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A General Equilibrium Analysis of the Impact of Climate Change on Agriculture in the People's Republic of China

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This paper examines the potential long-term impacts of global climate change on agricultural production and trade in the People's Republic of China (PRC). Using an economy-wide, global computable general equilibrium model, this paper simulates the scenarios of global agricultural productivity change induced by climate change up to 2080. The results suggest that with the anticipated decline in agriculture share of gross domestic product, the impact of climate change on the PRC's macro economy will be moderate. The food processing subsectors are predicted to bear the brunt of losses from the agricultural productivity changes caused by climate change. Production of some crop sectors (such as wheat), in contrast, is likely to expand due to increased demand from other regions of the world.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) forecasts that there will be an increase during this century in the average global surface temperatures by 2.8°C on average, with best-guess estimates of the increase ranging from 1.8 to 4.0°C (IPCC 2007a), brought about by the increase in the atmospheric concentration of greenhouse gases and assuming no emission control policies are instituted. The natural system would be altered in many ways by this increase: the frequency of extreme weather events would increase; the sea level would rise. Ocean currents would reverse and precipitation patterns would change. These changes could bring about serious long-term social and economic consequences.

Considering that weather and climate continue to play a major role in the agricultural productivity of most areas of the world despite the technological achievements in the latter half of the twentieth century, agriculture is among the sectors most vulnerable to the forecast climate change. Specifically, the potential of agricultural production will be substantially affected by the predicted changes in temperatures and rainfall patterns, as well as the resultant


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impacts on water availability, pests and disease, and extreme weather events. Literature on climate economics predicts that the long-term impact of global warming will be negative although global crop production is likely to be slightly boosted in the short term, or before 2030 (Bruinsma 2003, IPCC 2007b). The agricultural impact of climate change will most likely be unevenly distributed across regions:

low-latitude and developing countries are expected to be more adversely affected due to their geographical location, the greater share of agriculture in their economies, and their limited ability to adapt to climate change, while high-latitude countries are expected to benefit in terms of crop production. According to the recent global comprehensive estimate for over 100 countries by Cline (2007), global agricultural productivity will be reduced by 15.9 percent by the 2080s, with developing countries experiencing a disproportionately large decline of 19.7 percent, should measures to abate global warming fail to be carried out.

Despite rapid growth in recent decades, the People's Republic of China (PRC) is no exception to the effects of climate change. It also faces a great challenge to meet increasing demand for agricultural products due to increasing population and income level in the coming years. In the PRC, agriculture accounted for 11.7 percent of the national gross domestic product (GDP) in 2006 and agricultural crop land occupied 157 million hectares. Agricultural production has enabled the country to feed a population of 1.3 billion people, more than a fifth of the world's population, of whom 900 million live in rural areas, from an eighth of the world's arable land. Global climate change could cause rises in temperature, redistribution of rainfall, and more frequent flooding and droughts, and do considerable damage to crop production and the agricultural sector in general. At the national level, Xiong et al. (2009) found that the overall impact on crop production, assuming there is no carbon dioxide (CO2) fertilization (an effect explained later), is an estimated 7 to 14 percent reduction in rice, 9 to 10 percent reduction in maize, and 2 to 9 percent reduction in wheat. Assuming an average drop of 7 percent, this means a reduction of almost 40 million metric tons of food grain, and 20 percent of the global grain trade. Such a loss would undermine food security in the PRC, with particular health consequences for the poor and women, as females are primarily responsible for feeding the family.

In this paper, a computable general equilibrium (CGE) model that explains the relationships among industries, consumers, and governments across the global economy was used to study the potential impacts of climate change on the agriculture of the PRC. With its detailed region and sector disaggregation, the CGE model allows the observation of the spillover effects of sector- or country-specific shocks. The role of productivity growth in adapting to the climate change was also examined.

Section II examines the relationship between climate change and agricultural production in the PRC through a review of literature that has used modeling approaches to estimate the agricultural impacts of climate change. Section III describes the specifications of the CGE model used in this study. Section IV evaluates the impacts on the agricultural production, trade, and macro economy of the PRC of climate change-induced global agricultural productivity decline. Section V discusses the results and suggests directions for future study.

