Climate Change and The Uncertainty of CO2 Fertilization: Possible Effects on China's Grain Trade

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Abstract

This study analyzes the potential impact of climate change and the uncertainty of CO_2 fertilization on China's corn, wheat and rice domestic agricultural markets and the international markets out to the year 2050. The study provides a brief background and reviews research literature of climate change effects on China's crop yields. The paper presents the potential impact of climate change on China's yields and attempts to quantify the domestic and global market impacts. The analysis has four scenarios, which assumes two future levels of greenhouse gas emissions with the effects of CO_2 fertilization and no CO_2 fertilization. A 27 country commodity partial equilibrium simulation mathematical programming model (PEATSim) is used for this analysis. Results indicate under CO_2 fertilization, which increases yields, China's grain imports may decrease leading to a decrease in international prices. Under no CO_2 fertilization, yields decrease, China's grain imports may increase leading to increased international prices.

Key words: China, trade, climate change, rice, wheat, corn, dynamic partial equilibrium simulation mathematical model.

Introduction:

China and the world are facing global climate change from increasing greenhouse gases (GHG) at an increasing rate (IPCC 2007a&b). Climate change, as well as mitigation and adaptation policies could play a critical role in changing agricultural competitiveness globally. The impact of climate change on China's agriculture is of increasing concerns for China, and many other countries world-wide. China is the world's largest agricultural producing and consuming country and mostly self-sufficient in feeding a population of 1.34 billion people. A major source of uncertainty in the near future is China's policy decisions. In addition to climate change affects, implementation of mitigation and adaptation climate policies may have large effects on China's agriculture and world markets.

The Government of China has recognized the importance of climate change issue and formulated the China's National Climate Change Program to address climate change with specific objectives, principles, policies and measures. China's government has recognized that during the past 100 years, and especially the last 50 years, annual average air temperatures have increased, precipitation variation has increased among provinces/regions, occurrence of extreme climate and weather events are more frequent, the sea level have risen gradually, and mountain glaciers have retreated with the trend accelerating in recent years (NDRC-PRC, 2007). The government of China has explicitly stated its concern about the effects of climate change on agriculture. The government stated that climate change has already affected water conditions within China over the past 40 years with a decreasing trend in runoff in the six main rivers Haihe River, Huaihe River, Huanghe River, Songhuajiang River, Yangtze River, and Pearl River. The frequency of hydrological extreme events has increased, such as floods and droughts in the south and north. (NDRC-PRC, 2007).

Objectives:

This study analyzes the impact of climate change on China's grain sector out to the year 2050. The specific focus is on corn, wheat and rice and the effects and implications on China's domestic agricultural markets and the international markets. This analysis assumes two future levels of greenhouse gas emissions (GHG) plus two assumptions on CO_2 fertilization. This analysis incorporates the effects of CO_2 fertilization and no CO_2 fertilization under each of the

two GHG emissions projections. Four scenarios are developed to analyze the effect of climate change on corn, wheat and rice and the effect on China's grain production, domestic market and the international markets. The effect of increased GHG emissions on future crop yields depends upon the degree of CO_2 fertilization. Yields will increase with CO_2 fertilization, however, when no CO_2 fertilization occurs yields are decreased. Both the levels of future GHG greenhouse emissions and especially the degree of CO_2 fertilization are critical in analyzing China's domestic grain market and international agricultural markets.

The objectives of this research effort are threefold: first, to develop baseline projections to the year 2050 under normal conditions with no effects from climate change; second, to determine the appropriate climate change effects on yields for China's corn, wheat and rice, based on current agronomic and climate change literature; third, conduct four climate change scenarios to evaluate the effect on China's domestic agriculture, major agricultural countries, and international markets. This research on the effects on China of climate change provides a preliminary basis for future research that would provide greater detail, and incorporates the effects of global climate change on other countries. Future research would also address a broader effect of mitigation and adaptation policies for climate change on China's agriculture and the related food sector.

Background:

Development of long-term projections of GHG emissions, and the impact on climates for different countries and regions are critical for climate change research. Scientists rely on a unified set of assumptions and a set of long-term GHG emissions scenarios for their research, which are provided by the Intergovernmental Panel on Climate Change (IPCC). IPCC develops projections of GHG emissions, which are based on assumptions about the future world we will live in. These assumptions include different demographic developments, social-economic development and technological change, which are the major driving forces of GHG emissions. The long-term GHG emissions storylines developed by IPCC represent a range of these driving forces. Four different GHG emission storylines, A1, A2, B1 and B2, have been developed by IPCC (IPCC 2007a&b).

