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The Impact of Climate Change on China's Grain Market and Food Security—A CGE Model Approach*

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This paper examines the impact of climate change on China's grain production and food security. The research is one of the four studies on future conditions of China's food production system under the influence of climate change using numerical simulation methods, carried out under a national 973 project entitled "impacts of climate change on food systems in China and its adaptation". The other three studies focus on changes in cultivated land area and food production, while this study incorporates their grain yield results into a general equilibrium model to simulate future conditions of the grain market. Our simulation analysis arrives at the impact of climate change by comparing such economic variables as grain production, consumption, and GDP growth rate between a baseline scenario and two climate change scenarios. Our results are summarized as follows: (1) In 2050, the total grain production will reach 689.683 million tons—584.264 million tons of total grain consumption and 42.808 million tons of exports. Without considering losses and inventory demand, in 2050 China's grain supply and demand will remain well balanced, with a slight surplus expected. (2) Climate change is expected to benefit China's macro economy and individual sectors. In comparison with the baseline scenario of no climate change, real wage, real

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GDP, investment, household consumption, exports, and other macroeconomic indicators will rise under the climate change scenarios. As far as the agricultural, manufacturing, and service sectors are concerned, production, consumption, imports, and exports will each be favorably affected by climate change. (3) The favorable impact of climate change on China's macroeconomy and individual sectors under the high emissions scenario (A2) is stronger than that under the low emissions scenario (B2). (4) In the grain market, climate change is expected to increase supply, reduce imports, increase supply, and demand; and supply will increase more than demand does. All in all, if taking into the fertilization effect of CO_2 account, climate change is expected to strengthen China's grain supply and safeguard food security.

Keyword: climate change, Computable General Equilibrium (CGE), food security, food production, food consumption, economic growth

Introduction

Climate change is becoming one of the major concerns of human society. Human activity, especially intensive energy consumption in developed nations since the beginning of Industrial Revolution, has increased the content of greenhouse gases in the atmosphere, resulting in global warming in the past 50 years. Global warming has profound impact on the ecosystem, the health of which is crucial for agricultural production and human food supply. Because of the important roles agriculture plays in the ecosystem and economic system, understanding the impact of climate change on agriculture is of great importance for the Chinese economy.

Recognizing the significance of climate change research, Chinese government has included a research project (grant number: 2010CB951500) in the National Key Basic Research Initiatives (973 Initiatives), entitled *The Impact of Climate Change on China's Grain Production System and Adaptation Mechanisms* launched in 2010. The project contains four major components: (1) simulative forecasting of temporal dynamics of China's staple grain production under climate change scenarios, (2) simulative forecasting of spatial patterns of China's staple grain production under climate change scenarios, (3) system evaluation and policy analysis of climate change's impact on China's staple grain production, and (4) climate change's impact on the spatial distribution of China's grain food production and adaptation mechanism. Important findings of the project are summarized as follows: Xiong et al. (2012) developed a new method for studying the causes of climate change and pioneered a comprehensive national evaluation of the effects on grain production of the 1961-2010 changes in temperature, rainfall, solar radiation, and carbon dioxide content in the air. In particular, the study quantifies the differential effects of climate change in different parts of China. The study shows that the growth of grain production in the past 50 years was mainly due to technological progress and that climate change has negatively affected grain production. Changes in temperature, rainfall, and solar radiation have wiped out 8.6% of grain production growth.

Ye et al. (2012) adopted a multi-factor correlative analysis approach to develop a food security evaluation model, taking into account such bio-physical factors as agricultural production inputs, planting culture, and incidence of natural disasters, as well as such socio-economic factors as population size, degree of urbanization, planting acreage, technological change, and rural-urban grain consumption differentials. The model was used to evaluate China's grain food security around 2050. The food security index obtained in this study indicates that, after accounting for the fertilization effect of carbon dioxide, climate change will have a moderately positive effect on China's food security. The study also shows that socio-economic factors are highly important for food security. The authors argue that an environmental-friendly path of economic growth can lead to improved food security in comparison with the existing growth path featured with a large population and high emissions of greenhouse gases. The study also shows that the growth rate of gain yield is an important variable to monitor as far as food security is concerned; in other words, the growth rate of grain yield is a more effective indicator of food security than grain yield itself.

Ye et al. (2012) adopted the IMPACT model developed by International Food Policy Ressearch Institute (IFPRI) to simulate the future trends of China's staple grain yield, planted acreage, total production, imports and exports under various climate change scenarios. In addition, they evaluate China's food security in the middle of 21st century, taking into account per capita calorie intakes and mortality rates of children under five.

The Computable General Equilibrium (CGE) model is another widely adopted tool for evaluating the socio-economic impact of climate change. Two different ways of using the CGE model in climate change studies have appeared in the past literature. The first integrates bio-physical models into socio-economic models taking full account of the logic linkages among the sub-models, so that the overall socio-economic impact of climate change can be evaluated through quantifying the influences of climate variables on socio-economic variables. An example of this kind is the study by International Centre for Trade and Sustainable Development (2013), which compares the climate change impacts on Chinese economy between the autarky and free-trade settings. The results indicate that the climate change effects are much smaller in the free-trade model than in the autarky. Another study adopting this approach by Asian Development Bank (2013) shows that the effects of climate change in 2080 include 1.4% loss in GDP, 7.4% loss in grain production, 5.9% loss in livestock production, and 4.6% loss in food manufacturing. As shown in past literature (Asian Development Bank, 2013; World Bank Ethiopia, 2013), the overall effect of climate change on developing countries tends to be negative because agriculture accounts for a relatively large proportion of their GDP, but the negative effect will be moderate as the relative size of agriculture in the entire economy continues diminishing.

