Estimating the Economic Impacts of Climate Change on Global Food Market

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Abstract

This study investigates the impacts of climatic change on global markets of maize, rice, and wheat. The first step is to combine the Crop Yield Model estimated results and climate factors data predicted from five climate models (i.e. hadcm3, MIROC3_2_MEDRES, ECHAM5,CSIRO-MK30, and CNRM_CM3), and with the assumption that future world is in IPCC (2007) A1B scenario. Under such assumptions, we estimate the production impacts in 2030, 2040, and 2050. Moreover, using Global Trade Analysis Model (GTAP) and its data set we can further assess the economic impacts on food price, productivity, GDP, and social welfare.

Simulation results show that the negative impacts of future climate change are imposing serious effects on the production of maize, rice, and wheat. Moreover, results also indicate that adverse impacts on GDP and social welfare in various countries can be seen. Among these countries, India, Mexico, and Indonesia are experiencing larger magnitude of adverse impacts on GDP in three out of five climate models. On the other hand, the most significant negative effect on social welfare is in China, India, and Mexico

Keywords: Maximum Likelihood Estimation, Crop Production Model, Global Trade Analysis Project

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC, 2007) pointed out that global economic loss of crops, fishery, water resources, and human health induced by climate change in the period of 1991-2005 is approximately US$1,190 billion. Furthermore, the frequency and strength of extreme weather events such as heat waves, sudden drop in temperature, heavy rain, and drought will increase to make human face higher environment risks. Schellnuhuber et al. (2006) warned that if human activities do not slow down the speed of destroying the environment and adapt to climate change, human will face huge damages in agriculture, human health, the economy, and ecological system in the 21st century.

IPCC (2007) pointed out that the distribution of climate variables such as temperature, precipitation, wind speed, and water vapour in the air has significant impacts on the productivity of agriculture, especially extreme weather events can affect agriculture critically. In the end of 21^{th} century, Christensen et al. (2007) examined that the frequency and intensity of rainfall anomalies is largely augmented in Southern and Eastern Asia, East Australia, and Northern Europe, where the key agricultural production area located. IPCC (2007) simulated that precipitation in the northern and southern sub-tropic regions declines over 90 percent, and it results in land degradation and drop in crop yield. In the meanwhile, frequent heavy precipitation events over most regions have negative impacts on crops. Rosenzweig et al. (2002) mentioned that if U.S. is under scenarios of rising large precipitation, the loss of crop productions becomes doubled by 2030 to US$3 billion per year.

According to OECD-FAO 2011-2020 Agricultural outlook, price volatility is driven by a multitude of factors, and the most frequent and significant factor causing volatility is unpredictable weather condition. Climate change is altering weather patterns, but its impact on extreme weather events is not clear. This Outlook highlights both significant challenges to addressing global food insecurity and the major opportunities for food and agricultural producers arising from the higher average prices projected over the coming decade. The policy challenge is to promote productivity growth, particularly for small producers, that improves market resilience to external shocks, and that reduces waste and increases supplies to local markets, at affordable prices.

The severe weather becomes a normal phenomenon in recent years due to climate change, the influence of climate generates many unpredictable variables in the crops production. The food risk may not appear when the food stock sustains in domestic or government can use policy tool to control the food supply, even under the higher price variation in agricultural productions. However, people may appear expectation or panic behavior in the market demand or supply when the world faces hyper price variation in food productions. FAO and OECD consider that international food price won't come back to the highest history level in 2008, but the price also cannot reduce to the stabilize level during the last 12 years. They expect the average price in agricultural productions will increase 15%-40%, the food price and climate anomalies have a positive correlation.

World Bank projection explained the impacts of food price in the commodity market. Mensbrugghe et al. (2009, World Bank Expert Member) found the price index increases because climate change, energy usage in the food production process. Although the price declines in 2008, the price level still higher than 2003. The large amounts of energy usage will rise the density of greenhouse gases and severe the climate circumstances and therefore brings the direct and indirect impacts. Their study constructed an equation which evaluated the energy influences in all kinds of price index.

Fischer (2009, IIASA Expert Member) uses the socio-economic spatial model and predicts the food and agricultural production across the world in 2030/ 2050. Applying the global and spatial agro-ecological and socio-economic assessment which developed by International Institute for Applied Systems Analysis (IIASA). Fischer (2009, IIASA Expert Member) pointed that the climate changes can affect food production and further alters the quantities and qualities of commodities, finally these affections change food demand, supply and the pattern of commodity trade. The food demand, supply across regions moves forward to influence the global food trade market and the distribution of land use in different regions or areas. That is, the greenhouse effect changes the food price and production behavior.

Based on a state-of-the-art ecological-economic modeling approach, the model assumes that the biofuels feedstock demand is kept constant after 2008; the transport energy demand and regional biofuel use as projected by International Energy Agency (IEA) in its WEO 2008 Reference Scenario. The scenario-based quantified findings of the study rely on a modeling framework which includes as components, the FAO/IIASA Agro-ecological Zone model (AEZ) and the IIASA world food system model (WFS). The modeling framework encompasses climate scenarios, agro-ecological zoning information, demographic and socio-economic drivers.

The research result considers the food production process also produces some greenhouse gases such like carbon dioxide, these gases will yield negative effect and assaults the global food price in the medium or long run. The simulation predicts the global grain consumptions will rise from 35-100 million tons in present to 60-150 million tons in 2050; the productions in grains will increase from 20-50 million hectares to 25-60 million hectares. The growth of demand is larger than supply side.

In addition, the researcher simulated the impacts of climate change on production potential of rain-fed wheat and maize of current cultivated land (percent changes with respect to potential under current climate). Fischer (2009) analyzed for simulated impacts by the climate change influence in the cultivated land. The first impact is quantified without considering the effects of CO_2 fertilization and assumes that farmer's would be able to change cropping dates and crop types but would be limited to local crop varieties. The second one refers to results where CO_2 fertilization is still not considered but best adapted plant types, e.g. available elsewhere and adapted to higher temperatures, would be available to maximize production potential. The third and fourth impacts take into account effects of CO_2 fertilization and quantify outcomes respectively with limited and full adaptation of crop types.

The simulation results indicate that cultivated land of wheat will decline under the scenario without CO_2 fertilization. The developing countries face the most serious losses. However, the cultivated land in maize does not display similar simulation. The maize production areas will increase, especially under the scenario with considering CO_2 fertilization. There is indicating a warming that the climate change will force different regions' farming behavior change in the future. Maybe this change transforms the crop planting or the land application, after all, climate change will change the structure of food supply in the future and then this transformation will change the consumption pattern.

IFPRI projection uses the IMPACT model (International Model for Policy Analysis of Agricultural Commodities and Trade) which combines some factors like the hydrology, economic, population and the climate change and forecasts the global food price trend during 2010 to 2050. Nelson et al. (2010),who is the IFPRI expert member, takes into account the effects of climate change (higher temperatures, shifting seasons, more frequent and extreme weather events, flooding, and drought) on food production side and forecasts the future price index in the major food in 2050.

The assumptions in the model set based on the population research report in United Nation, 2008 version, the regional GDP predictions in World Bank (high, medium and low variant), and the GDP forecasts research in the Millennium Ecosystem Assessment. The simulation estimates three scenario: Baseline, Optimistic and Pessimistic. The results indicate the maize price will increase 87.3%-106.3% under three kinds of scenarios; the rice price will rise 31.2%-78.1% and the wheat price will go up 43.5% to 58.8% in the simulation. These price increases incorporate the effect of climate change. Relative to a world with perfect mitigation, prices in 2050 with climate change are 18.4 percent (optimistic for rice) to 34.1 percent (pessimistic for maize) higher.