Much of the research on crop yields has used A2 and B2 IPCC storyline scenarios, which are more moderate or mid-level than A1 and B1 in GHG emissions. GHG emission projections are greater under the A2 IPCC storyline than the B2 storyline. The A2 family scenario describes a heterogeneous world with self-reliance and preservation of local identities. Global population continues to increase with very slowly converging fertility patterns across regions. Economic development is regionally oriented, fragmented, and economic growth is slower than in other storylines (IPCC, 2001). Under the B2 scenario local solutions to economic, social and environmental sustainability are established for the world. The population growth rate is less than A2. This scenario is oriented toward more environmental protection and social equity (IPCC, 2001).

In our research the levels of GHG emissions are important and the degree of CO_2 fertilization is critical, because of the impacts on crop yields. Research on factors affecting yields and their interactions with climate variables is well-established. Levels of temperature, CO_2, soil moisture, quantity and timing of precipitation, day length, soil type, and nutrient levels are just some of the factors, which are critical in determining crop yield (Lobell and Asner, 2003; Morison and Lawlor, 1999). Crop models have been used to show effects of increased CO_2 on crop yields, growth and water use based on experimental literature (Acock and Allen, 1985). Plants have three types of carbon fixation during photosynthesis, two types are C3 plants and C4 plants. Plants such as rice, wheat, soybeans, and most other crops (C3 plants) are more efficient at utilizing atmospheric CO_2 for carbon fertilization to increase yields as atmospheric CO_2 increases, whereas corn, sugar cane, and sorghum (C4 plants) are less efficient (Kimball, 1983; Cure and Acock, 1986). In our analysis yields for corn, wheat and rice will increase with CO_2 fertilization and yields will decrease with no CO_2 fertilization for China, based on research by (Xiong, et al. 2008; Wang et al. 2009a; and Wang et al. 2010). The CO_2 fertilization effect has a large impact on yields, domestic production and trade, especially for wheat and corn. Some of the greatest uncertainty for China is with respect to CO_2 fertilization effect on yields.

Literature Review:

A large body of literature exists on climate change and the effects on China's agriculture with respect to yields and production. Most of this literature focuses on China's domestic agriculture

science, such as agronomic effects, like evapotranspiration and yields. More recently, the literature on climate change in China has expanded including economics of China's farms and agricultural related sectors, and most recently the international effects on global agricultural markets.

Research studies on climate change affecting China's agriculture exhibit a large variation over the past 20 years. The outcomes depend on the type of models chosen, the climate scenarios, domestic versus global scenarios of climate change, adaptation by farmers, the assumptions about CO_2 fertilization, linkages to water simulation models and water availability, incorporation of socio-economic variables and even policies regulating trade. More recent studies incorporate long-term GHG emission storylines established by IPCC 2007a, A1, A2, B1, and B2, which provide greater uniformity in climate change research and improves comparison of research.

A number of studies have looked at climate change and the effect on China's agriculture production and crop yields, many focusing on specific crops (Zhang et al., 2006; Lu et al., 2008; You et al., 2005; Wang Z. et al., 2008; Yao et al., 2007; Xiong et al., 2009). Most have studied the effects of climate change on yields of rice, wheat, and corn. Many studies using agronomic modeling for China assessing climate change indicate that yields will decrease (Parry et al., 2004; Wu et al., 2006; Yao et al., 2007). More recent studies, incorporating CO_2 fertilization and adaptation by farmers, indicate that yields will increase under climate change for many crops (Wang et al. 2008; Xiong et al., 2008).

Xiong et al.(2008) research on China's yields under IPCC climate scenario A2 with CO_2 fertilization and irrigation indicates that by 2050 rice and wheat yields will increase by 6.2%, and 25.1%, respectively, but corn will decrease by 2.2%. Under no CO_2 fertilization rice, wheat, and maize yields would decrease by 12.4%, 6.7%, and 11.9%, respectively. Under rain-fed conditions corn exhibited the greatest difference by the year 2050 with yields increasing 18.4% with CO_2 fertilization and decreasing by 22.8% with no CO_2 fertilization. Research using IPCC climate scenario B2 were conducted which showed a lower increase and decrease of yields. Under both scenarios, wheat exhibits the largest increase in yields and the smallest decrease, under CO_2 fertilization and no CO_2 fertilization respectively. Tao and Zhang (2010) research

results indicate that, without adaptation, corn yields, which are less responsive to CO_2 fertilization, in the North China Plain could decrease an average of 13.2% - 19.1% by the year 2050.

Only a few research studies focus on the loss or gain to China's farmers, impacts on crop prices, and especially agricultural trade due to climate change. Wang et al. (2009b) research based on 8405 households indicates that global climate change will likely be harmful to rain fed farms, but beneficial to irrigated farms. These impacts vary by region and increase in damages with a longer timeframe. Farms in Northwest and Northeast China are expected to be most adversely affected. Erda (1996) indicates that, with adaptation to climate change, the annual agricultural loss could be US$0.8 to $3.48 billion and, without adaptation, a loss of US$1.37 to $79.98 billion from 2000 to 2050. Research by Liu et al. (2004), based on county-level cross-sectional data on agricultural net revenues, and indicates the overall impact from five climate scenarios would be positive. The Southwest, Northwest and southern part of Northeast China may be negatively affected. Research results by Wang, J. et al. (2010) indicate grain prices will increase in China and the world without CO_2 fertilization effect, due to lower agricultural production. However, when CO_2 fertilization effect is accounted for in this research climate change may have a negative impact on grain prices, with wheat prices decreasing the most, due to increased production.