The other CGE-based modeling approach incorporates only climate variables, rather than bio-physical processes, into the CGE model. Recent studies (Centre of Policy Studies Monash University, 2013; Zhao, Wang, & Cai, 2008; Deng, Xia, & Yang, 2008) along this line develop CGE models accounting for changes of water resources in the economy, but these models thus far focus only on water price and taxation policy simulation without considering the impact of climate change. Between the two CGE-based models, the performance of the latter relies more on the accuracy of the data from external sources as it does not endogenize the bio-physical processes linking economic activity and climate change; the main advantage of the model lies in its simplicity. The former approach can directly incorporate climate change data into socio-economic models by linking the bio-physical and socio-economic models. Thus, this paper adopts the former approach to simulate the impact of climate change on China's food security.

Methodology and Data Sources

Methodology

To evaluate the impact of climate change with the CGE model, authors follow the following steps: (1) develop a baseline scenario without climate change, (2) quantify changes in such climate variables as rainfall and temperature under two alternative climate change scenarios, (3) compare the grain production under each climate scenario against that under the baseline, and (4) incorporate the change in grain production into the CGE model to assess the impact of climate change on the entire economy in general and on food security in particular.

Data Sources

The main data source in this study is a CGE database developed from the 2007 national input-output table (China Statistics Bureau, 2009). The CGE model uses the 2007 socio-economic data to develop the baseline scenario. In addition, yield and climatic factors associated with China's three staple grains (corn, rice, and wheat) shown in Table 1 and 2, are taken from the crop simulation model (Ye et al., 2012) based on average climatic conditions around 2000. As shown in Table 1, under the IPCC high emissions scenario of A2, the temperature will rise by 1.4℃ in 2020 and precipitation by 3.3%; the temperatures will rise by 2.6℃ in 2050 and precipitation by 7.0%. Under the low emissions scenario of B2, the temperature will increase by 0.9℃ in 2020, precipitation by 3.7%; the temperature will increase by 1.5℃ in 2050 and precipitation by 7.0%. After inputting these changes in the crop simulation model, Ye et al. (2012) obtained the yield changes of three staple crops caused by climate change, shown in Table 2.

Table 1

Changes in Climatic Conditions Under Two Emissions Scenarios

Year	A2 Scenario*			B2 Scenario*		
	Temperature increase/℃	Precipitation increase/%	CO_2/(μmol/L) Carbon dioxide	Temperature increase/℃	Precipitation increase/%	CO_2/(μmol/L) Carbon dioxide
2020	1.4	3.3	440	0.9	3.7	429
2050	2.6	7.0	559	1.5	7.0	492

Notes. * A2 and B2 were published by IPCC as the Special Report on Emissions Scenarios (SRES). The "A2" is medium-low emissions scenario and "B2" is high emissions scenario.

Table 2

Yield Changes of Staple Crops Under Two Climate Change Scenarios

Scenario	Production condition	Rice/%		Wheat/%		Maize/%	
		Year		Year		Year	
		2020	2050	2020	2050	2020	2050
A2	rain-fed	-9.3	-12.3	-4.7	-6.5	-11.4	-12.5
	irrigated	-2.1	-11.6	-3.2	-4.5	1	-2.8
B2	rain-fed	-4.2	-9.8	-3.2	-4.5	-9.5	-8.9
	irrigated	-1.2	-6.6	-1.4	0.2	-2	-1.9

Note. The results do not account for the CO_2 fertilization effect.

Model

The production process is modeled as a two-level technology (Figure 1). Level 1 represents the production of intermediate inputs and primary factors. A CES (Constant Elasticity of Substitution) function of land, capital, and labor is used to construct an aggregate index of primary factors. The use of the CES function here implies imperfect factor substitution, namely producers do change input combinations according to relative prices of land, capital, and labor, albeit with a fixed elasticity of substitution, for example, if land price goes down, more land will be used to replace a certain amount of capital and labor, but land will never completely replace capital and labor. The aggregate index of primary factors is written:

$$\mathrm{XPRIM}_i = \mathrm{CES}\left\{\frac{\mathrm{XLAB}_i}{\mathrm{ALAB}_i}, \frac{\mathrm{XCAP}_i}{\mathrm{ACAP}_i}, \frac{\mathrm{XLND}_i}{\mathrm{ALND}_i}\right\}$$

where XPRIM_i (quantities of primary factor input by industry) is the aggregate index of primary factors in sector *i*; XLAB_i (quantities of labour input by industry) and ALAB_i (labour-augmenting technical coefficient change) represent labor input and technology of sector *i*; XCAP_i (quantities of capital input by industry) and ACAP_i (capital-augmenting technical coefficient change of industry) represent the capital input and technology in sector *i*; XLND_i (quantities of land input by industry) and ALND_i (land-augmenting technical coefficient change of industry) represent the land input and technology in sector *i*.

A similar CES function index is also constructed for each intermediate input where the independent variables are domestic sources and imported source of that input, as follows:

$$\mathrm{XINP}_{c,i} = \mathrm{CES}\left\{\frac{\mathrm{XIINP}_{c,i}}{\mathrm{AIINP}_{c,i}}, \frac{\mathrm{XDINP}_{c,i}}{\mathrm{ADINP}_{c,i}}\right\}$$

Here, $\mathrm{XINP}_{c,i}$ (quantities of intermediate commodity input by industry both from domestic and imported) is the requirement of input *c* in sector *i*; $\mathrm{XIINP}_{c,i}$ (quantities of intermediate commodity input by industry from imported) and $\mathrm{AIINP}_{c,i}$ (intermediate input commodity(imported)-augmenting technical oefficient change of industry) represent the quantity and technology of imported products *c* used in sector *i*; $\mathrm{XDINP}_{c,i}$ (quantities of intermediate commodity input by industry from domestic) and $\mathrm{ADINP}_{c,i}$ (intermediate commodity (domestic) input-augmenting technical coefficient change of industry) represent the quantity and technology of domestically produced product *c* used in sector *i*. The CGE model contains 176 agriculture, manufacturing, and services sectors and products, indexed by *i* in the above equations.