Nelson et al. (2010) further predict the productivity for maize, rice and wheat in 2050. They found the productivity increases are only in developing countries, yields in developed countries actually fall under the baseline scenario simulation. The results display a 40 percent increase in IPRs in developing countries compare with baseline scenario values beginning in 2010.Yields in developing countries increase in varying amounts, from 8.9 percent for irrigated rice in middle-income developing countries to 28.8 percent for rainfed wheat in low-income developing ones. That is, in the expectation in time trend, the world food productions rely on developing countries if we considering the productivity or the production efficiency. In the crop categories, the simulation displays that the rice increase largest for irrigated part on middle-income developing countries. In the other hand, the wheat has best efficiency for rainfed in middle-income and low-income developing countries. Finally, in the simulation of price effects of improvements in overall efficiency, if the productivity or production efficiency increases, then the world price can decrease 15.1% to 21.5%. This outcome points that the critical issue is that how to raise production technology under the pressure of human growth and climate change.

Terjung et al. (1984) analyzed the response of the model YIELD to changes in a variety of basic environmental (temperature, solar radiation, and relative humidity regimes) and decision-making inputs (water application strategies, irrigation frequencies, soil types, and wind regimes) for paddy rice, winter wheat, and early potato. Among the results, yield decreased on the average by 4.9% (rice) and 6.0% (wheat) per 1℃ increase in air temperature. A 1% change in solar radiation resulted in an average of 1% (wheat) and 0.4% (rice) change in yield. Analogous changes in relative humidity caused yield changes of about 0.8% and nothing for wheat and rice, respectively. For all crops, the relationship between irrigation frequency and yield increase was near-linear for large irrigation intervals. This linearity vanished under high frequency waterings. With respect to irrigation amounts, 1 mm/ha of applied water was related, on the average, to 75 (potato), 19 (grain corn), 8 (rice), and 6 kg/ha (wheat) of harvestable yield.

Parry, et al (1999) investigated climate change due to increasing greenhouse gases is likely to affect crop yields differently from region to region across the globe. He used the HadCM2 climate change scenarios, finding that the effects on crop yields in mid- and high-latitude regions appear to be beneficial while those in low-latitude regions are expected to be detrimental. The HadCM3 scenario suggests that the beneficial effects at higher latitudes will occur within a specific climate range. If this is exceeded then even high mid-latitudes will witness adverse effects of climate change on agriculture. However, the more favorable effects on yield in temperate regions depend to a large extent on full realization of the potentially beneficial direct effects of CO_2 on crop growth. These regional differences are likely to grow stronger through time, leading to a significant polarization of effects, with beneficial effects on yields and production occurring in the developed world and negative

Hoogenboom (2000) presents an overview of crop modeling and applications of crop models, and the significance of weather related to these applications. To account for the impact of weather and climate variability on crop production, agrometeorological variables are one of the key inputs required for the operation of crop simulation models. Easy access to weather data, preferably through the Internet and the worldwide web, will be critical for the application of crop models for yield forecasting and tactical decision making. There still seems to be a large gap between the products, generated by crop simulation models and decision support systems,

At present, substantial researches have demonstrated there are significant relationships between climate change and agriculture with simulation-based crop growth models. Nevertheless, regression models using historical yield and climatic data are much more flexible and accurate to integrate and predict variations in crop yield to changes in climatic and socio-economic factors (Lobell and Asner. 2003; Lobell et al., 2005; Lobell and Field, 2007; Boubacar, 2010; Cabas et al., 2010). Such advantages could assist the government make adaptive strategy for the effects of climate change on agricultural production.

In the early stage, studies primarily examined that relationships between climate factors and mean yield, and predicted the impacts of future climate change on the mean of crop yield (Adams et al., 1999; Lewandrowski and Schimmelpfennig, 1999). CCAF (2002), Antle et al. (2004), and Porter and Semenov (2005) proposed that the impacts of ascending frequency and intensity of extreme weather events on crop yield are much bigger challenge in agricultural sector.

Recently, more and more studies start to focus on the sensitivity for crop yield average and variability to climate variability (Chen et al., 2004; Chen and Chang, 2005; Isik and Devadoss, 2006; McCarl et al., 2008; Cabas et al., 2010; Weersink et al., 2010). The majority of above-mentioned studies analyzed the impacts of climatic changes on crop yield in the finger region-specification within a single country. Therefore, this study extend the survey region to research the relation between climate change and three crop yield including maize, rice, and wheat within the major producing countries.

Tsigas et al. (1997) utilized GTAP(Global Trade Analysis Policy)model on global trade to estimate the effects of climate change. The model combines 24 regions into 8 aggregates (Canada, USA, Mexico, EU, China, ASEAN, and others) and 37 commodities into 8 aggregates (rice, wheat, other grains, other crops, livestock, processed agricultural commodities, and manufactures and services). The simulation is set to apply Goddard Institute of Space Stedies (GISS) climate change scenario and in concerning possible technical changes in crop and other sectors, Hicks-neutral technical change is being applied in assessing effects of climate change on general welfare. Moreover, the simulation impact design is divided into two scenarios in analyzing the positive and negative effects of CO2 on crop growth. One takes these effects of CO2 into consideration while another overlooks the effects of CO2. The result shows that when the positive effects of CO2 on crop growth are taken into account, overall welfare of Mexico and ASEAN declines by 2.7% and 1.7% respectively while the other countries decline 0.12%. The rest of the regions will experience a slight increase in welfare which ranges from 0.06% of the USA to 0.54% of China. As a result, an increase in general welfare of the world will be depicted. However, when overlooking the positive effects of CO2 climate change will cause the welfare level to drop in all regions.

About Taiwan domestic reference, Lee (1999) claimed that climate change will have significant impact on agricultural potential production. However, the agricultural land expansion and technical advance will prevent the world harvest hazard result from global population growth in the future. Lee use GTAP database and APEC regional agricultural trade data to reorganize how climate change(climate change data from Rosenzweig and Iglesias (1994)) impact on crop production. The simulation result shows that climate changes have the most significant impact in Asia, especially on Coarse grain net export.

The above studies also mentioned that the climate change influences the variability of crop yield as well as the average of crop yield. However, the lacks of the traditional stochastic production function are unable to reflect the realistic conditions, that is, if the input positively influences the output, also positively influences the variability of the output. In reality, the inputs, such as pesticides, irrigation equipment, and frost protection have a positive effect on crop yield, and have a negative effect on variability of crop yield.

This study applied Crop Yield Model to estimate the crop production impacts from climate factors (mean temperature and total precipitation), technical progress and crop harvesting from 1961 to 2009. Then we utilize the simulated annual mean temperature and annual total precipitation data under IPCC A1B Scenario from five climate models, including HadCM3, Miroc3.2 (medres), ECHAM5, CSIRO-MK3.0, and CNRM-CM3 to connect our estimated results. We use 2000 (the average value from 1961 to 2000) as baseline to calculate corresponding percentage change of mean temperature and precipitation in 2030 (the average value from 2021 to 2030), 2040 (the average value from 2031 to 2040), and 2050 (the average value from 2041 to 2050), this study combine the estimated results and percentage change of mean temperature and precipitation in

2030, 2040, and 2050 to predict the influences of future climate change on three crop yield distribution, as resented in Table 10. In 2030, 2040, and 2050, future global mean temperature and annual precipitation in five climate models for A1B scenario will all be increased, and we sum up the effects of future temperature and precipitation change on mean yield as the effects of future climate change on mean yield.

The objective of this study is to utilize stochastic production function with historical crop yields and climate data in the period of 1961-2009 to quantify the impacts of climatic variables on the average and variance of corn, rice, and wheat yield in ten major producing countries. The augmented Dickey–Fuller test (Dickey and Fuller, 1979) and maximum likelihood estimation approach will be adopted to get dependable estimates. Then, we use the estimates and elasticities to predict the implication of climate change for corn, rice, and wheat yield in the major producing countries. Through the empirical results, we can realize how much future possible global climate change will induce changes in corn, rice, and wheat yield in global major production areas, and assist government make adaptive policy of agriculture and food security. The next section in this study constructs the crop yield model with Just-Pope type (Just and Pope, 1978) to estimate the mean and variance of crop yield. Then, we combine the outcomes and predicted climate variables from five AGCMs, each with A1B scenario to predict the future three main cops production. Having GTAP as the final step, analysis can be made on assessing the economic impacts on food price, production power, and macroeconomic aspect-GDP, and society welfare.