Few studies address the effect of climate change on China's agricultural trade. Research by Wang et al. (2009a) finds under a scenario with no CO_2 fertilization effect, China's rice, wheat, and corn production will decrease and imports would increase. Under CO_2 fertilization effect, production will increase for all commodities, imports will decrease and exports will increase. The CO_2 fertilization effect has a large impact on domestic production and trade, especially for wheat and corn. Most of the research indicates that the greatest uncertainty for China is with respect to CO_2 fertilization.

The climate change literature on China's crop production and effects on yields under the IPCC storylines A2 and B2, with CO_2 fertilization and no CO_2 fertilization are used to establish our

climate change scenarios, described below and in table 1. The three studies we use are (Xiong, et al. 2008; Wang et al. 2009a; and Wang et al. 2010).

Methodology and Modeling Framework:

We analyze the impacts of climate change on China's agricultural economy and the international markets using a modeling framework with multiple commodities and countries that are interlinked through prices and biological relationships. For example, agricultural production is directly affected by changes in yields, which impacts consumer and livestock feed demand through prices, which then affects livestock sector production, grain inventories and trade. A multi-country and commodity partial equilibrium simulation model is used for this analysis, the dynamic Partial Equilibrium Agricultural Trade Simulation (PEATSim) model. The model accounts for simultaneous interaction among numerous commodities while maintaining identities for demand, supply, prices and trade, and balances for commodities, sectors, and individual countries. The PEATSim covers 27 countries/regions and thirty-two agricultural commodities -- nine major crops, ten oilseed markets, four livestock products, six dairy products as well as sugar, sugarcane, sugar beets, liquid fuels (ethanol and biodiesel), and dried distillers grains with solubles (DDGs) markets. Explicit representation of each country's domestic and trade policies pertaining to agricultural commodities are well developed. The PEATSim model is written in GAMS (General Algebraic Modeling System).

The model structure includes variables for yield, area, production, per capita consumption, total consumption, imports, exports, beginning and ending stocks, and prices for domestic producers and consumers and international markets. Numerous identities exist for individual commodities and regions in the model. Crops included in the model are corn, wheat, rice, other coarse grain, soybeans, sunflowers, rapeseed, other oil, cotton, and sugar. Livestock includes beef and veal, pork, poultry, and dairy products. Dairy products included are fluid milk, butter, cheese, nonfat dry milk, whole dry milk, and other dairy products. The last sector includes biofuel commodities such as ethanol, biodiesel, and DDGs. The country coverage for this research effort includes 14 countries or regions: China, United States, European Union (EU-27), Japan, South Korea, Canada, Mexico, Brazil, Argentina, Australia, India, New Zealand, Russia and the rest of the world.

The model balances supply and demand for each tradable commodity i in region r and time t as follows:

$$NET_{i,r,t} = PRD_{i,r,t} + EST_{i,r,t-1} - CON_{i,r,t} - EST_{i,r,t} \qquad (39)$$

where $PRD_{i,r,t}$ is production, $EST_{i,r,t-1}$ is lagged ending stocks (or beginning stocks for time t), $CON_{i,r,t}$ is consumption, $EST_{i,r,t}$ is ending stocks.

Equilibrium conditions for world markets require that the sum of exports, $EXP_{i,r,t}$, to be equal to the sum of imports, $IMP_{i,r,t}$, across regions for tradable commodity i in region r and year t:

$$\sum_{r} EXP_{i,r,t} = \sum_{r} IMP_{i,r,t}$$

and under the complementarity condition (Mixed Complementarity Problem, Dirkse, 1994a , Dirkse and Ferris, 1994b, Dirkse et al., 1994c) the world price, $PRF_{i,r,t}$, is the equilibrating variable in the world balance equation, or

$$\sum_{r} EXP_{i,r,t} = \sum_{r} IMP_{i,r,t} \quad \perp \quad PRF_{i,r,t} \geq 0$$

Scenarios and Baseline:

Scenarios conducted include climate change effect on crop yields, for rice, wheat, and corn in China. Four scenarios are formulated to capture the impact of alternative climate change possibilities. The scenarios are based on a review of the climate change literature for China's agriculture under IPCC climate change scenarios A2 and B2 with CO_2 fertilization and without CO_2 fertilization. Specifically, the scenarios are based on the research by Xiong, et al., 2008; Wang, et al., 2009a; and Wang, et al., 2010. The scenarios are presented in table 1, which presents the percent change in yields from the baseline projection. The first set of scenarios includes IPCC scenario A2 with and without CO_2 fertilization. The second set of scenarios includes IPCC scenario B2 with and without CO_2 fertilization. Under CO_2 fertilization most yields increase except for rice, which decreases under B2. Without CO_2 fertilization, all crop yields are likely to decrease, with corn exhibiting the largest decrease at -16.25 percent by the year 2050.