The aggregate primary factors and intermediate inputs, the outputs of level-1 production, become the inputs in level-2 production. A Leontief function is assumed to represent the level-2 technology. With zero elasticity of substitution, the Leontief production function implies no substitution among aggregate intermediate and primary factors, for example, fertilizer used to produce wheat cannot be replaced by pesticides, labor, or machinery. Formally, the production function for level-2 technology is written:

$$\mathrm{XTOT}_i = \frac{1}{A_i} \times \mathrm{MIN}\left\{\frac{\mathrm{XINP}_{c,i}}{\mathrm{AINP}_{c,i}}, \frac{\mathrm{XPRIM}_i}{\mathrm{APRIM}_i}, \frac{\mathrm{XOCT}_i}{\mathrm{AOCT}_i}\right\}$$

where XTOT_i (quantities of Industry outputs) and *Ai* (augmenting technical coefficient of industry) are respectively the output and technological parameter of sector *i*; $\mathrm{XINP}_{c,i}$ and $\mathrm{AIINP}_{c,i}$ represent the quantity and technology of intermediate input *c* in sector *i*; $\mathrm{XPRIM}_\mathrm{i}$ and $\mathrm{APRIM}_\mathrm{i}$ represent the quantity and technology of the aggregate primary factor in sector *i*; XOCT_i (quantities of other cost input by industry) and AOCT_i (other cost-augmenting technical coefficient change of industry) represent the quantity and technology of the other costs of sector *i*.

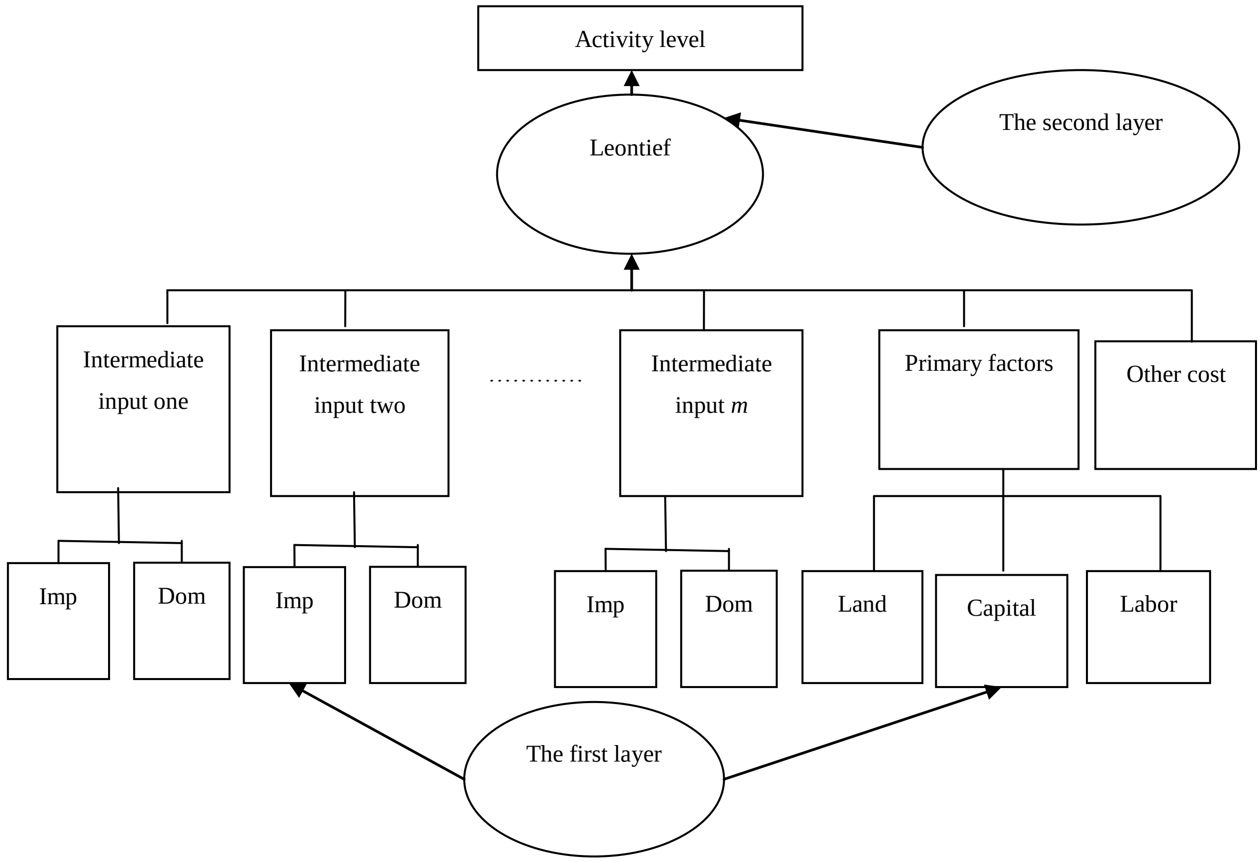

Figure 1. Schematic diagram of the CGE production model.

Notes. The ellipses represent functions, squares represent inputs and outputs, Imp means imported goods; and Dom means domestically produced goods.