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Impacts of Climate Change on Agriculture in the PRC: A Literature Review

Many efforts have been made to analyze the projected effects of climate change on agriculture. Until 1999, very little research in this area was focused on developing countries (Mendelsohn and Dinar 1999). Although more studies dedicated to developing countries have emerged since then, few national level studies for the PRC have been done. The impacts of climate change on agriculture have been assessed by either partial equilibrium or general equilibrium approaches. Partial equilibrium models depict part of an overall economy, assuming that industries have no effects on each other or the rest of the economy. General equilibrium models look at the economy as a complete, interdependent system, thereby providing an economy-wide prospective analysis capturing links between agriculture and non-agriculture sectors.

Partial Equilibrium Analysis

The partial equilibrium analysis in the literature on agricultural impacts of climate change can be classified into three basic approaches: crop simulation models, agroeconomic zone (AEZ) models, and Ricardian models.

Crop simulation models draw on controlled experiments where crops are grown in field or laboratory settings that simulate different climates and levels of CO2 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).

The second approach, AEZ analysis, combines crop simulation models with land management decision analysis, 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. Crop modeling and environmental matching procedures are used to identify crop-specific environmental limitations under various levels of inputs and management conditions, and provide estimates of the maximum agronomically attainable crop yields for a given unit of land. However, as the predicted potential attainable yields from AEZ models are often much larger than current actual yields, the models may overestimate the effects of autonomous adaptation. Cline (2007) observed that AEZ studies tend to attribute excessive benefits to the warming of cold high-latitude regions, thereby overstating global gains from climate changes.

The Ricardian cross-sectional approach explores the relationship between agricultural capacity (measured by land value) and climate variables (usually temperature and precipitation) on the basis of statistical estimates from farm survey or country-level data. This approach automatically incorporates efficient climate change adaptations by farmers. 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).

Among the three approaches, crop simulation models have been more extensively used to assess the impacts of climate change on agricultural production in various regions in the PRC. Due to the characteristics of the crop simulation modeling, these studies focus on only a few types of grain crops such as rice, maize, and wheat. General findings of crop simulation models suggest that crop yields will decrease with the increases in temperature and declines in rainfall. One recent example of crop simulation modeling studies for the PRC is Tao et al. (2008), who assessed how rice production and water use would change with increasing global mean temperature (GMT) under various uncertain 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. Higher latitude regions will have warmer temperature than lower latitude regions. The results show that changes in rice production and water use will also vary across regions. Without consideration of CO2 fertilization effects,[1] the authors found that increases in GMT would reduce the rice growing period by 4.2–27.9 percent and rice yield by 6.1–40.2 percent depending on location and the degree of temperature increase. Although the CO2 fertilization effects potentially increase rice yield by 6.1–31.6 percent, the higher temperature will offset the increases in the yield, leading to an overall fall in rice production.


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Another recent study to apply a crop model is Wu et al. (2006), who attempted to quantify the production potential of winter wheat in the North China Plain by taking into account climate change. The study results demonstrated that low rainfall is a constraint for winter wheat in the northern part of the plain, while low radiation and high temperature restrict the crop growth in the southern part. However, the authors admit several limitations of the study, including lack of consideration of temperature effect during

[1] Carbon fertilization effect refers to the positive impact of atmospheric CO_2 concentration on crop yields. This positive impact comes from enhanced plant photosynthesis and reduced water loss via plant respiration. This effect is strong for crops such as rice, wheat, soybeans, fine grains, legumes, and most trees, which have a lower rate of photosynthetic efficiency.

the growing season, simplification of soil character, and limitation of data on irrigated and rain-fed winter wheat yields.

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

Both crop simulation and agroecological zone models do not take into account economic considerations and human capital limitations, which are important factors for a farmer's decision (Mendelsohn and Dinar 1999). The Ricardian approach has an advantage over the other two approaches in that it can incorporate farmers' adaptations in response to climate change (Mendelsohn and Dinar 1999). This approach assumes that each farmer has profit maximization characteristics subject to exogenous conditions to their farms (Wang et al. 2008a). 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. Assuming the non-linear relation between crop revenue and climate, the authors concluded that increases in both temperature and precipitation would have a positive impact on agriculture in the PRC. However, their findings vary across regions and seasons.

While Liu et al. (2004) found that warming would have a positive impact on agricultural production, findings of more recent Ricardian study by Wang et al. (2008a) show the opposite. Their results suggest that a 1°C increase in temperature would reduce farm revenues per hectare by US$10. However, not all findings of the two studies disagree. Both studies concluded that higher precipitation would increase agricultural production. Furthermore, both studies found high seasonal variations in the effects of climate change.