2. Crop Yield Model and Estimation

This study makes use of the Just-Pope production function (Just and Pope, 1978, 1979) to investigate climate factors impacts the mean and variability of crop yield, which is shown as follow:

$$Y = f(X,\beta) + h(X,\alpha)^{1/2}\varepsilon \qquad (1)$$

where Y is the crop yield, X is a vector of independent variables, ε is the error term with zero mean and single variance σ^2. $f(X,\beta)$ is the mean crop production function ($E(Y) = f(X,\beta)$), $h(X,\alpha)$ is the variance crop production function ($V(Y) = h(X,\alpha)\sigma^2$), and α and β are the estimated parameters, which connect X_t to the variance and mean of the crop yield respectively. In this study, the forms of the function are the linear and Cobb-Douglas specifications.

Equation (1) could be estimated by a three-step feasible generalized least squares (FGLS) and a maximum likelihood estimation (MLE) (Just and Pope, 1978, 1979). Saha et al. (1997) examined that if the sample size is small, MLE is more efficient and unbiased than FGLS. Because our sample size is not big enough, which has 49 samples in the period of 1961-2009, this study use the MLE method (Saha et al., 1997; Huang, 2004; Isik and Devadoss, 2006). Along with the assumption of $Y_t \sim N(f(X_t,\beta), h(X_t,\alpha))$ and

$\varepsilon_t \sim N(0,1)$, the log likelihood function is shown as below:

$$\ln L = -\frac{1}{2}[n*\ln(2\pi) + \sum \ln(h(X,\alpha)) + \sum \frac{(Y - f(X,\beta))^2}{h(X,\alpha)}] \qquad (2)$$

where n is the number of the observations. Maximizing Equation (2), we get ML estimates of α and β. We estimate the Just-Pope production function for maize, rice, and wheat yield.

Due to the concentration on the effects of climate change on crop yield in this study, temperature and precipitation are the main climatic variables. Aside from the mean of climate conditions affecting crop yield, the variance in climate conditions has significant impacts on crop yield (Chen and Chang, 2005; IPCC, 2007; McCarl, et al., 2008; Cabas, et al., 2010). Hence, we consider the mean and variation of monthly temperature during the crop growing season, the annual total precipitation, and the variation in the monthly total precipitation within a year. The annual total precipitation could reveal the direct impacts of accumulative rainfall on crop yield, and the variance in temperature and precipitation could display the influence of the extreme events on the crop yield. Besides, the planted area ratio and time trend are adopted in this study. The planted area ratio is the ratio of a certain crop planted area (maize, rice, or wheat) to the whole agricultural area. Time-trend is able to show the technology progress such as the appearance of high-yielding crop varieties, implement of agronomic practices, and application of fertilizers, etc. The empirical model is shown in Equation (3).

$$Y_t = f(Parea_t, Atem_t, SDtem_t, Tprec_t, SDprec_t, T) \qquad (3)$$

where t and T is the time period from 1961 to 2009, Y_t is the crop yield in metric tons per hectare in the period t, $Parea_t$ is the ratio of crop planted area to the whole country agricultural area, $Atem_t$ is the mean of monthly average temperature during crop growing season in Celsius degrees in the period t, $SDtem_t$ is the standard deviation of monthly mean temperature during crop growing season in the period t, $Tprec_t$ is the total precipitation in the period t, $SDprep_t$ is the standard deviation of the monthly total precipitation within the period t.9. The research regions contain the most important production area within the ten critical producing countries for three crops (maize, rice, and wheat), and all data sets are annual data.

2.1 Statistics Description

This study investigates the extent of the climate variables (temperature and precipitation) and related crop planted area having effects on the mean and variance of maize, rice, and wheat yield in ten major production countries. Data on yield, crop planted area, and national agricultural area is from Food and Agriculture Organization of the United Nation (FAO), and the period of data ranges from 1961 to 2009. The data on precipitation and temperature use the main related crop region in each ten major production countries as representations from USDA Foreign Agricultural Service Office of Global Analysis. Because FAO integrates 27 European countries as a whole to make the adoption of the climate variables more difficult, this study doesn't consider the 27 European countries. The temperature data contains the mean and variance observations during the growing season of major producing countries. The precipitation data includes annual total rainfall and the variance of monthly total rainfall within a year.

The descriptive statistics are shown in Table 1. The largest mean maize, rice, and wheat yield in the major producing crop countries is United State (6805.299 Kg/Ha), Japan (5956.192 Kg/Ha), and Germany (5583.481 Kg/Ha), respectively. About the production variance ,the highest maize standard deviation is in France- 2012.984Kg/Ha, the highest rice standard deviation is in China -1387.134 Kg/Ha, and about the wheat standard deviation, Germany 1539.149 kg per ha is the largest range of variance. As to the climate condition of producing three crops, we could see that producing maize needs moderate temperature and precipitation, producing rice needs high temperate and precipitation, and producing wheat needs low temperate and precipitation. Moreover, producing wheat area has the bigger inter annual variability of temperature and precipitation than maize and rice.

Table 1. Descriptive Statistics

Country		Yt	Pareat	Atemt	SDtemt	Tprect	SDprept
	Unit	Kg/Ha		℃		mm	
Maize							
Argentina	Mean	3773.384	2.206	20.280	3.533	852.790	51.123
	StDev	1637.101	0.004	4.362	1.744	140.368	21.520
Brazil	Mean	2107.659	5.198	23.231	3.262	898.089	67.951
	StDev	818.969	0.004	1.612	1.341	137.901	29.601
Canada	Mean	6232.104	1.392	16.014	2.616	901.600	40.401
	StDev	1268.622	0.005	6.469	0.617	88.132	12.329
China	Mean	3534.027	30.447	14.738	3.332	655.463	55.171
	StDev	1380.293	0.062	10.460	0.938	172.323	20.657
France	Mean	6407.520	5.163	16.403	4.171	919.046	49.492
	StDev	2012.984	1.197	1.011	0.667	176.085	15.162
India	Mean	1400.002	3.482	23.167	3.982	734.111	70.122
	StDev	408.079	0.004	4.370	0.977	186.305	23.660
Indonesia	Mean	1951.269	7.451	27.710	0.722	1172.200	67.145
	StDev	931.356	0.010	0.657	0.211	158.460	25.648
Mexico	Mean	1884.371	7.153	19.250	1.670	965.900	47.868
	StDev	682.536	0.006	0.789	0.864	163.877	19.327
South Afirca	Mean	2117.18	4.371	17.819	3.309	824.700	85.936
	StDev	897.288	0.008	2.387	0.551	212.286	23.515
USA	Mean	6805.229	6.312	18.896	2.969	714.091	43.182
	StDev	1787.876	0.008	10.457	1.106	76.530	15.182
Rice							
Bangladesh	Mean	2444.31	87.752	25.079	1.690	2253.800	119.415
	StDev	791.504	0.067	1.687	0.628	104.652	29.337
Brazil	Mean	2171.171	2.047	21.440	3.317	1674.059	45.923
	StDev	862.201	0.006	3.265	0.872	138.961	14.108
China	Mean	4796.557	7.185	20.300	0.850	1640.900	63.767
	StDev	1387.134	0.014	2.537	1.126	102.229	15.870
India	Mean	2275.91	22.529	21.292	0.820	2201.556	117.203
	StDev	630.721	0.015	0.812	0.486	132.606	22.319
Indonesia	Mean	3496.855	23.449	27.750	0.752	1836.680	55.857
	StDev	1059.806	0.027	0.681	0.376	87.689	14.507
Japan	Mean	5956.192	39.912	22.067	2.145	1839.427	55.896
	StDev	564.918	0.045	1.557	0.611	93.599	22.406