Baseline Scenario Simulation

Simulation Principles

The common use of CGE model in simulation analysis falls into two categories: predictive modeling and policy simulation. The simulation analysis usually begins with the establishment of a baseline scenario and a policy intervention scenario. The baseline scenario describes the equilibrium conditions of the economic system when the policy is absent. Policy scenario describes the new equilibrium conditions after policy is introduced into the baseline scenario. In the baseline scenario, predictive modeling refers to the process of calculating the predicted value of some economic variables based on the given values of other variables. In policy scenario, simulation refers to policy simulation, in which policy variables in the baseline scenario now are changed according to the new policy so that the change of the equilibrium conditions of the economic system can be identified. Between the baseline and policy scenarios, the difference in equilibrium values of the main economic variables represents the effect of the policy, for example, if the forecasted real GDP growth rate in 2020 is 7% under the baseline scenario and 6% under the policy scenario, the effect of the policy is 1% reduction in real GDP. The following schematic diagram illustrates these basic simulation principles (Figure 2).

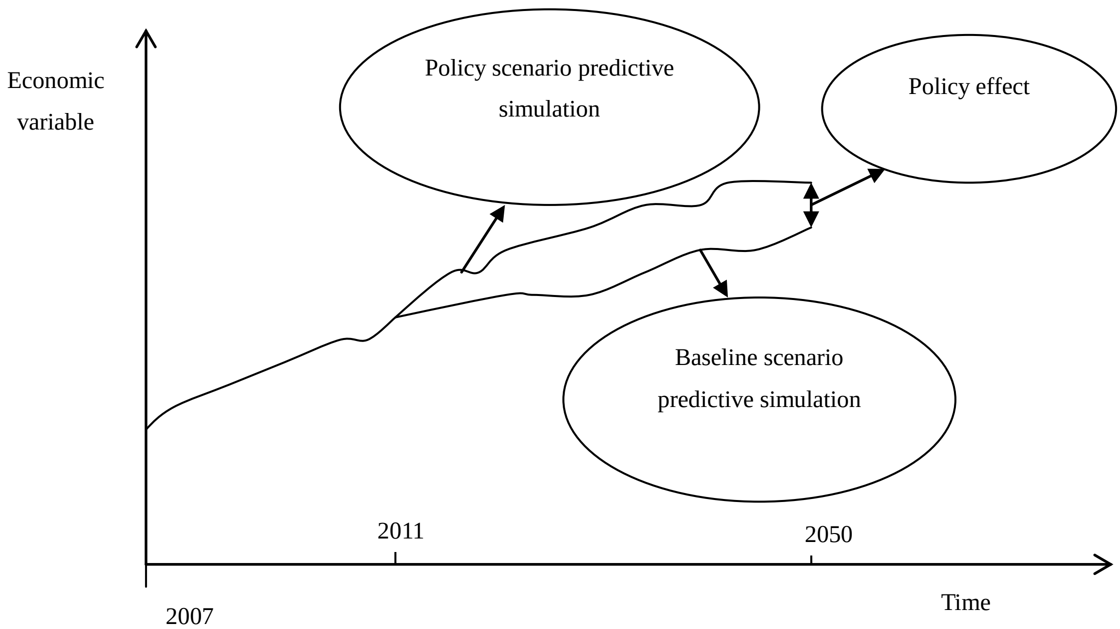

Figure 2. A schematic diagram of simulation principles.

Note. The policy effect on the economic variables, including real GDP, employment, prices, disposable income, etc. is represented by the deviation of policy scenario from baseline scenario.

Baseline Scenario

The CGE model is used in this study to represent changes of China's economy from the short-term to long-term, and the closure rules are as follows: (1) Consumption is endogenous and average propensity to consume (apc_gnp) is exogenous; (2) investment is endogenous and shift in capital supply curve (f5tot) is exogenous; (3) government expenditure is endogenous and the corresponding shift variable (twistsrc_c) is exogenous; (4) imports is endogenous and preference in favor of imports (feq_gen) is exogenous; (5) exports is endogenous and shift in export demand curve is exogenous; and (6) GDP price index is endogenous and economy-wide all primary factor productivity (a1primgen) is exogenous.

In projecting model parameters, authors assume that the Chinese economy will evolve following the historical trends. Table 3 shows the preference, technology, shift in export demand and other behavioral and structural changes projected from historical data. These behavioral and structural changes are incorporated in forecasting simulations.

Table 3

Model Parameters Projected From Historical Data (Unit: %)

Macroeconomic variables	2002-2007	2002-2009	Corresponding preference and technical change variables	2002-2007	2002-2009
Consumption	6.8	6.8	apc_gnp	-4.1	-3.3
Investment	11.3	10.5	d_f_eeqror*	-0.003	-0.003
Government	7.4	8.2	f5tot	7.4	8.2
Exports	20.9	17.1	feq_gen	48.1	42.3
Imports	15	11.7	twistsrc_c	6.3	-0.1
GDPprice index	4.9	5.3	a1primgen	-6.7	-6.3

Note. * Change of this variable is the actual change instead of percentage change.

Policy Simulation

Figure 3 shows the simulation results of some macroeconomic variables from 2015 to 2050. Employment is a variable depending on population size, so it will gradually decrease as the population growth rate turns negative. The real GDP growth rate will fall with the slowdown of economic growth and will arrive at a growth rate of 3.12% in 2050. Other variables exhibit a similar downward trend. The overall picture depicted by Figure 3 shows that the economic growth will maintain at a stable rate in the short term as the size of China's economy gets larger, and gradually slow down in the medium and long term. Table 4 presents numerical values of some of the macroeconomic variables in Figure 3.