A baseline projection is established to the year 2050. The baseline provides commodity projections for crop and livestock sectors to the year 2050, without the effects of climate change. The dynamic PEATSim model long term baseline reflects the macroeconomic drivers of the ERS Macroeconomic Projections (USDA, 2011). Primary data sources are USDA's production, supply, and disappearance database (PS&D, USDA, November, 2009) and OECD Aglink database. Population projections are obtained from the U.S. Department of Commerce, U.S. Census of Bureau and the U.S. Department of Agriculture, Economic Research Service (2011). We assume long run steady economic growth for all countries, with emerging market countries maintaining growth at 2 to 4 percent greater than developed countries. Long-term global economic growth rate is assumed to average 3.3 percent, with emerging markets. continued to underpin world macroeconomic gains. The steady economic growth supports, longer-term gains in world food demand, and global trade. Developing countries are most responsive, because of increased food consumption, especially meat, and increased feed use as consumer's move away from staple foods. Strong and steady global economic growth over the projection period contributes to the continued slowing of global population gains as birthrates decline. In the baseline projection, China's population begins to decrease in 2026, after reaching 1.395 billion and declines to 1.304 billion by 2050.

The major differences between scenarios, listed below, exist because of the level of GHG emissions and the effects with CO_2 fertilization and no CO_2 fertilization. Under the IPCC A2 scenarios, scenarios 1 and 2, GHG emissions are greater than IPCC B2 scenarios, scenarios 3 and 4. Under CO2 fertilization yields increases, whereas if CO2 fertilization does not occur then yields will decrease. The impacts on yields are amplified by the level of GHG emissions, which is represented in the A2 scenarios.

 Scenario 1 (table 1). Under this scenario CO_2 fertilization does occur, and is in the IPCC family scenario A2, which results in increased yields for all commodities. In 2012 corn, wheat and rice yields are increased by 0.37, 1.01, and 0.22 percent from the baseline, respectively. By the year 2025 the increase from baseline yield is 5.12, 14.12, and 3.15 percent for corn, wheat, and rice, respectively. In the final projection year 2050, yield increases are greater than the baseline by 8.46, 21.61, and 5.57 percent for corn and wheat and rice.

Scenario 2 (table 1). Under this scenario CO_2 fertilization does not occur, and is in the IPCC family scenario A2, which results in decreased yields for all commodities. Without CO_2 fertilization yields decrease for all three crops. In 2012 corn, wheat and rice yields are decreased by -0.57, -0.76, and -0.65 percent from the baseline, respectively. By the year 2025 the percent decrease from the baseline yield is -8.05, -10.63, and -9.10 percent for corn, wheat, and rice respectively. In the final projection year 2050, yields are less than the baseline by -16.25, -11.81, and -11.90 percent for corn and wheat and rice respectively.

Scenario 3 (table 1). Under climate scenario B2 and CO_2 fertilization. Under this scenario CO_2 fertilization does occur, which results in increased yields for corn and wheat, but rice yields decrease. In 2012 corn and wheat yields increase by 0.04 and 0.60 percent from the baseline, respectively. Rice yields decrease in 2012 by -0.03 percent. By the year 2025 the percent increase from baseline yield for corn and wheat is 0.56 and 8.46 percent. Rice yields decrease by -0.37 percent from the baseline. In the final projection year 2050, yields are greater than the baseline by 3.50 and 10.77 percent for corn and wheat, respectively but rice is less by -1.05 percent.

Scenario 4 (table 1). Under climate scenario B2 and without CO_2 Fertilization. Under this scenario CO_2 fertilization does not occur, which results in a decrease in yields for all three crops. In 2012 corn, wheat and rice yields are less than the baseline by -0.44, -0.31, -0.09 percent, respectively. By the year 2025 the percent decrease from the baseline yield is -6.13, -4.28, and -1.31 percent for corn, wheat, and rice, respectively. In the final projection year 2050, yields are less than the baseline by -5.54, -7.82, and -3.98 percent for corn and wheat and rice, respectively.

Table 1: Scenarios 1, 2, 3 and 4 are presented as percent change from the yield baseline projections, which are under climate scenarios A2 and B2, With and Without CO_2 fertilization.