Country		Yt	Pareat	Atemt	SDtemt	Tprect	SDprept
	Unit	Kg/Ha		℃		mm	
Myanmar	Mean	2675.304	49.718	27.442	2.019	2351.643	108.839
	StDev	802.281	0.076	1.565	1.133	193.816	43.859
Philippines	Mean	2412.253	35.254	28.221	1.126	2237.260	104.190
	StDev	794.488	0.039	1.090	0.121	134.912	37.948
Thailand	Mean	2161.798	48.290	24.470	2.416	1904.083	93.368
	StDev	393.613	0.037	2.404	0.512	117.503	18.061
Vietnam	Mean	3035.6	81.309	26.317	2.078	1883.900	88.627
	StDev	1105.736	0.068	3.051	1.554	168.613	35.103
wheat							
Australia	Mean	1446.208	2.117	17.294	2.194	847.167	20.050
	StDev	363.88	0.005	3.194	1.080	229.137	15.078
Canada	Mean	1974.276	16.361	11.500	6.690	525.110	17.445
	StDev	432.749	0.028	6.899	1.424	158.211	9.638
China	Mean	2632.931	6.077	15.014	1.036	1009.743	54.636
	StDev	1275.702	0.009	9.367	0.303	125.571	21.627
France	Mean	5403.489	14.886	14.912	4.603	736.812	33.165
	StDev	1533.698	2.248	1.002	0.748	126.088	7.613
Germany	Mean	5583.481	13.648	13.73	3.903	659.591	26.233
	StDev	1539.149	2.855	2.406	0.610	108.386	7.272
Indonesia	Mean	1871.100	12.163	17.757	0.944	1058.625	77.880
	StDev	684.587	0.026	5.382	0.695	114.797	23.063
Iran	Mean	1269.302	9.603	14.060	7.696	596.936	19.406
	StDev	484.455	0.018	7.805	2.223	287.216	10.437
Pakistan	Mean	1677.663	27.525	17.817	6.491	456.275	63.812
	StDev	568.57	0.034	8.121	2.019	170.213	16.941
Turkey	Mean	1783.255	23.097	13.390	7.523	372.314	28.528
	StDev	419.576	0.012	7.997	1.474	155.855	13.936
USA	Mean	2347.369	5.492	13.207	1.490	901.373	22.673
	StDev	391.666	0.008	6.333	0.924	167.671	8.059

Note:t and T i:1961 to 2009, Y_t i:e crop yield in metric tons per hectare in the period t, $Parea_t$: ratio of crop planted area to the whole country agricultural area, $Atem_t$:mean of monthly average temperature in Celsius degrees in the period t, $SDtem_t$:standard deviation of monthly mean temperature in the period t, $Tprec_t$: total precipitation in the period t, $SDprep_t$: standard deviation of the monthly total precipitation within the period t

2.2 Estimated Results

First of all, we use the augmented Dickey–Fuller (ADF) root test (Dickey and Fuller, 1979) to ensure whether variables are stationary. Empirical results are shown in Table 2, and we could see the variables display stationary in the test formulation with constant and time trend or only with constant. Then we estimate the yield mean and variance functions of three crops with MLE, and the majority of empirical results are statistically significant at 5% or 10% level. The log-likelihood and R^2 in yield mean and variance functions are the same while MLE is simultaneously estimating the coefficients of the yield mean and variance regressions. In addition, the form of functions we adopt is log-linear, so the estimates stand for the elasticity, which is the ratio of the percentage change in one variable such as crop planted area, temperature, and precipitation to the percentage change in crop yield.

Table 2. ADF Unit Root Test

		Y_t	$Parea_t$	$Atem_t$	$SDtem_t$	$Tprec_t$	$SDprep_t$
Maize							
Argentina	A	-1.075	-2.575*	-3.402**	-3.003**	-1.165	-3.339**
	B	-3.017**	-2.746*	-2.018	-2.688*	-3.309**	-3.577**
Brazil	A	-2.316	-2.173	-3.590**	-1.891	-3.481**	-3.046**
	B	-4.024**	-2.682*	-3.443**	-2.803*	-2.957*	-2.252
Canada	A	-2.032	-2.875*	-2.351	-3.175**	-0.988	-4.028**
	B	-3.526**	-3.037**	-3.486**	-1.785	-2.807*	-2.265
China	A	-1.274	-1.611	-2.124	-3.789**	-2.192	-3.215**
	B	-3.449**	-2.569*	-3.065**	-2.247	-3.250**	-3.083**
France	A	-3.797**	-3.073**	-4.864**	-1.615	-1.056	-3.653**
	B	-2.146	-2.766*	-3.725**	-3.693**	-3.000**	-2.847*
India	A	-2.881*	-3.298**	-1.802	-2.737*	-1.859	-3.400**
	B	-4.135**	-2.493*	-2.726*	-2.705*	-2.757*	-2.260
Indonesia	A	-2.863*	-2.863*	-1.949	-2.894*	-2.186	-3.672**
	B	-3.079**	-2.942*	-3.549**	-2.860*	-3.148**	-2.628*
Mexico	A	-2.233	-1.870	-2.991*	-1.005	-3.173**	-2.011
	B	-3.044**	-2. 622*	-3.204**	-2.854*	-3.135**	-3.197**
South Africa	A	-1.954	-2.269	-3.046**	-1.999	-2.953*	-3.222**
	B	-2.968**	-3.225**	-2.997*	-2.964*	-1.660	-2.528
USA	A	-2.503*	- 2.012	-3.526**	-3.998**	-2.827*	-2.902*
	B	-3.084**	-2.831**	-3.777**	-2.834*	-2.794*	-1.132
Rice							

Bangladesh	A	-2.931*	-3.031**	-3.011**	-3.210**	-3.533**	-3.078**
	B	-2.564*	-2.378	-2.888*	-1.904	-2.095	-2.152
Brazil	A	-2.482	-1.964	-2.965*	-3.564**	-1.102	-2.346
	B	-4.051**	-2.912*	-2.930*	-2.114	-3.294**	-2.625*
China	A	-3.025**	-2.879*	-3.363**	-3.327**	-3.662**	-3.190**
	B	-2.246	-2.471	-2.095	-2.563*	-2.206	-3.417**
India	A	-2.371	-1.862	-2.957*	-2.004	-1.312	-2.921*
	B	-3.098**	-2.869*	-3.168**	-3.192**	-3.923**	-1.143
Indonesia	A	-2.273	-2.925*	-2.781*	-3.387**	-3.728**	-3.248**
	B	-4.090**	-2.122	-1.600	-2.248	-3.575**	-3.115**
Japan	A	-2.866*	-3.120**	-2.092	-3.134**	-3.075**	-3.892**
	B	-2.904*	-1.754	-3.102**	-3.357**	-2.132	-4.169**
Myanmar	A	-1.650	-0.987	-3.253**	-2.825*	-3.065**	-3.577**
	B	-3.407**	-2.804*	-1.829	-1.324	-2.939*	-2.012
Philippine	A	-1.313	-2.689*	-1.088	-3.761**	-2.904*	-3.340**
	B	-2.994**	-2.657*	-3.092**	-2.607*	-2.074	-3.400**
Thailand	A	-3.558**	-2.950*	-2.048	-2.483	-1.813	-2.253
	B	-4.959**	-1.659	-3.037**	-3.957**	-3.224**	-1.197
Vietnam	A	-2.853*	-1.858	-3.495**	-3.203**	-3.010**	-3.844**
	B	-3.319**	-2.754*	-3.454**	-3.165**	-1.079	-2.911*
Wheat							
Australia	A	-2.912*	-1.969	-3.280**	-3.113**	-1.165	-3.537**
	B	-3.164**	-2.571*	-3.514**	-2.442	-3.311**	-2.558*
Canada	A	-1.865	-3.328**	-1.976	-3.621**	-2.875**	-3.516**
	B	-2.840*	-3.191**	-3.495*	-3.879**	-3.137**	-2.085
China	A	-2.849*	-2.965*	-2868*	-1.123	-3.002**	-1.395
	B	-2.831*	-2.844*	-1.112	-3.191**	-2.967*	-3.963**
France	A	-3.075**	-2.765*	-2.307	-3.615**	-2.037	-1.937
	B	-1.868	-3.161**	-3.216**	-2.001	-3.002**	-3.412**
Germany	A	-3.701**	-4.155**	-3.437**	-2.542	-2.713*	-3.855**
	B	-2.444	-1.610	-3.515**	-3.601**	-3.323**	-1.995
India	A	-1.054	-2.810*	-3.158**	-3.060**	-2.193	-3.100**
	B	-2.943*	-2.204	-3.029**	-2.024	-3.252**	-3.755**
Iran	A	-2.738*	-2.980*	-3.514**	-1.011	-4.217**	-3.948**
	B	-2.451	-2.945*	-1.976	-2.873*	-2.371	-2.220
Pakistan	A	-1.065	-3.153**	-3.061**	-2.181	-2.461	-3.091**
	B	-2.838*	-2.870*	-2.048	-3.007**	-3.649**	-3.311**