Building on their previous study, Wang et al. (2008b) examined how farmers would adapt to climate change in the PRC. More specifically, they studied irrigation choice, crop mix choice, and climate forecast for 2050 and 2100. Their results show that the impact of climate on farmers' irrigation choice is large and varies across locations and seasons. In general, farmers in cool regions tend to choose irrigation while those in warm regions are likely to choose to rain-feed their farms. Furthermore, crop mix choice also depends significantly on climate and varies by season. Farmers choose cotton, wheat, oil crops, and maize with increasing temperatures and rice, cotton, vegetables, soybeans, oil crops, and sugar with more precipitation. Finally, the authors examined how these decisions would change in response to climate change using three different climate change scenarios for 2050 and 2100. They found that by 2050, the likelihood that farmers choose to irrigate their farms would decrease by 13–23 percent. In addition, their results predicted that farmers would be likely to choose to grow more wheat and cotton, and less rice and soybeans. The changes were estimated to be larger in 2100.

General Equilibrium Models

Because climate change may affect various sectors of the economy directly or indirectly, interactions between different sectors must be studied to assess the impacts of climate change on agriculture. CGE models are well-suited to depict interactions between agriculture and other sectors in the economy. Treating agricultural policies in the CGE framework poses a challenge of introducing allocation of lands for different uses. Two broad approaches have been used to assess impacts of climate change on agriculture within the CGE framework. The first approach is to develop an integrated assessment model, which couples a CGE model with a partial equilibrium agricultural land use model. The second approach is to improve modeling of land within the CGE framework itself.

Of the two approaches, the more common and simpler method of introducing endogenous land use allocation in a CGE model is improving the functional form within the CGE framework through a constant elasticity of transformation function. Early studies of this type usually treated land as homogenous, ignoring biophysical characteristics of land and spatial interactions. To overcome this limitation, some studies used a constant elasticity of substitution (CES) aggregator function to distinguish between different uses of land. An example of this type of study is Palatnik and Roson (2009), who used a dynamic multi-regional CGE model with 17 industries in eight regions, in which the PRC and India together represent a region. Their results suggest that land productivity will decrease in 2001–2050 in the world as a whole, severely hitting some agricultural regions, such as India and the PRC. Furthermore, the authors argued that production of cereal crops would decline in all regions while prices of crops would increase.

Another way to introduce heterogeneity of land within a CGE model is to classify land types by regional and climatic differences through an AEZ approach. One of the studies that took this approach is Darwin et al. (1995), who evaluated impacts of global climate change on world agriculture using a future agriculture resource model made up of a geographic information system and a CGE model. Their analysis disaggregated land into six classes differentiated by the length of growing season for eight regions of the world and 11 sectors. The PRC was included in East Asia with Hong Kong, China; Taipei,China; and Republic of Korea. The study found that global climate change would not endanger food production in the world as a whole for the next century. However, the authors claimed that costs and benefits of climate change would vary across regions. For example, GDP in high-latitude regions and some mid-latitude regions such as Japan and East Asia was expected to increase while that in tropical regions was expected to decline. Moreover, the authors found that world agricultural production would decrease in general with severe climate change.

While the above studies attempted to introduce land heterogeneity within the CGE framework, other research combined the CGE with partial equilibrium models. This approach further improves realism; however, integration of models is sometimes technically and theoretically complicated to implement. For example, Ronneberger et al. (2008) coupled a global agricultural land use model, Kleines Land Use Model (KLUM), with a CGE model to assess the integrated impacts of climate change on global cropland allocation. KLUM is a partial equilibrium model in which a farmer maximizes farm profits for each unit of land. The authors applied scenarios of yield changes due to climate change in 2050 to KLUM and calculated changes in land use, which, in turn, fed into the CGE model. The authors found that emissions in the currently developing regions, including the PRC and sub-Saharan Africa, would be higher than those in developed regions. Moreover, they claimed that yield growth would decrease in almost all countries while

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prices of crops and land allocations for growing crops would increase. For example, the authors found that yield losses in PRC, United States (US), and South America would be compensated for by price increases. Finally, their results suggest that almost all regions considered in their study are likely to suffer negative impacts of climate change in terms of GDP and welfare. Of the 16 regions included in their study, only Central America and South Asia were predicted to have strong gains; sub-Saharan Africa, Canada, and Western Europe showed small gains from climate change.