Climate Scenarios/ IPCC		With CO_2 Fertilization			Without CO_2 fertilization		
		Scenario 1*			Scenario 2		
	Years	Corn	Wheat	Rice	Corn	Wheat	Rice
A2	2012	0.37	1.01	0.22	-0.57	-0.76	-0.65
	2025	5.12	14.12	3.15	-8.05	-10.63	-9.10
	2035	6.45	17.12	4.12	-11.33	-11.10	-10.22
	2050	8.46	21.61	5.57	-16.25	-11.81	-11.90
		Scenario 3			Scenario 4		
	Years	Corn	Wheat	Rice	Corn	Wheat	Rice
B2	2012	0.04	0.60	-0.03	-0.44	-0.31	-0.09
	2025	0.56	8.46	-0.37	-6.13	-4.28	-1.31
	2035	1.74	9.39	-0.64	-6.80	-4.78	-2.38
	2050	3.50	10.77	-1.05	-7.82	-5.54	-3.98

Scenarios 1 and 2 are A2 With CO_2 Fertilization and Without CO_2 Fertilization
Scenarios 3 and 4 are B2 With CO_2 Fertilization and Without CO_2 Fertilization
* All scenarios are presented as percent difference from the yield baseline projection.
Source: derived from research by Xiong et al. 2007, Wang et al. 2009a, Wang et al. 2010

Results:

The results for rice, wheat, and corn from Scenario 1 (A2 With CO_2 Fertilization), Scenario 2 (A2 Without CO_2 Fertilization), Scenario 3 (B2 With CO_2 Fertilization), and Scenario 4 (B2 Without CO_2 Fertilization) are provided in tables 2, 3, 4, and 5. These tables present the impacts on China's yield, area harvested, production, consumption, stocks, trade, and domestic prices. Tables 6 and 7 provide individual country results for imports, exports and global prices for scenarios 1 and 2. The results for A2 under both With and Without CO_2 Fertilization (Scenario 1 and 2) have the greatest impact on China's agricultural economy and world trade. Only scenarios 1 and 2 will be discussed in detail, because they capture the greatest extremes for both increases and decreases in yields for corn, wheat and rice. Scenarios 3 and 4 under IPCC family scenario B2 are more moderate and can be considered to line between the two extreme cases discussed in scenarios 1 and 2.

Production:

Under Scenario 1 (A2 With CO_2 Fertilization), yields are increased throughout the projection period from the base, table 2, for all commodities. Increased yields cause production to increase, which leads to lower domestic prices and a slight decrease in area harvested for all three commodities. Corn, wheat, and rice production increases by 4.88, 13.47, and 2.89 percent in 2025 and by 8.07, 20.72, and 5.19 percent by 2050, respectively. The results indicate that increased yields from climate change are more likely to have a large impact on production, which leads to lower domestic prices. Farmers respond to lower prices by slightly decreasing area harvested, revenue is a function of yields and prices, leading to decreases by less than one half of a percent throughout the projection period.

Under Scenario 2 (A2 Without CO_2 Fertilization) effects of decreased yields for all commodities throughout the projection period are shown in table 3. Decrease in yields cause production to decrease, leading to higher domestic prices in China and slight increase in area. Corn, wheat, and rice production decreases by -0.39, -0.71, and -0.26 percent in 2012; by -7.8, -10.31, and -8.36 percent in 2025 and by -15.64, -11.56, and -11.18 percent by 2050, respectively. Without CO2 fertilization the decrease in yields has a large effect on production, which leads to higher prices, and a slight increase in area harvested. Area is responding to changes in revenue, which are both changes in prices and yields.

Consumption:

Under Scenario 1, (A2 With CO_2 Fertilization) China's corn, wheat and rice consumption respectively increase only marginally, with wheat consumption increasing the most by half a percent by 2050, listed in table 2. Increased consumption results from slightly lower consumer and farm prices as production increases. The low response of consumers to lower prices, is because of inelastic demand. Lower corn prices lead to a small increase in feed demand, and industrial use. Feed demand continues to grow throughout the projection period as livestock operations modernize, increasingly utilizing cost minimizing feed rations with corn. Under Scenario 2, (A2 Without CO2 Fertilization) China's corn, wheat and rice consumption are lower by -0.20 to -0.40 percent throughout the projection period. Because of increased prices due to

lower grain production, consumption of all grains decreases. Livestock production profitability is reduced as feed prices increase also leading to higher meat prices and lower consumption.

Prices:

In the PEATSim model China's grain markets are opened to the international markets, with price transmissions from world market to individual countries quite high. Under Scenario 1 (A2 With CO_2 Fertilization) prices decrease because of increased production, shown in table 2. Wheat price declines the most, by -6.14 and -8.28 percent in 2025 and by 2050, respectively for both farmers and consumers. Corn prices decrease by -4.23 and -6.05 percent in 2025 and by 2050, respectively. Rice prices decrease by -4.80 and -6.80 percent, in 2025 and 2050, respectively. Climate change with CO_2 fertilization is more likely to increase domestic supplies and lead to lower prices, which impact the international markets, trade, and prices.