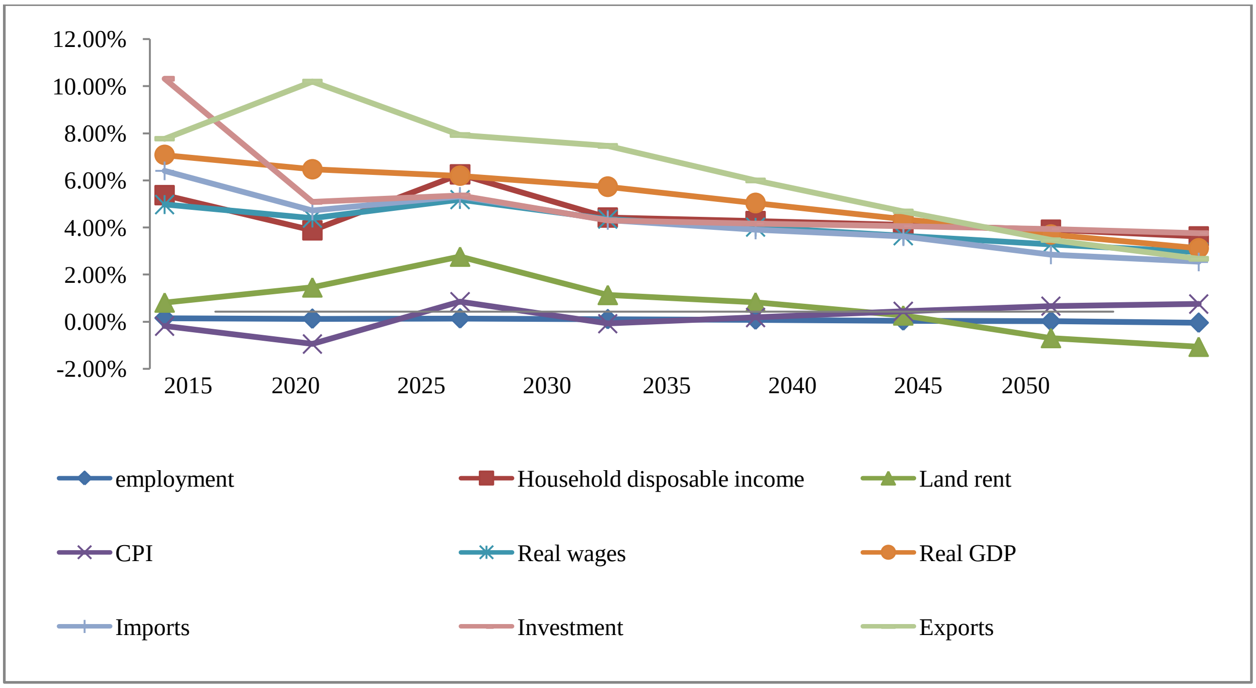

Figure 3. Baseline forecasts of macroeconomic variables.

Table 4

Macroeconomic Forecasting

Year	Real GDP 100 million Yuan	Employment 10 thousand individuals	Investment 100 million Yuan	Imports 100 million Yuan	Exports 100 million Yuan	Consumption 100 million Yuan
2030	1,494,009	80,452.28	482,270	487,652.2	887,344.1	252,662.7
2050	4,081,868	82,652.48	1,812,382	1,376,590	1,077,307	2,382,693

Simulation Results for Grain Production

Table 5

Baseline Results of Grain Supply

Year	Output/thousand tons			Imports/thousand tons		
	Corn	Wheat	Rice	Corn	Wheat	Rice
2030	235,385	110,210	207,915	1,551	1,081	517
2050	344,605	107,863	237,215	1,456	1,009	487

Table 5 presents the projected future outputs of three staple grains (corn, wheat, and rice) which are obtained by multiplying the simulated production growth rate by the base year output data in China Statistics Yearbook 2012 (China Statistics Bureau, 2012). In 2030, the output of corn, wheat, and rice will reach 235,385, 110,210, and 207,915 thousand tons, respectively; and 1,551, 1,081, and 517 thousand tons will be imported. In 2050, the output of corn, wheat, and rice will reach 344,605, 107,863, and 237,215 thousand tons, respectively; and 1,456, 1,009, and 487 thousand tons will be imported.

The CGE model contains the data for demand of intermediate factors, exports, household consumption, and government purchases; therefore, authors adopt these data for the policy simulation. Data are available for such intermediate products as labor, forage, and seed, but no data are available for inventory and depreciation. Data for intermediate factors and household consumption are taken from the estimation results of CAPSIM model (Huang & Li, 2013). Exports data are taken from China Agricultural Statistics Yearbook 2012 (China Statistics Bureau, 2012). Table 6 shows that 25,011 thousand tons of rice will be used as an intermediate product in 2030, 137,943 for household consumption and 25,000 for exports; in 2050, these numbers will be 37,517, 151,738, and 35,000 thousand product, respectively. In 2030, 17,294 thousand tons of wheat will be used as an intermediate factor, 91,199 for household consumption, and 4,969 for exports; in 2050, these numbers will be 20,753, 109,439, and 6,957 thousand tons, respectively. In 2030, for rice, 198,113 thousand tons will be used as an intermediate product, 7,648 for household consumption, and 1,263 for exports; in 2050, these numbers will be 257,169, 7,648, and 851 thousand tons, respectively.

Table 6

Baseline Results of Grain Demand

Year	Rice/thousand tons			Wheat/thousand tons			Rice/thousand tons		
	Intermediate products	Household consumption	Exports	Intermediate Products	Household consumption	Exports	Intermediate products	Household consumption	Exports
2030	25,011	137,943	25,000	17,294	91,199	4,969	198,113	7,648	1,263
2050	37,517	151,738	35,000	20,753	109,439	6,957	257,169	7,648	851

Policy Simulation

Simulation Scenarios

Grain production will deviate from the baseline projections under the high emissions A2 scenario and no more than medium emissions B2 scenario. Although grain production was only projected for two years—2030 and 2050, production data were simulated year on year to reflect the accumulative effects of climate change. The following are the results from two climate scenarios (Table 7).

A2 scenario: Under this high emissions scenario, in 2030 the production of rice, wheat, and corn will be 9.94%, 0.55%, and 5.54% higher than the production under the baseline scenario. In 2050, they will be 18.67%, 12.19%, and 10.72% higher.