In most of the above global studies, the PRC was included in a group with another country, such as India, or was grouped with other economies in a region, such as East Asia. Therefore, these studies rarely identify climate change effects on the PRC economy alone. To the best of our knowledge, the current paper is the first attempt to analyze the link between climate change and agriculture for the PRC under a global CGE framework.[2]

The CGE Model

The CGE model of the global economy used in this study was built on the World Bank's LINKAGE model, and has its intellectual roots in the group of multi-country applied general equilibrium models used over the past two decades

[2] Despite a growing number of studies that apply CGE models to environmental problems in the PRC in recent years (see, for example, Huang and Wang 2002 and Wang 2003 for a review), there is a limited number of CGE modeling exercises for impacts of climate change policies in the PRC. See, for example, Garbaccio et al. (1998), Zhang (2000), He et al. (2002), Wei (2002), and O'Connor et al. (2003). The China Agricultural Policy Simulation Model developed by the Center for Chinese Agricultural Policy, Chinese Academy of Sciences is one of the most comprehensive agricultural models developed in the PRC. This model incorporates a CGE model but has not yet been fully applied to study the impacts of global climate change on the PRC's agriculture.

for analysis of global trade and environmental issues (Shoven and Whalley 1992, Hertel 1997). This section describes the major features of the model; its detailed specification can be found in van der Mensbrugghe (2005).

The CGE model uses the nested CES function to model the production in each sector of the economy and assumes constant returns to scale. Production structures are classified into three types in terms of activities. The substitution possibility between extensive and intensive farming is shown in the crop sectors, while that between pasture and intensive feeding is reflected in the livestock sectors. The standard capital-labor substitution is reflected in all other sectors.

In the Armington assumption, there is a supposition that products are differentiated by region of origin (Armington 1969). Following a CES function, there is an allocation of top-level aggregate Armington demand between goods produced domestically and an aggregate import. Using an additional CES nest, aggregate import is further disaggregated in the second level across the various trade partners. On the aspect of export, there is an assumption that domestic and foreign markets are not treated differently. Consequently, the law of one price finds application because the price of export products is the same as that of domestic supply.

An Implicitly Direct Additive Demand System (AIDADS) (Rimmer and Powell 1996) is used to allow the maximization by households of the utility of incomes generated from production that are accrued to a single representative household in each region. AIDADS allows the marginal budget shares to vary as a function of total expenditure. Recent work by Yu et al. (2004) has demonstrated the superiority of AIDADS over other demand systems in projecting food demand, especially for long-term projections involving a wide range of countries.

Among the five primary factors of production, agricultural land and skilled and unskilled labor have full mobility across sectors within a region.[3] Through the vintage capital structure, rigidities in the capital market are adjusted to allow the "new" capital to be fully mobile across sectors, while "old" capital in a sector can be disinvested only when this sector is in decline. Constraints in natural resource sectors of forestry, fishing, and mining are determined once


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a sector-specific factor (illustrated by an upward sloping supply curve) is introduced into the function of production. Meanwhile, stocks of other primary factors are fixed for any given year. The manufactured export price index of the high-income countries, which is held fixed, is considered as the numeraire of the model. All commodity and factor markets are assumed to clear through prices.

The model is recursive dynamic, beginning with the base year of 2004 and being solved annually through 2080. Exogenous population and labor growth, savings-driven capital accumulation, and exogenous technological process are the fundamental forces behind the dynamics of the model. Population and labor force projections were based on the United Nations' medium variant forecast. Because the United Nations' population forecast covers only 2005–2050, the growth rates of population and labor force were assumed to decline exponentially at a rate of 2 percent per year. The household savings rate was set as a function of economic growth and demographic changes, which were drawn from a global multi-country analysis by Bosworth and Chodorow-Reich (2007). Technological progress was assumed to be labor-augmented, so the model could reach a steady state in the long run. The model, which is calibrated to the Global Trade Analysis Project (GTAP) (version 7) global database,

[3] There is only one type of land in the model used in this paper. Ideally, the model would disaggregate different types of land and link them to various land use activities. This would provide a more realistic representation of the shifting of land use among different activities. The recently developed Global Trade Analysis Project-land database (Lee et al. 2005) has made this possible and it will be the subject of our future study.