Under Scenario 2 (A2 Without CO_2 Fertilization) prices are more likely to increase because of decreased production, shown in table 3. Rice price increase the most, by 10.40 and 12.05 percent in 2025 and by 2050, respectively for both farmers and consumers. Corn prices increase by 6.19 and 9.45 percent in 2025 and by 2050, respectively. Wheat prices increase by 6.82 and 7.84 percent, in 2025 and 2050, respectively. Climate change without CO_2 fertilization causes a decrease in domestic supplies and lead to higher prices.

Trade:

Climate change may have large effects on imports and exports. The greatest effect of climate change on China's grain trade would be determined by the level of CO_2 fertilization. Under scenario 1 grain yields are more likely to increase in China which leads to increased production, reduce consumption and decreased imports. In tables 6 and 7 trade results are presented for scenario 1 and 2, respectively. Under scenario 1 in 2025 China's imports would decrease by -34.47, -24.01, and -8.46 percent for corn, wheat and rice, respectively. In 2050 corn, wheat and rice imports would decrease by -21.56, -15.20, and -5.97 percent, respectively. China's imports are more likely to decrease as supply increases, which leads to lower international and domestic prices. In 2025 corn exports would decrease by -10.84, -3.13, and -14.25 percent for the United States, Argentina, and Brazil respectively. By 2050 corn exports would decrease by -22.97, -

4.35, and -43.78 percent for the United States, Argentina, and Brazil, respectively. Because of lower world prices, countries that import corn, such as Mexico, Japan and Canada, increase their imports from 0.7 percent to slightly over 3 percent. Under scenario 1 the wheat sector exhibits a similar response to that of corn, yields are increased, which increases production, and China decreases wheat imports by 13 to 15 percent throughout the projection period. Because of lower international wheat prices a number of countries will decrease wheat exports ranging from -1 to -5.6 percent throughout the projection period. These countries include United States, European Union, Australia, Canada, and Argentina. Importing countries will increase wheat imports, which include Mexico, Brazil, Japan, and South Korea, throughout the projection period.

Under scenario 2, climate change would decrease yields for all three grains and this would lead to decreased supply, increased domestic prices, lower consumption, and increased imports. China's imports of corn, and wheat would increase by 53.20 and 19.05 percent in 2025; and by 36.65, and 8.84 percent by 2050, respectively. Because of the increase in corn prices, exporting countries will increase exports. This includes United States, Argentina, European Union, and Brazil while a number of other countries that import corn, such as Mexico, Japan and Canada, would decrease imports. Similar to corn, wheat exports would increase for exporting countries including United States, European Union, Australia, Canada, Argentina and Russia because of the higher prices as China's wheat imports increased. A number of countries would decrease wheat imports, including Mexico, Japan, Brazil and South Korea.

Summary and Conclusions

The main contribution of this research is to investigate potential implications of climate change on China's grain markets and analyze quantitatively the impacts of yield changes due to climate change on domestic and international commodity markets. This study begins with a brief background section and review of research literature on climate change specifically focusing on China's agriculture sector. The paper presents the potential impact of climate change on China's grain yields and attempts to quantify the domestic and global impacts. Understanding the impact of climate change on China's agriculture sector is critical for China and the international markets as they respond to new supply and demand conditions.

The key distinctions in our scenarios are the level of GHG emissions, and CO_2 fertilization or no CO_2 fertilization. Higher levels of GHG emissions, A2, have a more pronounced effect on yields under both CO_2 fertilization and no CO_2 fertilization. In our simulation model, we conducted two major types of scenarios under different levels of GHG emissions, A2 and B2; first is climate change with CO_2 fertilization and the second is climate change without CO_2 fertilization. The effects of CO_2 fertilization are critical in understanding future impact of climate change on agriculture, due to its effects on yields. With CO_2 fertilization, grain yields increase from 5 to almost 22 percent by 2050, which has a large impact on international market and depressing international prices. Under the conditions of climate change with no CO_2 fertilization, grain yields are decreased from -10 to -16 percent by the year 2050, which has a large impact on international markets due to tighter supplies leading to price increases of 5 to 10 percent. These results are similar to previous research of Wang et al. 2009a, and Wang et al. 2010. One of the insights from this type research is that climate change will have global effects on commodity markets and will impact most countries, both domestic and international prices and potentially affect individual countries competitiveness in agriculture trade.

This study provides insights into the potential effects of climate change on China and the international markets. This research points out the importance of understanding the effects of CO_2 fertilization on grain yields. This research also has a number of areas for improvement, for example this model did not include irrigated and rain-fed production systems, which can be affected differently under climate change. Also, future model enhancements should include measures of producer and consumer welfare to capture the total impacts of climate change.

Results:

Table 2: Scenario 1, Results for China.