B2 scenario: Under this low to medium emissions scenario, in 2030, the production of rice, wheat, and corn will be 10.99%, -0.11%, and 6.55% higher than the production under the base line scenario. In 2050, they will be 7.92%, 8.47%, and 5.51% higher.

Simulation Results

Macroeconomic impact. Under the A2 scenario, the majority of the macroeconomic variables have higher values than the baseline results. That is, the increase in grain production due to climate change has a positive effect on China’s economy. Climate change will increase employment by 0.0095% in 2030 and by 0.0295% in 2050. It will increase GDP by 0.0413% in 2030 and by 0.0822% in 2050. Climate change will lower Consumer Price Index (CPI) because increased grain supply lowers the cost of living. Specifically, with climate change, CPI will be 0.036% lower in 2030 and 0.066% lower in 2050.

Table 7

Production Change Under Climate Change Scenarios (Unit: %)

Scenario	A2 scenario			B2 scenario		
Year	Rice	Wheat	Corn	Rice	Wheat	Corn
2030	9.94	0.55	5.54	10.99	-0.11	6.55
2050	18.67	12.19	10.72	7.92	8.47	5.51

Table 8

Macroeconomic Results (Unit: %)

Scenario	A2 scenario		B2 scenario	
Macroeconomic variables	2030	2050	2030	2050
Employment	0.0095	0.0295	0.009	0.011
Land rent	0.0046	0.0225	0.004	0.005
CPI	-0.036	-0.066	-0.038	-0.035
Real wage	0.0128	0.0402	0.015	0.03
Real GDP	0.0413	0.0822	0.044	0.043
Imports	0.0279	0.0584	0.029	0.029
Investment	0.0175	0.0357	0.018	0.026
Household consumption	0.0376	0.0629	0.039	0.031
Exports	0.0421	0.0894	0.044	0.039

Under the B2 scenario, the 2030 employment will be 0.009% higher than the baseline value, and the 2050 employment will be 0.011% higher. Real GDP will be 0.044% higher in 2030 and 0.043% higher in 2050. CPI will be lower by 0.038% in 2030 and by 0.035% in 2050.

Under both climate scenarios, exports will increase because of the higher production of grains. Imports will increase as well because a higher GDP means a higher consumer demand. Under the high emissions A2 scenario, the 2030 imports will be 0.0279% higher than the baseline value and the 2050 imports will be 0.0584% higher. Exports will increase by 0.0421% in 2030 and by 0.0894% in 2050. Under the low to medium emissions scenario, imports will increase by 0.029% in both 2030 and 2050; exports will increase by 0.044% in 2030 and by 0.039% in 2050.

Under both climatic scenarios, investment appears higher than the baseline value due to the GDP growth brought by climate change. Under the high emissions A2 scenario, the 2030 investment is 0.0175% above the baseline and the 2050 investment is 0.0357%. Under the low to medium emissions B2 scenario, investment will increase by 0.018% in 2030 and by 0.026% in 2050.

Table 8 shows that climate change will boost land rent. The planting acreage in China will gradually decrease in the future. Therefore, the increased production of staple grains means higher land productivity and thus higher rent. Between the two climate scenarios, climate change will increase land rent by a larger margin when emissions are lower.

Climate change will also increase household consumption simply because of the GDP growth. Under the high emissions A2 scenario, climate change will increase household consumption by 0.0376% in 2030 and by 0.0629% in 2050. Under the low emissions B2 scenario, household consumption will be 0.039% higher in 2030 and 0.031% higher in 2050.

Higher DGP will also boost real wage. Under the higher emissions A2 scenario, climate change will increase wage by 0.0128% in 2030 and by 0.0402% in 2050. Under the low emissions B2 scenario, it will increase wage by 0.015% in 2030 and by 0.03% in 2050.

Sectorial impact. Table 9 presents the results from the high emissions A2 scenario on the impact of climate change on the agricultural, manufacturing, and service sectors. Since climate change will increase grain production as shown earlier, production and consumption of all agricultural products will increase, and imports will decrease. The entire agricultural sector's gross output will increase by 0.043% and 0.052% in 2030 and 2050, respectively; consumption will increase by 0.141% and 0.28%, exports increase by 0.05% and 0.09%, and imports decline by 0.018% and 0.028%. The production of corn, wheat, and rice will be 0.132%, 0.058%, 0.207% above the baseline in 2030 and 0.194%, 0.411%, and 0.307% in 2050. Consumption of the three staple crops will be 0.544%, 0.086%, and 0.675% above the baseline in 2030, and 0.85%, 1.009%, and 0.967% in 2050. Exports in 2030 will be 0.06%, 0.05%, and 0.05% higher than the baseline, and in 2050, 0.11%, 0.1%, and 0.1%. Imports of corn, wheat and rice in 2030 will be 1.404%, 0.167%, and 2.397% lower than the baseline; in 2050, they are 2.47%, 2.586%, and 3.906% lower.

Table 9

Sectorial Impact Under A2 Scenario (Unit: %)

Sector	Production		Consumption		Exports		Imports	
	2030	2050	2030	2050	2030	2050	2030	2050
Agriculture	0.043	0.052	0.141	0.28	0.05	0.09	-0.018	-0.028
Corn	0.132	0.194	0.544	0.85	0.06	0.11	-1.404	-2.47
Wheat	0.058	0.411	0.086	1.009	0.05	0.1	-0.167	-2.586
Rice	0.207	0.307	0.675	0.967	0.05	0.1	-2.397	-3.906
Hogs	0.043	0.07	0.048	0.062	0.05	0.1	-0.022	-0.006
Sheep	0.047	0.075	0.056	0.072	0.05	0.09	-0.041	-0.015
Other livestock	0.049	0.083	0.055	0.07	0.05	0.1	-0.041	-0.014
Other agricultural products	0.02	0.052	0.021	0.035	0.06	0.12	0.004	0.041
Manufacturing	0.025	0.056	0.022	0.04	0.03	0.06	0.02	0.044
Services	0.028	0.058	0.024	0.05	0.03	0.07	0.035	0.053

A similar positive effect of climate change appears in the livestock sector (Table 9). Hog and sheep production in 2030 will be 0.043% and 0.047% above the baseline, and in 2050, 0.07% and 0.075%. Hog and sheep consumption in 2030 will be 0.048% and 0.056% above the baseline, and in 2050, 0.062% and 0.072%. Exports of hogs and sheep in 2030 will be 0.05% and 0.05% above the baseline, and in 2050, 0.1% and 0.09%. Imports of hogs and sheep in 2030 will be 0.022% and 0.041% below the baseline, and in 2050, 0.006% and 0.015%.