Table 1.**Projected Climate Changes and Their Impacts on Agricultural Productivity in 2080s**

Climate Variables	Land Area	Farm Area
Base levels		
Temperature (°C)	13.15	16.20
Precipitation (mm per day)	2.20	2.44
By 2080s		
Temperature (°C)	18.10	20.63
Precipitation (mm per day)	2.33	2.51
Impacts on Agricultural Productivity (%)	**Without Carbon Fertilization Effect**	**With Carbon Fertilization Effect**
World (output weighted)	–15.9	–3.2
Industrialized countries	–6.3	7.7
Developing countries	–21.0	–9.1
Africa	–27.5	–16.6
Asia	–19.3	–7.2
People's Republic of China	–7.2	6.8
Middle East and North Africa	–21.2	–9.4
Latin America	–24.3	–12.9

°C = degree Celsius; mm = millimeter.
Source: Cline (2007).

covers 21 countries/regions and 19 sectors; 10 of the sectors pertain to agriculture and food.

Key Findings

Baseline Scenario

For the period 2004–2080, a baseline scenario was created to serve as a reference against which to examine the effects of climate change-induced damages to agriculture, through a growth trajectory formulated under the assumption that there are no climate change impacts on economic activities. The International Monetary Fund's medium baseline projection provides the exogenous GDP growth up to 2013 in the baseline, while for each region, an economy-wide, labor-augmented productivity grows endogenously over the simulation period of 2005–2013 to match the pre-specified GDP growth path. For the period 2013 to 2040, the productivity growth rate is fixed at the 2013 level and declines after 2040 by 1 percent per year. In high-income countries, agricultural land supply is assumed to be fixed, while in Asia, it is assumed to grow by 0.12 percent annually, and in Latin America, Africa, and other regions, there is an assumption of 0.2 percent annual growth.

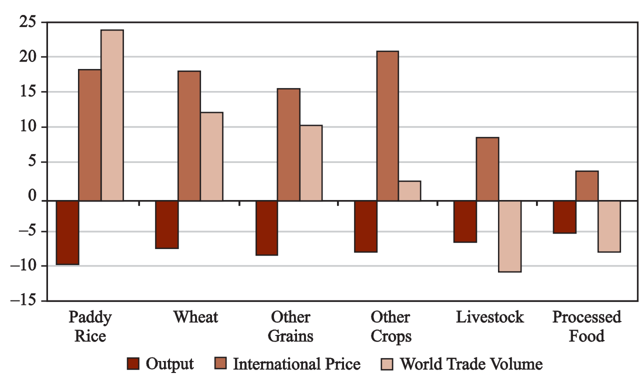
The projections under the baseline scenario over the next seven decades are global average annual GDP growth rates of 3.1 percent (2010–2050) and 2.5 percent (2050–2080). The average annual growth of the PRC over 2010–2080 is 1.7 percentage points higher than that of the world average, and its share in global GDP increases from 6 percent in 2008 to 20 percent in 2080. Growth will be accompanied by rapid structural change in developing countries. The share of agricultural value added, in volume terms, would decline from nearly 15 percent in 2004 to 5 percent in 2080 in the PRC.

Scenario with Climate Change Impact

In the counterfactual scenario with agricultural damages, we introduced global crop productivity shocks that were calculated based on the estimates of Cline (2007) to reflect the effects of climate change. Using both Ricardian and crop models, Cline (2007) came up with a set of consensus agricultural impact estimates for over 100 countries for the decade of the 2080s. Table 1 contains the key estimates arrived at by (i) developing geographically detailed projections of temperature and precipitation changes to occur by the 2080s using the IPCC's baseline emission projection, (ii) applying the projections to the models to evaluate the effects of climate change on agricultural productivity, and (iii) computing the weighted average of the estimates from the Ricardian and crop models.

In Cline's study, the climate models used calculated an increase by 2085 in the CO2 atmospheric concentrations to 735 parts per million (ppm) from the current level of

Impacts of Climate Change on International Outputs, Prices, and World Trade of Agricultural Goods, 2080
(percent change from baseline)



Source: Computable general equilibrium model simulation results.