Turkey	A	-2.814*	-2.773*	-3.137**	-3.203**	-3.909**	-2.862*
	B	-2.962*	-2.970*	-3.253**	-2.165	-2.198	-1.108
USA	A	-2.887*	-3.268**	-2.993*	-2.630*	-3.483**	-2.227
	B	-2.525	-3.501**	-2.213	-3.150**	-1.958	-3.302**

Note: t and T i:1961 to 2009, Y_t i:e crop yield in metric tons per hectare in the period t, $Parea_t$: ratio of crop planted area to the whole country agricultural area, $Atem_t$:mean of monthly average temperature in Celsius degrees in the period t, $SDtem_t$:standard deviation of monthly mean temperature in the period t, $Tprec_t$: total precipitation in the period t, $SDprep_t$: standard deviation of the monthly total precipitation within the period t

2.3 Mean Yield Function

The estimated results of maize, rice, and wheat yield mean regressions are shown from Table 3 to Table 5. In terms of the non-climatic factor within the major producing countries, the ratio of crop planted area and time trend have positive impacts on average yield across three crops. As for the ratio of crop planted area, the rice yield in Thailand is most significantly influenced by the ratio of rice planted area within ten major producing maize countries, where 1% increases of the ratio of rice planted area make 0.208% increases of the rice yield. In India, rice and wheat yield are both most remarkably affected by the ratio of rice planted area within the major producing maize and wheat countries, which elasticity is 0.083 and 0.087, respectively. Time trend variable captures technology progress, and has positive impacts on mean yield of these three crops. The biggest impacted degree of maize, rice and wheat yield is in United State, Japan, and India separately.

From our estimated results, the climatic condition has major impact on the mean yield across these three crops. The average temperature during maize growing season has positive impacts on mean yield of maize in United State, China, Brazil, Argentina, Mexico, India, South Africa, Mexico, and Canada, but has opposite effects on Indonesia. Among them, Canada has the biggest positive impacted degree with rising temperature, and Indonesia has the worst impacted degree, which elasticity is 0.187 and -0.092 individually. We supposed that the appropriate maize growing temperature is between 16 ℃ and 26℃. If the temperature exceeds this range, there is a disadvantageous influence on the maize growth. Therefore, the mean temperature during maize growing season in Indonesia is over 25℃ to bring about the negative impacts of mean temperature on the maize yield, and other nine countries with lower mean temperature is increased with rising temperature. As to other two crops, mean temperature during rice and wheat growing season has detrimental effects on rice and wheat yield, and the largest impacted extent within major producing rice and wheat countries is in Japan and United State, respectively. 1% increases of mean temperature in Japan cause 0.637% decreases of rice yield, and 1% increases of mean temperature in United State induce 0.334% decreases of rice yield. In three crops, the variance in temperature during crop growing season has adverse influences on crop yield. The impacted magnitude of maize yield in India, rice yield in Thailand, and wheat yield in Iran is the largest in major producing countries, which elasticity is -0.718, -0.197, and -0.709, respectively.

Ascending annual total precipitation is harmful to maize and rice yield, and the reduced level of maize yield in Brazil and rice yield in Myanmar is the greatest, which individual elasticity is -0.919 and -0.275. For wheat, there exist disadvantageous relationships between annual total precipitation and wheat yield in China, India, United State, Canada, Pakistan, France, and Germany, and India is most significantly influenced. However, there exist advantageous relationships in Australia, Turkey, and Iran, and Australia has the vastest impacted degree. As for inter-monthly variation in annual precipitation, all of three crop yield is negatively influenced, and the biggest effected degree on these three crops is in India. We think that India is located in tropical monsoon climate area, which features are extraordinarily rainy wet seasons and pronounced dry seasons.

Table 3. Estimated parameters for maize yield mean function

	$Parea_t$	$Atem_t$	$SDtem_t$	$Tprec_t$	$SDprep_t$	T	*Constant*	*Log-likelihood*	R^2
Argentina	0.016**	0.072*	-0.625**	-0.736**	-0.387**	0.101**	44.804**	-1924.719	0.435
	(2.905)	(2.625)	(-3.534)	(-3.157)	(-3.043)	(6.796)	(11.253)		
Brazil	0.017*	0.055**	-0.670**	-0.919*	-0.465**	0.134**	31.493**	-2388.963	0.386
	(2.622)	(2.592)	(-3.391)	(-2.927)	(-3.372)	(8.005)	(17.192)		
Canada	0.017**	0.187**	-0.424**	-0.804**	-0.188**	0.173**	44.303**	-2144.654	0.400
	(2.782)	(2.936)	(-3.137)	(-2.915)	(-2.834)	(9.001)	(11.294)		
China	0.014**	0.142*	-0.511**	-0.708**	-0.304**	0.116**	58.607**	-2279.279	0.302
	(2.891)	(2.639)	(-3.068)	(-3.004)	(-3.146)	(9.851)	(19.321)		
France	0.024**	0.098**	-0.642**	-0.593**	-0.271**	0.184**	45.126**	-2283.519	0.418
	(2.746)	(2.756)	(-3.019)	(-2.854)	(-3.109)	(7.740)	(14.078)		
India	0.022*	0.048*	-0.718**	-0.827**	-0.548**	0.162**	57.601**	-2727.133	0.380
	(2.539)	(2.675)	(-3.463)	(-3.176)	(-3.226)	(7.945)	(16.424)		
Indonesia	0.015**	-0.092**	-0.236**	-0.693**	-0.244**	0.127**	52.623**	-3066.332	0.397
	(2.884)	(-2.886)	(-2.925)	(-2.992)	(-2.913)	(6.904)	(12.741)		
Mexico	0.008*	0.094**	-0.383**	-0.561**	-0.301**	0.092**	50.367**	-2544.909	0.416
	(2.736)	(3.042)	(-2.942)	(-2.944)	(-2.952)	(6.803)	(11.992)		
South Africa	0.010*	0.119*	-0.504**	-0.483*	-0.429**	0.122**	46.999**	-3007.712	0.361
	(2.704)	(2.642)	(-3.029)	(-2.962)	(-3.057)	(7.836)	(13.538)		
USA	0.013*	0.084*	-0.496**	-0.834**	-0.237**	0.198**	42.581**	-2510.552	0.433
	(2.524)	(2.667)	(-3.253)	(-3.022)	(-2.990)	(7.907)	(15.698)		

Note: ** and * indicate 5% and 10% significance levels, respectively.

t-statistics in parentheses.

Note:t and T i:1961 to 2009, Y_t i:e crop yield in metric tons per hectare in the period t, $Parea_t$: ratio of crop planted area to the whole country agricultural area, $Atem_t$:mean of monthly average temperature in Celsius degrees in the period t, $SDtem_t$:standard deviation of monthly mean temperature in the period t, $Tprec_t$: total precipitation in the period t, $SDprep_t$: standard deviation of the monthly total precipitation within the period t