Under the high emissions scenario, the output of manufacturing and service sectors in 2030 will be 0.025% and 0.028% higher than the baseline, and in 2050, 0.056% and 0.058%. Consumption will be 0.022% and 0.024%

higher than the base line in 2030, and 0.04% and 0.05% in 2050. Exports will be 0.03% and 0.03% higher than the baseline in 2030, and 0.06% and 0.07% in 2050. Imports will be 0.02% and 0.035% higher than the base line in 2030, and 0.044% and 0.053% higher in 2050.

The simulation results under the low emissions B2 scenarios are presented in Table 10 below. Since climate change will increase grain production as shown earlier, production and consumption of all agricultural products will increase, and imports will decrease. The entire agricultural sector's gross output will increase by 0.042% and 0.009% in 2030 and 2050, respectively; consumption will increase by 0.143% and 0.148%, exports increase by 0.038% and 0.032%, and imports decline by 0.015% and 0.016%. The production of corn, wheat, and rice will be 0.149%, 0.008%, 0.232% above the baseline in 2030 and 0.105%, 0.279%, and 0.155% in 2050. Consumption of the three staple crops will be 0.614%, 0.056%, and 0.754% above the baseline in 2030, and 0.407%, 0.713%, and 0.418% in 2050. Exports in 2030 will be 0.065%, 0.064%, and 0.054% higher than the baseline, and in 2050, 0.055%, 0.054%, and 0.046%. Imports of corn and rice in 2030 will be 1.583% and 2.654% lower than the baseline, but imports of wheat will be 0.190% higher than the baseline; in 2050, imports of corn, wheat, and rice will be 1.244%, 1.889%, and 1.849% lower than the baseline.

Table 10

Sectorial Impact Under B2 Scenario (Unit: %)

Sector	Production		Consumption		Exports		Imports	
	2030	2050	2030	2050	2030	2050	2030	2050
Agriculture	0.042	0.009	0.143	0.148	0.038	0.032	-0.015	-0.016
Corn	0.149	0.105	0.614	0.407	0.065	0.055	-1.583	-1.244
Wheat	0.008	0.279	0.056	0.713	0.064	0.054	0.19	-1.889
Rice	0.232	0.155	0.754	0.418	0.054	0.046	-2.654	-1.849
Hogs	0.044	0.031	0.05	0.027	0.049	0.041	-0.022	-0.006
Sheep	0.049	0.034	0.058	0.032	0.061	0.052	-0.041	-0.005
Other livestock	0.051	0.038	0.057	0.032	0.041	0.034	-0.041	-0.005
Other agricultural products	0.021	0.024	0.022	0.017	0.042	0.036	0.005	0.02
Manufacturing	0.026	0.025	0.024	0.019	0.023	0.021	0.021	0.022
Services	0.03	0.03	0.025	0.03	0.066	0.055	0.037	0.026

A similar positive effect of climate change appears in the livestock sector. Hogs and sheep production in 2030 will be 0.044% and 0.049% above the baseline, and in 2050, 0.031% and 0.034% above the baseline. Hogs and sheep consumption in 2030 will be 0.05% and 0.058% above the baseline, and in 2050, 0.027% and 0.032%. Exports of hogs and sheep in 2030 will be 0.049% and 0.061% above the baseline, and in 2050, 0.041% and 0.052 above the baseline. Imports of hogs and sheep in 2030 will be 0.022% and 0.041% below the baseline, and in 2050, 0.006% and 0.005%.

Under the low to medium emissions scenario, the output of manufacturing and service sectors in 2030 will be 0.026% and 0.03% higher than the baseline, and in 2050, 0.025% and 0.03%. Consumption will be 0.024% and 0.025% higher than the base line in 2030, and 0.019% and 0.03% in 2050. Exports will be 0.023% and 0.066% higher than the baseline in 2030, and 0.021% and 0.055% in 2050. Imports will be 0.021% and 0.037% higher than the base line in 2030, and 0.022% and 0.026% higher in 2050.

Impact on Grain Supply and Demand

Table 11 reports the results of the impact of climate change on grain supply. Under the high emissions A2 scenario, production of corn, wheat, and rice will increase from the baseline by 341.86, 69.87, and 473.47 thousand tons in 2030, and 734.2, 487.21, and 801 thousand tons in 2050. Imports will decline from the baseline by 23.96, 1.99, 13.62 thousand tons in 2030, and by 39.57, 28.7, and 20.95 thousand tons in 2050. Under the low to medium emissions B2 scenario, production of corn, wheat, and rice will increase from the baseline by 385.53, 9.28, and 530.06 thousand tons in 2030, and 399.83, 330.68, and 403.2 thousand tons in 2005. Imports of corn and rice will decline from the baseline by 27.01 and 15.08 thousand tons in 2030, but rice imports will increase from the baseline by 2.26 thousand tons. In 2050, imports of corn, wheat, and rice will be 19.92, 20.96, and 9.92 thousand tons lower than the baseline.