Table 2. **Impact of Projected Climate Change on Global Welfare, GDP, and Production, 2080** (percent change)

				Sectoral Output		
	GDP	Welfare (EV as Percent of GDP)	Terms of Trade	Crop Agriculture	Livestock	Processed Food
World	−1.4	−1.3		−7.4	−5.9	−4.6
Australia	−0.3	−0.6	−0.4	−42.9	7.1	−0.2
New Zealand	0.2	1.5	2.7	140.6	−11.0	−3.8
Japan	0.0	−0.2	−0.4	1.9	0.5	2.2
People's Republic of China	−1.3	−1.1	−0.2	−0.1	−1.9	−3.6
Korea, Rep. of	−0.2	−0.6	−0.5	−5.1	−1.4	−0.4
Southeast Asia*	−1.4	−1.7	−0.4	−17.3	−1.4	−4.5
India	−6.2	−5.2	−1.8	−24.0	−19.1	−29.1
Rest of South Asia	−1.9	−2.7	−4.1	−19.5	-3.1	−10.8
Central Asia	−1.9	−1.5	1.8	49.7	−10.9	−0.5
Rest of Asia	−0.4	−0.7	−0.4	−18.4	1.0	−5.2
Canada	−0.2	0.2	0.8	22.1	−15.3	−1.6
United States	−0.1	−0.0	0.4	5.1	−7.0	−0.3
European Union	−0.2	0.0	0.4	21.4	−10.1	3.6
Latin America	−1.7	−2.1	−0.8	−24.3	−2.7	−5.2
Sub-Saharan Africa	−2.2	−3.2	−1.3	−29.6	−0.8	−4.3
Rest of the world	−1.0	−1.2	−0.5	−10.1	−4.7	−2.1

* Southeast Asia includes Indonesia, Malaysia, Philippines, Singapore, Thailand, and Viet Nam.

CGE = computable general equilibrium; EV = equivalent variation; GDP = gross domestic product.

Source: CGE model simulation results.

380 parts per million and a rise in GMT by 3.3ºC under the IPCC's scenario A2.[4] Average surface temperature of land areas, which will warm more than oceans, are predicted to increase by 5.0ºC weighting by land area and 4.4ºC weighting by farming area. When the carbon fertilization effect was included in the analysis, the global agricultural productivity by the 2080s was predicted to decline by about 3 percent; without the said effect, the productivity was calculated to decrease by about 16 percent. In general, the countries located in lower latitudes would experience larger losses because they are already close to or beyond the thresholds at which further warming will reduce agricultural productivity. As a result, developing countries are expected to suffer the brunt of these losses: their productivity decrease was estimated at 9 percent with the carbon fertilization effect and 21 percent without the effect, in contrast to the effects to be experienced by industrial countries, calculated at 8 percent gain with the carbon fertilization effect and 6 percent loss without it. In the PRC, the impacts of climate change on agricultural production were estimated at 6.8 percent gain with the carbon fertilization effect and 7.2 percent loss without it.

In the counterfactual scenario for climate change, the crop productivity shocks (without carbon fertilization effects) reported in Table 1 were imposed gradually over the period of 2009–2080 for the four agricultural sectors of paddy rice, wheat, other grain, and other crops. Due to the lack of sector-specific estimates of productivity damage, the productivity shocks were assumed to be uniform across sectors. A comparison of the counterfactual and baseline scenarios will provide the basis for the assessment of the impacts of climate change.

[4] Scenario A2 is the second highest emission scenario among the six scenarios considered by the Third and Fourth Assessment Reports of the IPCC.

Table 3. **Changes in the PRC's Output and Trade by Sector, 2080**
(percent change)

	Output	Exports	Imports
Paddy rice	–0.5	46.8	–34.1
Wheat	4.2	126.7	–17.6
Other grains	–0.5	63.7	–14.9
Other crops	–0.2	110.4	–30.1
Livestock	–1.9	10.3	–11.3
Forestry and fishing	–1.6	–3.6	–0.3
Mining	–1.7	–3.1	–1.2
Processed food	–3.6	–5.7	–3.7
Other manufacturing	–1.6	–1.7	–0.8
Services	–1.0	–1.5	0.3

CGE = computable general equilibrium;
PRC = People's Republic of China.
Source: CGE model simulation results.