Table 4. Estimated parameters for rice yield mean function

	Pareat	*Atemt*	*SDtemt*	*Tprect*	*SDprept*	*T*	*Constant*	*Log-likelihood*	R^2
Bangladesh	0.205**	-0.331*	-0.103**	-0.168**	-0.281**	0.200**	60.101**	-2155.340	0.414
	(3.188)	(-2.628)	(-3.149)	(-3.064)	(-2.994)	(12.934)	(17.913)		
Brazil	0.056*	-0.428*	-0.093**	-0.068*	-0.258**	0.232**	52.631**	-2929.384	0.466
	(2.648)	(-2.655)	(-3.007)	(-2.651)	(-2.863)	(10.193)	(14.820)		
China	0.101**	-0.524*	-0.078**	-0.175**	-0.232**	0.269**	80.853**	-2019.752	0.481
	(3.146)	(-2.683)	(-3.461)	(-3.096)	(-2.980)	(13.035)	(25.047)		
India	0.083*	-0.303**	-0.059**	-0.207**	-0.374**	0.261**	69.297**	-2228.034	0.353
	(2.775)	(-3.057)	(-3.118)	(-3.154)	(-3.081)	(14.288)	(18.369)		
Indonesia	0.149*	-0.362**	-0.034**	-0.092**	-0.207**	0.227**	67.126**	-2584.619	0.428
	(2.652)	(-3.477)	(-3.192)	(-2.915)	(-3.243)	(13.106)	(15.085)		
Japan	0.097**	-0.637**	-0.118**	-0.240**	-0.095**	0.318**	68.936**	-2554.361	0.319
	(3.115)	(-3.169)	(-3.193)	(-3.195)	(-3.270)	(15.074)	(19.777)		
Myanmar	0.115*	-0.412*	-0.105**	-0.275**	-0.223**	0.176**	60.542**	-2500.176	0.436
	(2.709)	(-3.160)	(-3.292)	(-3.219)	(-3.184)	(12.824)	(18.079)		
Philippine	0.087*	-0.357**	-0.048**	-0.237**	-0.056**	0.204**	71.019**	-1924.665	0.322
	(2.663)	(-3.291)	(-3.066)	(-2.952)	(-3.303)	(11.815)	(22.642)		
Thailand	0.208*	-0.561**	-0.197**	-0.153**	-0.319**	0.283**	56.765**	-2385.943	0.371
	(2.731)	(-3.249)	(-2.948)	(-3.148)	(-3.102)	(11.179)	(17.408)		
Vietnam	0.036*	-0.509**	-0.156**	-0.102**	-0.203**	0.192**	75.826**	-3028.572	0.335
	(2.692)	(-2.952)	(-3.021)	(-2.981)	(-2.846)	(10.881)	(21.394)		

Note: ** and * indicate 5% and 10% significance levels, respectively.

t-statistics in parentheses.

Note:t and T i:1961 to 2009, Y_t i:e crop yield in metric tons per hectare in the period t, $Parea_t$: ratio of crop planted area to the whole country agricultural area, $Atem_t$:mean of monthly average temperature in Celsius degrees in the period t, $SDtem_t$:standard deviation of monthly mean temperature in the period t, $Tprec_t$: total precipitation in the period t, $SDprep_t$: standard deviation of the monthly total precipitation within the period t

Table 5. Estimated parameters for wheat yield mean function

	$Parea_t$	$Atem_t$	$SDtem_t$	$Tprec_t$	$SDprep_t$	T	*Constant*	*Log-likelihood*	R^2
Australia	0.059** (3.291)	-0.218** (-3.129)	-0.563** (-2.964)	0.282** (2.937)	-0.592** (-3.297)	0.307** (4.469)	52.907** (18.964)	-2303.412	0.442
Canada	0.043** (2.894)	-0.196** (-2.770)	-0.375** (-2.882)	-0.176** (-3.251)	-0.318** (-2.945)	0.220** (5.518)	57.002** (16.848)	-2630.920	0.376
China	0.066** (2.890)	-0.278* (-2.693)	-0.405** (-3.387)	-0.264** (-2.918)	-0.718** (-2.833)	0.265** (6.894)	37.195** (14.332)	-2158.509	0.485
France	0.045** (2.926)	-0.239** (-3.008)	-0.416** (-2.959)	-0.201** (3.163)	-0.427** (-3.204)	0.285** (5.613)	48.376** (17.094)	-2418.367	0.433
Germany	0.051** (3.069)	-0.214** (-2.823)	-0.470** (-2.915)	-0.188** (-2.832)	-0.396** (-3.150)	0.300** (6.146)	44.935** (17.212)	-2394.052	0.409
India	0.087** (3.247)	-0.239** (-2.908)	-0.432** (-3.149)	-0.347** (-2.772)	-0.907** (-3.171)	0.371 (6.515)	38.227** (15.361)	-3054.345	0.378
Iran	0.012** (2.773)	-0.199* (-2.652)	-0.709** (-3.031)	0.179** (3.024)	-0.317** (-2.963)	0.305** (6.494)	35.172** (15.199)	-2305.425	0.327
Pakistan	0.018** (2.925)	-0.240* (-2.671)	-0.507** (-3.013)	-0.164** (-2.887)	-0.362** (-2.971)	0.294** (5.573)	35.433** (12.385)	-1901.597	0.241
Turkey	0.033** (3.104)	-0.225* (-2.709)	-0.624** (-3.249)	0.209** (3.063)	-0.483** (-3.190)	0.144** (4.969)	40.174** (17.096)	-2252.334	0.348
USA	0.034** (3.013)	-0.334** (-3.008)	-0.294** (-2.813)	-0.192** (-3.254)	-0.556** (-2.894)	0.218** (5.424)	51.834** (14.543)	-2503.720	0.415

Note: ** and * indicate 5% and 10% significance levels, respectively.

t-statistics in parentheses.

Note:t and T i:1961 to 2009, Y_t i:e crop yield in metric tons per hectare in the period t, $Parea_t$: ratio of crop planted area to the whole country agricultural area, $Atem_t$:mean of monthly average temperature in Celsius degrees in the period t, $SDtem_t$:standard deviation of monthly mean temperature in the period t, $Tprec_t$: total precipitation in the period t, $SDprep_t$: standard deviation of the monthly total precipitation within the period t

2.4 Variance of Yield Function

The estimated results of maize, rice, and wheat yield variance regressions are shown from Table 6 to Table 8. Increases in the ratio of crop planted area and time trend reduce maize, rice, and wheat yield variance. Among the producing crop countries, maize yield variance in France, rice yield variance in Brazil, and wheat yield variance in Germany are most significantly negatively impacted by the crop planted area, which elasticity is -0.018, -0.128, and -0.047, respectively. Time trend has the greatest effects on maize yield variance in United State, rice yield variance in India, and wheat yield variance in Germany.

Crop yield variance is remarkably influenced by climatic factors. Compared with crop mean yield, the change in variability of maize, rice, and wheat yield caused by the change in climatic factors is much greater than crop mean yield. Moreover, all of the climatic factors in this study have positive impacts on crop yield variance. The largest impacted magnitude of increases in mean temperature during crop growing season causing variability of maize, rice, and wheat yield is in Indonesia (elasticity 0.810), in Japan(2.525%), and in Canada(1.020%) within major producing crop countries,. Rice yield variance in Japan and wheat yield variance in Canada are also most impacted by variance in temperature during crop growing season, which elasticity is 0.510 and 1.807, respectively. As to maize yield variance, India has the greatest impacted degree, where 1% increases in variance in temperature during crop growing season enlarge 0.417% increases in maize yield variance. The biggest impacted magnitude of increase in annual total precipitation causing variability of maize and rice yield is in India within major producing these two crops countries, which individual elasticity is 0.371 and 1.382. The greatest increased magnitude of annual precipitation affecting wheat yield variance is in Egypt, where 1% increases in annual precipitation enlarge 0.398% increases in wheat yield variance. Where the greatest increased magnitude of inter-monthly variability of annual precipitation impacting maize, rice, and wheat yield variance is in India, which individual elasticity is 0.279, 1.748, and 1.754. The supposed reason is also the climate in India is tropical monsoon climate.