Years and Commodity	Scenario 1, A2 With CO2 Fertilization (in percent change from the base)						
	Area	Yield	Production	Consumption	Stocks	Imports	Domestic Prices
Corn							
2012	0.02%	0.37%	0.39%	0.02%	0.03%	-8.13%	-0.36%
2025	-0.23%	5.12%	4.88%	0.08%	0.43%	-34.47%	-4.23%
2035	-0.29%	6.46%	6.15%	0.09%	0.52%	-25.56%	-5.07%
2050	-0.36%	8.46%	8.07%	0.12%	0.63%	-21.56%	-6.05%
Wheat							
2012	-0.01%	1.01%	1.00%	0.03%	0.05%	-13.40%	-0.45%
2025	-0.56%	14.12%	13.47%	0.41%	0.64%	-24.01%	-6.14%
2035	-0.64%	17.12%	16.36%	0.44%	0.74%	-18.73%	-7.15%
2050	-0.73%	21.61%	20.72%	0.48%	0.87%	-15.20%	-8.28%
Rice							
2012	-0.14%	0.22%	0.08%	0.07%	0.02%	0.00%	-1.37%
2025	-0.25%	3.15%	2.89%	0.05%	0.49%	-8.46%	-4.80%
2035	-0.30%	4.12%	3.81%	0.07%	0.59%	-7.00%	-5.72%
2050	-0.36%	5.57%	5.19%	0.10%	0.71%	-5.97%	-6.80%

Source: PEATsim Model Results, Economic Research Service, USDA, April 2011.

Table 3: Scenario 2, Results for China

Years and Commodity	Scenario 2, A2 Without CO2 Fertilization (in percent change from the base)						
	Area	Yield	Production	Consumption	Stocks	Imports	Domestic Prices
Corn							
2012	0.19%	-0.57%	-0.39%	-0.36%	-0.03%	0.00%	0.28%
2025	0.27%	-8.05%	-7.80%	-0.26%	-0.60%	53.27%	6.19%
2035	0.47%	-11.33%	-10.92%	-0.36%	-0.73%	41.46%	7.64%
2050	0.73%	-16.25%	-15.64%	-0.49%	-0.90%	36.65%	9.45%
Wheat							
2012	0.04%	-0.76%	-0.71%	-0.11%	-0.04%	10.85%	1.56%
2025	0.36%	-10.63%	-10.31%	-0.05%	-0.66%	19.05%	6.82%
2035	0.33%	-11.10%	-10.81%	0.00%	-0.70%	12.85%	7.32%
2050	0.28%	-11.81%	-11.56%	-0.07%	-0.75%	8.84%	7.84%
Rice							
2012	0.39%	-0.65%	-0.26%	-0.25%	-0.02%	0.00%	4.24%
2025	0.81%	-9.10%	-8.36%	-0.37%	-0.98%	23.65%	10.40%
2035	0.82%	-10.22%	-9.49%	-0.38%	-1.05%	16.85%	11.14%
2050	0.82%	-11.90%	-11.18%	-0.40%	-1.13%	12.46%	12.05%

Source: PEATsim Model Results, Economic Research Service, USDA, April 2011.

Table 4: Scenario 3, Results for China.

Years and Commodity	Scenario 3, B2 With CO2 Fertilization (in percent change from the base)						
	Area	Yield	Production	Consumption	Stocks	Imports	Domestic Prices
Corn							
2012	-0.01%	0.04%	0.03%	0.00%	0.01%	-0.53%	-0.08%
2025	-0.03%	0.56%	0.53%	0.07%	0.12%	-4.44%	-1.21%
2035	-0.12%	1.74%	1.62%	-0.02%	0.17%	-7.15%	-1.69%
2050	-0.23%	3.50%	3.27%	0.04%	0.23%	-8.94%	-2.30%
Wheat							
2012	-0.03%	0.60%	0.58%	0.03%	0.02%	-7.10%	-0.21%
2025	-0.37%	8.46%	8.06%	0.34%	0.31%	-14.05%	-3.01%
2035	-0.38%	9.39%	8.97%	0.34%	0.33%	-9.97%	-3.25%
2050	-0.38%	10.77%	10.35%	0.35%	0.36%	-7.30%	-3.50%
Rice							
2012	0.02%	-0.03%	-0.01%	-0.01%	0.01%	0.00%	0.05%
2025	0.05%	-0.37%	-0.32%	-0.07%	0.08%	0.68%	-0.76%
2035	0.09%	-0.64%	-0.55%	-0.09%	0.07%	0.78%	-0.72%
2050	0.14%	-1.05%	-0.91%	-0.12%	0.06%	0.83%	-0.64%

Source: PEATsim Model Results, Economic Research Service, USDA, April 2011.

Table 5: Scenario 4, Results for China.