Global Impacts

Simulated impacts of projected climate changes on global welfare, GDP, and agricultural production are presented in Table 2 as percentage deviation from the "no damage" baseline. Global real GDP is predicted to decline by 1.4 percent by 2080, with India suffering the largest GDP loss of 6.2 percent, followed by sub-Saharan Africa, other South Asian countries, and Central Asia. The PRC is expected to see a drop in real GDP of 1.3 percent, slightly lower than that of the world's average. New Zealand is noted as the only region in the model that would experience an increase in real GDP, largely due to a 2.2 percent increase in crop productivity as a result of climate change, estimated by Cline (2007).

While aggregate welfare effects generally follow changes in real GDP, international price adjustment plays a role in the distribution of global welfare losses. After the incorporation of agricultural damage, the international prices of crop products were projected to climb by 16 to 22 percent relative to the price of manufacturing exports of high-income countries, reflecting the inelastic demand structure of agricultural products (see Figure). The resultant changes in terms of trade would benefit net agricultural exporting countries but damage net agricultural importing countries. For regions experiencing deterioration of terms of trade, effects of agricultural damage will be amplified, and welfare losses will generally be larger than the GDP decline.

By 2080, global crop production is seen to decline by 7.4 percent, less than half of Cline's estimate. This is partly owing to the decrease in the contribution of developing countries in the global crop production for the period 2004–2080, which would suffer more from the adverse impacts of climate change as opposed to developed countries. In Cline's original estimate, agricultural output values in 2003 were used as weights to obtain the estimate for global impact. The reallocation of resources across sectors also in part offset the direct impact of agricultural productivity slowdown, contributing to the smaller magnitude of output contraction in the crop sectors. There are great variations across regions in terms of the output impact. There would be a 141 percent increase in the crop output of New Zealand owing to higher agricultural productivity under climate change and the relatively small size of the crop sectors in the country's economy while Central Asia, European Union (EU), US, and Japan would experience increases of 2–50 percent in response to the crop price hikes. A more moderate but still significant decrease in crop output would be experienced in Southeast Asia, where crop production is predicted to slow down by 17.3 percent. In East Asia, the PRC and Republic of Korea are seen to experience declines of 0.1 and 5.1 percent, respectively. The most adverse effects in crop production would be in Australia, sub-Saharan Africa, Latin America, and South Asia.

With the consequent rise in input cost, crop agriculture's downstream sectors, such as livestock and processed food, would also experience declines in global production by 5.9 percent and 4.6 percent, respectively. Variations across regions also exist. Japan, Australia, and some Asian economies would experience increases in livestock output and Japan and the EU would experience increases in processed food output while a significant drop in both of those sectors is seen for India. International patterns in agricultural commodities would be greatly influenced by the shifting comparative advantages brought about by climate change, resulting in more global trade in crop agriculture and less global trade in livestock and processed food (see Figure).

Table 4. **Impacts of Climate Change on the PRC under Alternative Assumption about Baseline Agricultural Productivity Growth, 2080**
(percent change)

	Results from Alternative Baseline	Results from Original Baseline
Real GDP	–2.1	–1.3
Welfare (EV as % of GDP)	–2.1	–1.1
Terms of trade	–0.9	–0.2

CGE = computable general equilibrium; EV = equivalent variation;
GDP = gross domestic product; PRC = People's Republic of China.
Source: CGE model simulation results.

Sectoral Impacts on the PRC

Table 3 presents the changes in sectoral output and trade for the PRC. Although the loss of the PRC's crop productivity from climate change is as large as 7.2 percent in the 2080s (Table 1), the reduction in crop production is much more muted (Table 3). As explained above, higher crop prices attract more production labor and capital to flow to crop sectors. This reallocation of resources across sectors partly offsets the direct impact of agricultural productivity dwindling, contributing to the smaller magnitude of output contraction. With the exception of wheat, the PRC's crop outputs are expected to slightly shrink by 0.2 to 0.5 percent in 2080, compared to the baseline scenario. Wheat production would expand by 4.2 percent relative to the baseline. The negligible or even positive changes in crop output of the PRC reflect the changes of global patterns in comparative advantage for agriculture. As the PRC's crop productivity will be less damaged by future changes in climate than the world average, its crop producer prices will fall relative to the international prices of crops, leading to more exports and fewer imports in the PRC's crop sectors. The second column of Table 3 shows that the PRC's paddy rice export will increase by 46.8 percent, wheat by 126.7 percent, other grains by 63.7 percent, and other crops by 110.4 percent. Because the wheat sector in the PRC has a higher export-output ratio than other crop sectors in the baseline, its export expansion leads to a larger output enhancement effect.