Table 6. Estimated parameters for maize yield variance function

	$Parea_t$	$Atem_t$	$SDtem_t$	$Tprec_t$	$SDprep_t$	T	*Constant*
Argentina	-0.006*	0.313**	0.264**	0.157*	0.135**	-0.155**	12.071**
	(-2.664)	(3.016)	(3.004)	(2.677)	(2.914)	(-3.384)	(5.953)
Brazil	-0.013*	0.524**	0.287**	0.212**	0.167**	-0.162**	9.070**
	(-2.553)	(2.888)	(3.110)	(3.002)	(2.857)	(-3.122)	(5.662)
Canada	-0.013**	0.508**	0.108**	0.189**	0.092**	-0.204**	8.006**
	(-3.256)	(2.994)	(2.720)	(3.141)	(3.061)	(-3.988)	(4.923)
China	-0.009**	0.672*	0.228**	0.316**	0.148**	-0.174**	10.809**
	(-2.912)	(2.601)	(2.964)	(3.184)	(3.106)	(-3.540)	(7.070)
France	-0.018*	0.475**	0.261**	0.220*	0.151**	-0.219**	8.634**
	(-2.705)	(2.923)	(3.018)	(3.043)	(2.928)	(-3.667)	(5.016)
India	-0.016**	0.597**	0.417**	0.371*	0.279**	-0.158**	11.627**
	(-2.821)	(2.931)	(3.240)	(3.205)	(2.996)	(-4.296)	(5.538)
Indonesia	-0.002**	0.810**	0.152**	0.262**	0.115**	-0.185**	9.010**
	(-2.871)	(3.239)	(2.907)	(2.876)	(2.801)	(-4.176)	(5.377)
Mexico	-0.012**	0.294*	0.133**	0.204*	0.096**	-0.091**	8.830**
	(-2.787)	(2.605)	(2.762)	(6.648)	(3.090)	(-3.949)	(4.529)
South	-0.007**	0.456*	0.290**	0.243**	0.203**	-0.167**	9.660**
Africa	(-3.021)	(2.712)	(3.125)	(2.762)	(3.183)	(-3.241)	(4.715)
USA	-0.010*	0.348**	0.129**	0.255**	0.102**	-0.231**	9.339**
	(-2.599)	(3.192)	(2.818)	(2.907)	(3.064)	(-4.028)	(6.891)

Note: ** and * indicate 5% and 10% significance levels, respectively.
t-statistics in parentheses.
Note:t and T i:1961 to 2009, Y_t i:e crop yield in metric tons per hectare in the period t, $Parea_t$: ratio of crop planted area to the whole country agricultural area, $Atem_t$:mean of monthly average temperature in Celsius degrees in the period t, $SDtem_t$:standard deviation of monthly mean temperature in the period t, $Tprec_t$: total precipitation in the period t, $SDprep_t$: standard deviation of the monthly total precipitation within the period t

Table 7. Estimated parameters for rice yield variance function

	$Parea_t$	$Atem_t$	$SDtem_t$	$Tprec_t$	$SDprep_t$	T	$Constant$
Bangladesh	-0.099**	0.913**	0.162**	1.056**	1.354**	-0.115**	8.947**
	(-2.993)	(2.916)	(2.774)	(3.017)	(3.091)	(-4.098)	(4.697)
Brazil	-0.128*	1.793**	0.404**	0.338**	0.563**	-0.080**	6.710**
	(-2.709)	(3.184)	(2.738)	(2.914)	(2.991)	(-3.592)	(4.389)
China	-0.054*	2.114**	0.089**	0.594**	0.829**	-0.185**	13.381**
	(-2.653)	(2.977)	(3.145)	(2.956)	(2.782)	(-4.631)	(5.427)
Vietnam	-0.021**	1.176**	0.277**	0.424**	0.897**	-0.092**	9.549**
	(-3.026)	(3.251)	(2.823)	(2.823)	(2.990)	(-3.861)	(5.627)
India	-0.042**	1.028**	0.072**	1.382**	1.748**	-0.204**	7.469**
	(-3.182)	(3.094)	(2.926)	(3.215)	(3.116)	(-5.177)	(4.691)
Indonesia	-0.019*	0.751**	0.053**	0.508*	0.817*	-0.131**	10.489**
	(-2.605)	(3.159)	(3.081)	(2.749)	(2.983)	(-4.652)	(5.615)
Japan	-0.045**	2.525**	0.510**	0.642**	-1.642**	-0.176**	7.409**
	(-2.873)	(2.926)	(3.122)	(3.127)	(3.127)	(-5.240)	(4.872)
Vietnam	-0.009**	0.570*	0.236**	0.819*	1.044**	-0.123**	11.020**
	(-2.924)	(2.683)	(3.159)	(2.772)	(2.923)	(-4.529)	(6.844)
Philippine	-0.073*	0.493*	0.128**	0.265*	1.149**	-0.054**	17.754**
	(-2.636)	(2.661)	(2.964)	(2.647)	(2.875)	(-4.167)	(5.708)
Thailand	-0.085**	1.632**	0.305**	0.671**	0.901**	-0.159**	10.395**
	(-2.837)	(3.008)	(2.917)	(2.960)	(2.806)	(-3.973)	(6.043)

Note: ** and * indicate 5% and 10% significance levels, respectively.

t-statistics in parentheses.

Note:t and T i:1961 to 2009, Y_t i:e crop yield in metric tons per hectare in the period t, $Parea_t$: ratio of crop planted area to the whole country agricultural area, $Atem_t$:mean of monthly average temperature in Celsius degrees in the period t, $SDtem_t$:standard deviation of monthly mean temperature in the period t, $Tprec_t$: total precipitation in the period t, $SDprep_t$: standard deviation of the monthly total precipitation within the period t

Table 8. Estimated parameters for wheat yield variance function

	$Parea_t$	$Atem_t$	$SDtem_t$	$Tprec_t$	$SDprep_t$	T	$Constant$
Australia	-0.010**	0.731**	1.252**	0.166**	1.288**	-0.094**	2.795**
	(-2.965)	(2.804)	(2.941)	(2.825)	(3.164)	(-3.845)	(4.173)
Canada	-0.018**	1.020**	1.807**	0.273**	0.451**	-0.107**	3.180**
	(-2.804)	(2.983)	(2.953)	(3.164)	(2.876)	(-4.441)	(5.463)
China	-0.042*	0.639**	1.342**	0.087**	1.539**	-0.163**	2.447**
	(-2.618)	(2.941)	(2.918)	(3.026)	(3.162)	(-4.490)	(5.707)
France	-0.040**	0.906**	1.675**	0.234**	0.843**	-0.195**	3.018**
	(-2.835)	(3.114)	(3.182)	(2.907)	(3.029)	(-4.164)	(4.755)
Germany	-0.047**	1.008**	1.439**	0.212**	0.775**	-0.213**	3.276**
	(-3.129)	(2.925)	(3.064)	(2.958)	(3.128)	(-4.192)	(5.049)
India	-0.036**	0.157**	0.704**	0.069**	1.754**	-0.115**	3.658**
	(-3.328)	(2.863)	(3.317)	(2.874)	(3.220)	(-4.006)	(6.021)
Iran	-0.027**	0.839**	1.062**	0.151**	0.500**	-0.059**	2.213**
	(-3.146)	(3.221)	(2.809)	(2.862)	(2.895)	(-4.273)	(4.592)
Pakistan	-0.031**	0.243**	1.194**	0.338*	0.679**	-0.036**	2.019**
	(-3.222)	(3.116)	(3.018)	(3.295)	(3.002)	(-3.906)	(3.846)
Turkey	-0.013*	0.778**	1.126**	0.287*	0.912**	-0.067**	2.321**
	(-2.676)	(3.052)	(3.246)	(2.943)	(3.049)	(-4.128)	(5.239)
USA	-0.009**	0.594**	1.567*	0.135**	1.046**	-0.138**	4.963**
	(-3.147)	(3.127)	(2.680)	(3.251)	(2.943)	(-3.927)	(5.918)

Note: ** and * indicate 5% and 10% significance levels, respectively.

t-statistics in parentheses.

