56	3.00
Sugar	0.24	0.32	0.24	0.58	0.23	0.51	0.81	2.06

Note: The base period is 2012.

Source: CAPSiM and CAPSiM+GTAP simulations

Table 5. Impacts of climate change on crop net import under RCP 2.6 and 8.5

	RCP 2.6				RCP 8.5			
	CAPSiM		CAPSiM+GTAP		CAPSiM		CAPSiM+GTAP	
	2030	2050	2030	2050	2030	2050	2030	2050
Rice	9.86	22.16	16.31	61.88	15.35	43.93	1.66	-50.37
Wheat	10.86	20.33	13.22	43.11	22.87	56.81	16.69	30.87
Maize	-1.11	-0.47	-1.50	-10.87	0.64	1.69	-4.74	-1.70
Soybean	-0.06	-0.05	-0.99	-3.31	-0.02	0.28	-3.75	-13.71
Cotton	0.60	-0.62	0.12	-1.97	-2.60	-3.00	-3.12	-7.81
Oil seeds	-0.11	-0.35	-0.15	0.80	-0.38	0.46	-0.62	0.14
Sugar	0.33	0.50	0.41	0.98	0.91	1.52	1.32	3.02

Note: The base period is 2012.

Source: CAPSiM and CAPSiM+GTAP simulations

Table 6. Impacts of climate change on crop self-sufficient rate under RCP 2.6 and 8.5

	RCP 2.6				RCP 8.5			
	CAPSiM		CAPSiM+GTAP		CAPSiM		CAPSiM+GTAP	
	2030	2050	2030	2050	2030	2050	2030	2050
Rice	-0.05	-0.11	-0.08	-0.29	-0.08	-0.21	-0.01	0.23
Wheat	-0.24	-0.48	-0.28	-1.00	-0.50	-1.37	-0.37	-0.78
Maize	0.16	0.13	0.23	2.85	-0.09	-0.46	0.70	0.71
Soybean	0.06	0.04	0.31	0.77	0.00	-0.21	1.04	4.02
Cotton	-0.27	0.34	-0.05	1.07	1.15	1.63	1.38	4.24
Oil seeds	0.02	0.07	0.04	-0.08	0.08	-0.08	0.15	0.08
Sugar	-0.06	-0.13	-0.08	-0.26	-0.18	-0.40	-0.27	-0.83

Note: The base period is 2012.

Source: CAPSiM and CAPSiM+GTAP simulations

Appendix Table 1 The estimated impacts of climate change on the yield of wheat, rice, maize and soybean in China

	Wheat	Rice	Maize	Soybean
climate during growing season				
Temperature	-0.0675*	0.0431***	-0.0160	-0.0372
	(1.73)	(3.25)	(0.32)	(0.39)
Temperature squared	0.0012	-0.0014***	-0.0015	0.0005
	(0.71)	(3.95)	(0.99)	(0.20)
Precipitation	0.0005**	0.0001**	0.0005***	0.0014***
	(2.41)	(2.31)	(2.72)	(4.69)
Precipitation squared	-0.0000007***	-0.0000001***	-0.0000002***	-0.00000072***
	(3.83)	(4.80)	(2.79)	(4.51)
climate variation in growing season				
Standard deviation of temperature	-0.0254**	0.0061	-0.0569***	-0.0176
	(2.10)	(1.60)	(4.78)	(0.95)
Standard deviation of precipitation	-0.0015**	-0.0004***	-0.0011**	-0.0019***
	(2.27)	(2.71)	(2.33)	(2.70)
Production inputs				
Fertilizer (yuan/ha) (log)	0.2366***	0.2078***	0.2906***	0.0232
	(9.09)	(13.68)	(10.76)	(1.10)
Labor days (days/ha) (log)	-0.0327	-0.0406***	0.0345	0.1754***
	(1.33)	(2.73)	(1.23)	(3.85)
Other material input (yuan/ha) (log)	0.2290***	0.1547***	0.1586***	0.2457***
	(7.23)	(9.41)	(6.57)	(5.46)
Technology progress				
Year	0.0109***	0.0025***	0.0113***	0.0183***
	(7.68)	(3.16)	(7.57)	(8.34)
Province dummy	Not reported			Not reported
Constant	-15.7207***	1.0055	-16.3939***	-31.3032***
	(5.71)	(0.63)	(5.72)	(7.29)
Adj R-squared	0.841	0.6588	0.7858	0.6750
Observations	697	1171	658	438

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix Table 2. The estimated impacts of climate change on the yield of cotton, rapeseed, peanut, cane and sugar beet in China

	Cotton	Rapeseed	Peanut	Cane	Sugar beet
climate during growing season					
Temperature	0.3366***	0.0251	0.0469	-0.3769	-0.1893
	(2.69)	(0.44)	(0.26)	(0.93)	(1.06)
Temperature squared	-0.0074**	-0.0020	-0.0001	-0.0004	0.0027
	(2.34)	(0.83)	(0.01)	(0.03)	(0.50)
Precipitation	-0.0002	0.0012***	0.0002	-0.0022	0.0003
	(0.65)	(3.29)	(0.59)	(1.45)	(0.24)
Precipitation squared	0.00000005	-0.0000007***	-0.0000001	0.00000061	-0.00000026
	(0.29)	(3.52)	(0.64)	(1.40)	(0.17)
climate variation in growing season					
Standard deviation of temperature	-0.0327	-0.0087	-0.0513*	0.1423	-0.0400
	(1.18)	(0.35)	(1.86)	(1.07)	(1.22)
Standard deviation of precipitation	-0.0026***	-0.0019*	-0.0011*	-0.0021	-0.0036*
	(3.68)	(1.92)	(1.66)	(0.77)	(1.75)
Production inputs					
Fertilizer (yuan/ha) (log)	0.3737***	0.1026***	0.0192	0.5326***	0.0265
	(6.26)	(2.97)	(0.43)	(3.77)	(0.44)
Labor days (days/ha) (log)	0.1994***	0.0666	0.1751**	0.0093	0.0582
	(2.78)	(1.49)	(2.35)	(0.04)	(0.65)
Other material input (yuan/ha) (log)	-0.0279	0.0611	0.1035	0.1714	0.0163
	(0.51)	(1.45)	(1.48)	(1.50)	(0.26)
Technology progress					
Year	0.0132***	0.0197***	0.0202***	-0.0170	0.0369***
	(4.81)	(7.96)	(5.36)	(1.26)	(7.60)
Province dummy	Not reported	Not reported	Not reported	Not reported	Not reported
Constant	-25.4083***	-33.9056***	-35.1063***	47.6406*	-61.6706***
	(4.87)	(7.12)	(4.60)	(1.75)	(6.75)
Adj R-squared	0.553	0.6343	0.5380	0.2349	0.8065
Observations	387	393	329	159	149

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1