As a result of the crop productivity losses, production in non-crop agriculture, mining, manufacturing, and services in the PRC is expected to drop by 1.0 to 2.0 percent in 2080 compared to the baseline scenario, reflecting the combined effects of increased input costs and resources being diverted away from them to the crop sectors. It is not surprising that the food processing sector would experience the largest output drop of 3.6 percent, given its more intensive use of crop products as inputs. However, this contraction in production is still smaller than the world average of 4.6 percent (Table 2), owing to the less significant rises in crop prices in the PRC and its relatively higher efficiency in the use of intermediate crop inputs.

Sensitivity to the Assumption about Baseline Agricultural Productivity Growth

Fueled by technological progress and market-oriented reform, the PRC has achieved rapid growth in agricultural productivity over the past three decades. This agricultural productivity growth has improved the food security of PRC households and enabled the PRC to release its abundant

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rural labor for industrialization. Because the PRC has made significant progress toward a market-driven economic system and has reached a relatively high stage of agricultural technical development, its rate of agricultural productivity growth from technological catch-up and institutional reform is likely to slow in the coming decades. To account for this uncertainty regarding agricultural productivity growth for the PRC, an alternative baseline scenario was developed with slower productivity growth in the PRC's agricultural sectors—specifically, one percentage point lower on annual average than the original baseline, thereupon repeating the scenario of incorporating agricultural damages. The key simulation results are presented in Table 4. Because the results for the rest of the world are only slightly changed from the original results, only revised aggregate results for the PRC are reported.

Because of the slower agricultural productivity growth in the PRC, its agricultural output in 2080 under the alternative baseline is only half of that in the original baseline. This leads to a smaller agricultural share in GDP and greater import dependence for agricultural products in the PRC. As a result of higher import dependence, the PRC would be more vulnerable to the rise in the world prices of agricultural products. The simulations under the alternative baseline with slower agricultural productivity improvement suggest that the PRC's terms of trade would deteriorate by 0.9 percent as a result of the global climate change, significantly larger than that obtained from the original baseline. On the production front, although the lower share of agriculture in economic activity would induce more muted impacts of agricultural productivity shrinking on aggregate output, this effect would be more than offset by the slower capital accumulation, because the worsened terms of trade would reduce real income and real investment. Therefore, the results from the alternative simulations suggest larger losses in both GDP and welfare for the PRC in comparison with the original baseline.

Conclusion

This paper has examined the potential impacts of global climate change on the PRC's agricultural production and trade as well as its macro economy through changes in agricultural productivity. The results suggest that with the anticipated decline in agriculture's share of GDP, the impact of climate change on the PRC's macro economy will be moderate. The baseline results show that climate change will result in a 1.3 percent decline in GDP and a welfare loss equivalent of 1.1 percent in 2080 for the PRC. However, if future growth in the PRC's agricultural productivity is slower, the PRC's dependence on world agricultural markets will be higher, leading to more welfare and output losses through worsening terms of trade. Because the climate change induced reduction in agricultural productivity in the PRC is lower than the world average, its food processing sectors, rather than crop sectors, would be the major losers from the global agricultural productivity changes caused by climate change. In fact, some crop sectors (such as wheat) in the PRC are likely to expand because of increased demand from other regions of the world.

It is worth noting that a significant number of market and non-market impacts of global warming are not considered in this paper. Thus, considering the great uncertainties in both the scientific projections and technical, social, and economic prospects, the results in this paper are mere illustrations and should not be taken as forecasts. They are intended to give an overview of the direction and extent of the possible impacts of climate change, both in the medium and long term, which are determined by some key potential driving forces also discussed in this paper.

Furthermore, while agricultural productivity losses from climate change may be moderate for the PRC in the aggregate, failure to account for geographic details within a country in the current global model may cause the model to underestimate the intra-country distributional impact of climate change-induced agricultural damage. Given the PRC's large geographic area, different regions within it may experience different losses, depending on the typology and geographical conditions. The southwest region, where the PRC's poverty is concentrated (Guangxi, Guizhou, Tibet, and Yunnan), is expected to be hit the hardest. Given the PRC's geographic and demographic complexities across regions, it will be useful to examine regional level impact of climate change on agriculture and the economy in future studies.


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