Table 11

Impact on Exports and Imports (Unit: Thousand Tons)

Scenario item crop	A2 scenario				B2 scenario			
	Production		Exports		Production		Imports	
	2030	2050	2030	2050	2030	2050	2030	2050
Corn	341.86	734.2	-23.96	-39.57	385.53	399.83	-27.01	-19.92
Wheat	69.87	487.21	-1.99	-28.7	9.28	330.68	2.26	-20.96
Rice	473.47	801	-13.62	-20.95	530.06	403.2	-15.08	-9.92

Table 12 shows the impact of climate change on the demand of the three staple grains. Under the high emissions A2 scenario, the results for 2030 are as follows. Household consumption of corn will be 1.53 thousand tons lower than the baseline; and the amount of corn used as an intermediate product and exported will be 172.88 and 0.74 thousand tons above the baseline. Household consumption of wheat will be 2.08 thousand tons below the baseline; and the amount of wheat used as an intermediate product and exported will be 221.07 and 0.09 thousand tons above the baseline. Household consumption, intermediate product use, and exports of rice will be 0.36, 39.31, and 2.64 thousand tons above the baseline.

Table 12

Impact on Demand (Unit: Thousand Tons)

Scenario crop	Demand	A2 scenario		B2 scenario	
		2030	2050	2030	2050
Corn	Household consumption	-1.53	-0.98	-2.19	-0.51
	Use as intermediate products	172.88	215.01	205.95	160.68
	Exports	0.74	3.35	0.62	-0.28
Wheat	Household consumption	-2.08	3.86	-2.67	3.23
	Use as intermediate products	221.07	279.9	251.75	155.78
	Exports	0.09	0.29	0.1	-1.1
Rice	Household consumption	0.36	0.49	0.39	0.12
	Use as intermediate products	39.31	90.14	42.67	54.91
	Exports	2.64	30.8	2.43	21.52

Under the high emissions A2 scenario, the results for 2050 are as follows: Household consumption of corn will be 0.98 thousand tons lower than the baseline, and the amount of corn used as an intermediate product; and exported will be 215.01 and 3.35 thousand tons above the baseline. Household consumption of wheat will be 3.86 thousand tons above the baseline and the amount of wheat used as an intermediate product and exported will be 279.90 and 0.29 thousand tons above the baseline. Household consumption, intermediate product use, and exports of rice will be 0.49, 90.14, and 30.8 thousand tons above the baseline.

Under the low to medium emissions B2 scenario, the results for 2030 are as follows: Household consumption of corn will be 2.19 thousand tons lower than the baseline; the amount of corn used as an intermediate product and exported will be 205.95 and 0.62 thousand tons above the baseline. Household consumption of wheat will be 2.67 thousand tons below the baseline; the amount of wheat used as an intermediate product and exported will be 251.75 and 0.1 thousand tons above the baseline. Household consumption, intermediate product use, and exports of rice will be 0.39, 42.67, and 2.43 thousand tons above the baseline.

Under the low to medium emissions B2 scenario, the results for 2050 are as follows: Household consumption and exports of corn will be 0.51 and 0.28 thousand tons lower than the baseline, and the amount of corn used as an intermediate product will be 160.68 thousand tons above the baseline. Household consumption of wheat will be 3.23 thousand tons above the baseline, the amount of wheat used as an intermediate product will be 155.78 above the baseline, and wheat exports will be 0.29 thousand tons below the baseline. Household consumption, intermediate product use, and exports of rice will be 0.12, 54.91, and 21.52 thousand tons above the baseline.

Conclusions

Balanced Grain Demand and Supply With Slight Surplus Expected in the Future

Under the baseline scenario, the total supply of the three staple grains will be 553,510 and 689,683 thousand tons in 2030 and 2050, respectively. The total demand will be 508,440 and 627,072 thousand tons. Without accounting for inventory and depreciation, there will be a slight surplus in the grain market, but the demand and supply will remain largely balanced.

Positive Impact of Climate Change on the National Economy and Individual Sectors

Taking into account the fertilization effect of carbon dioxide, climate change has the following effects on China's national economy: an increase in real GDP by 0.0413% and 0.0822% in 2030 and 2050 under the high emissions A2 scenario, and by 0.044% and 0.043% in 2030 and 2050 under the low emissions B2 scenario. Exports, real wage, investment, employment, and household consumption will rise in response to climate change, but CPI will decline. The sectorial analysis shows that climate change is expected to affect favorably production, consumption, imports and exports; a similar positive effect is also found on macroeconomic variables.

Taking an Environmental-friendly Path of Economic Growth

Both the national and sectorial analysis show that the favorable outcomes of climate change will be larger in the high emissions scenario and the low to medium. This is likely due to the fertilization effect of carbon dioxide, resulting in higher yields when emissions are higher. Due to data limitation, however, the difference between the two emissions scenarios is not significant. Therefore, the results should not be interpreted in support of a high emissions growth strategy. The high emissions strategy incurs significant higher costs to the environment and natural resources that are not fully taken into account in our analysis. Therefore, China should continue its search for an environmental-friendly and sustainable path of economic growth.

Climate Change Strengthening Food Security

Regardless of the emissions scenario, climate change will increase grain supply and reduce imports, and the growth of supply will be larger than the growth of demand. Under the high emissions A2 scenario, total grain production in 2030 will increase by 885.2 thousand tons, and demand will increase by 433.5 thousand tons, and in 2050 the supply and demand increases will be 2,022 and 622.8 thousand tons. Under the low to medium emissions B2 scenario, total grain production in 2030 will increase by 924 thousand tons, and demand will increase by 499 thousand tons, and in 2050 the supply and demand increases will be 1,133 and 394 thousand tons. In light of the fertilization effect of carbon dioxide, therefore, climate change will strengthen food supply and have favorable implications for food security.

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