Years and Commodity	Scenario 4, B2 Without CO2 Fertilization (in percent change from the base)						
	Area	Yield	Production	Consumption	Stocks	Imports	Domestic Prices
Corn							
2012	0.19%	-0.44%	-0.24%	-0.23%	-0.01%	0.00%	0.12%
2025	0.11%	-6.12%	-6.02%	-0.54%	-0.01%	39.79%	0.11%
2035	0.10%	-6.80%	-6.71%	-0.53%	-0.03%	26.31%	0.27%
2050	0.12%	-7.82%	-7.71%	-0.51%	-0.08%	19.55%	0.80%
Wheat							
2012	-0.04%	-0.31%	-0.34%	0.08%	-0.02%	5.63%	0.20%
2025	0.10%	-4.28%	-4.19%	-0.14%	-0.02%	7.42%	0.22%
2035	0.09%	-4.78%	-4.70%	-0.10%	-0.03%	5.39%	0.34%
2050	0.08%	-5.54%	-5.46%	-0.05%	-0.07%	4.08%	0.69%
Rice							
2012	0.04%	-0.09%	-0.05%	-0.05%	-0.01%	0.00%	0.78%
2025	0.03%	-1.31%	-1.28%	-0.17%	0.00%	3.15%	0.04%
2035	0.12%	-2.38%	-2.26%	-0.21%	-0.07%	3.67%	0.75%
2050	0.22%	-3.98%	-3.77%	-0.25%	-0.18%	3.95%	1.81%

Source: PEATsim Model Results, Economic Research Service, USDA, April 2011.

Table 6: Scenario 1, changes in global trade for individual countries.

Commodity	Scenario 1, A2 With CO2 Fertilization Difference from the baseline projection in percent (Selected Years)			
	2012	2025	2035	2050
Corn				
World price	-0.35%	-4.40%	-5.40%	-6.58%
Exporters				
United States	-0.51%	-10.84%	-14.87%	-22.97%
Argentina	-0.27%	-3.13%	-3.72%	-4.35%
European Union	-0.29%	-4.48%	-3.06%	-2.49%
Brazil	-0.93%	-14.25%	-22.65%	-43.78%
Importers				
China	-8.13%	-34.47%	-25.56%	-21.56%
Mexico	0.31%	2.90%	2.89%	2.84%
Japan	0.06%	0.68%	0.75%	0.86%
Canada	0.45%	3.15%	2.85%	1.97%
Wheat				
World price	-0.45%	-6.20%	-7.29%	-8.53%
Exporters				
United States	-0.35%	-4.71%	-5.13%	-5.59%
European Union	-1.09%	-5.19%	-4.65%	-4.43%
Australia	-0.23%	-3.09%	-3.49%	-3.87%
Canada	-0.25%	-3.20%	-3.61%	-4.09%
Argentina	-0.24%	-3.62%	-4.21%	-4.78%
Importers				
Mexico	0.15%	1.74%	1.72%	1.64%
China	-13.40%	-24.01%	-18.73%	-15.20%
Brazil	0.12%	1.38%	1.41%	1.36%
Japan	0.04%	0.62%	0.98%	1.91%
South Korea	0.07%	0.63%	0.79%	0.99%

Source: PEATsim Model Results, Economic Research Service, USDA, April 2011.

Table 7: Scenario 2, changes in global trade for individual countries.

Commodity	Scenario 2, A2 Without CO2 Fertilization Difference from the baseline projection in percent (Selected Years)			
Corn	**2012**	**2025**	**2035**	**2050**
World Price	0.27%	6.37%	7.77%	9.53%
Exporters				
United States	-0.09%	16.94%	24.04%	38.67%
Argentina	0.11%	4.65%	5.58%	6.62%
European Union	0.23%	7.11%	5.06%	4.35%
Brazil	0.05%	20.59%	33.54%	66.63%
Importers				
China	0.00%	53.20%	41.46%	36.65%
Mexico	-0.03%	-4.60%	-4.45%	-4.51%
Japan	-0.03%	-0.91%	-1.00%	-1.17%
Canada	0.66%	-8.27%	-7.91%	-6.10%
Wheat				
World price	0.42%	6.87%	7.33%	7.80%
Exporters				
United States	0.28%	4.19%	3.85%	3.42%
European Union	0.87%	4.67%	3.63%	2.91%
Australia	0.19%	3.02%	3.03%	2.98%
Canada	0.20%	3.07%	3.04%	2.98%
Argentina	0.21%	3.64%	3.76%	3.77%
Russia	0.64%	6.24%	5.10%	4.05%
Importers				
Mexico	-0.13%	-1.46%	-1.13%	-0.81%
China	10.85%	19.05%	12.85%	8.84%
Brazil	-0.10%	-1.15%	-1.01%	-0.82%
Japan	-0.04%	-0.55%	-0.78%	-1.38%
South Korea	-0.04%	-0.10%	-0.03%	-0.29%

Source: PEATsim Model Results, Economic Research Service, USDA, April 2011.

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