Note:t and T i:1961 to 2009, Y_t i:e crop yield in metric tons per hectare in the period t, $Parea_t$: ratio of crop planted area to the whole country agricultural area, $Atem_t$:mean of monthly average temperature in Celsius degrees in the period t, $SDtem_t$:standard deviation of monthly mean temperature in the period t, $Tprec_t$: total precipitation in the period t, $SDprep_t$: standard deviation of the monthly total precipitation within the period t

3. IPCC Climate Scenario and Climate Model

This study applied Crop Yield Model to realize the crop production impacts from climate factors (mean temperature and total precipitation), technical progress and crop harvesting from 1961 to 2009. Then we utilize the simulated annual mean temperature and annual total precipitation data under IPCC A1B Scenario from five climate models, including HadCM3, Miroc3.2 (medres), ECHAM5, CSIRO-MK3.0, and CNRM-CM3 to connect our estimated results. We use 2000 (the average value from 1961 to 2000) as baseline to calculate corresponding percentage change of mean temperature and precipitation in 2030 (the average value from 2021 to 2030), 2040 (the average value from 2031 to 2040), and 2050 (the average value from 2041 to 2050), this study combine the estimated results and percentage change of mean temperature and precipitation in 2030, 2040, and 2050 to predict the influences of future climate change on three crop yield distribution, as resented in Table 10. In 2030, 2040, and 2050, future global mean temperature and annual precipitation in five climate models for A1B scenario will all be increased, and we sum up the effects of future temperature and precipitation change on mean yield as the effects of future climate change on mean yield.

3.1 IPCC Climate Scenario

The Intergovernmental Panel on Climate Change (IPCC) developed long-term emissions scenarios which have been widely used in the analysis of possible climate change, its impacts, and strategies to mitigate climate change. In 1996, IPCC Plenary developed the newest set of scenarios. The new set of scenarios is presented in Special Report of IPCC Working Group III Report- Emissions Scenarios.

By 2100 the world will have changed in ways that are difficult to imagine – as difficult as it would have been at the end of the 19th century to imagine the changes of the 100 years since. The scenarios built up four different baselines, in which each assumes a distinctly different direction for future developments, such that the four baselines differ in increasingly irreversible ways. Together they describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces. They cover a wide range of key "future" characteristics such as demographic change, economic development, and technological change. For this reason, their plausibility or feasibility should not be considered solely on the basis of an extrapolation of current economic, technological, and social trends. Table 8 describes the main Characteristics of the four SRES storylines and scenario families

We choose A1B as our study's climate scenario, and the details about the four baselines are as follows:

• The A1 baseline describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources(A1B)(Balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies.)

•The A2 baseline describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

•The B1 baseline describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 baseline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

• The B2 baseline describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 baselines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels

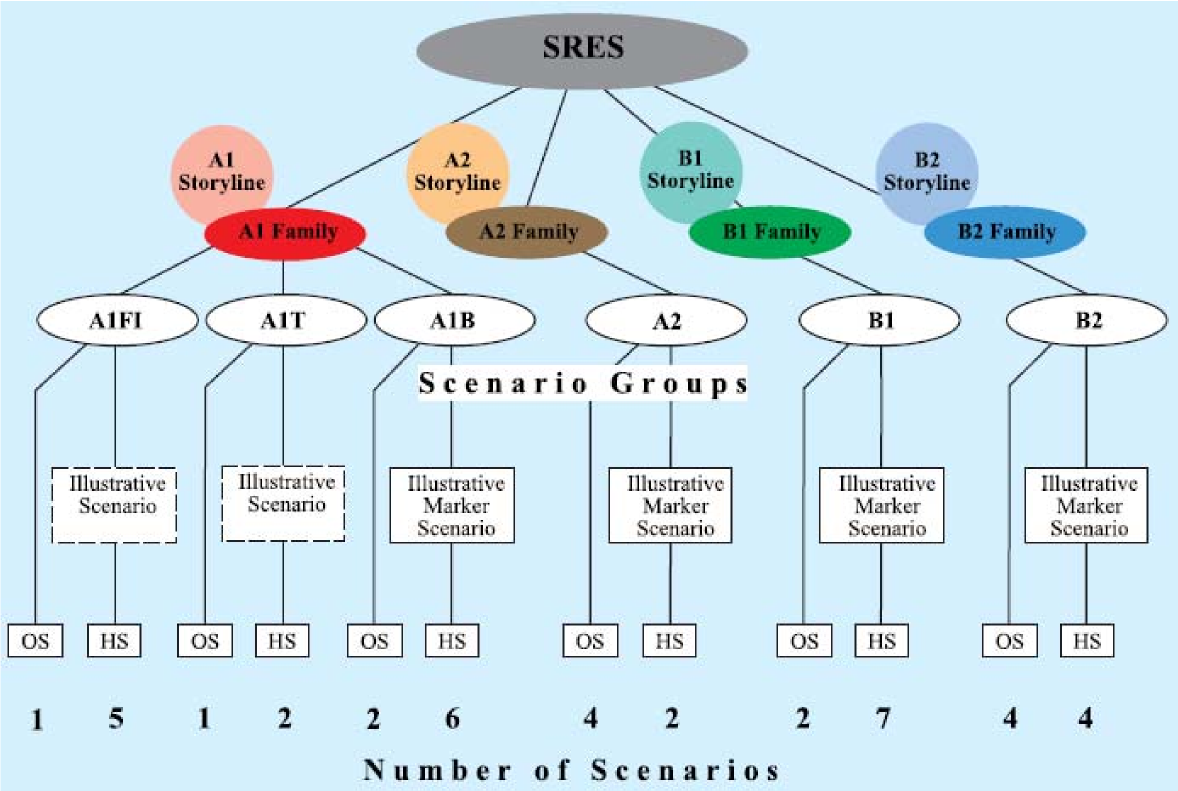

Figure 1 Main Characteristics of the four SRES storylines and scenario families Source: Intergovernmental Panel on Climate Change (2007)

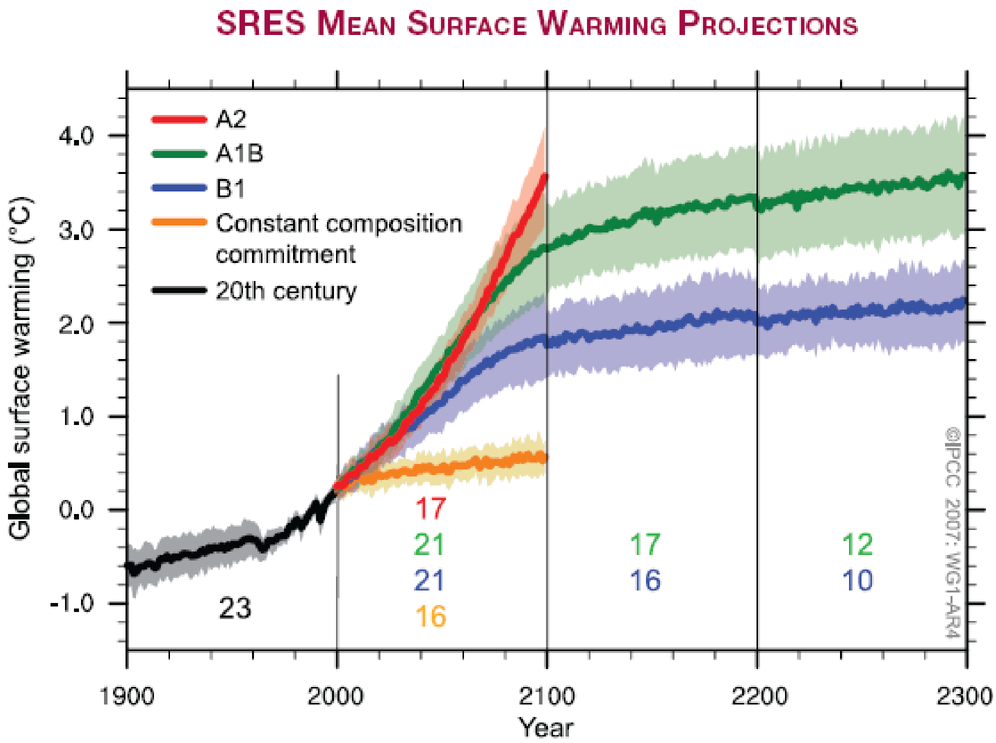

Figure 2 Temperature scenario ranges for various GHG emissions pathways

Source: Intergovernmental Panel on Climate Change (2007)

Figure 2 shows the range of average surface temperature outcomes for the GHG pathways un the SRES scenarios of the IPCC .By 2030, 2040 and 2050,the global surface warming for the A1B, A2 and B1senarios are roughly the same, at about 1℃ above the reference period of the 20th century. Because the temperature from A2, A1B and B1 scenarios differs little, and there is no single emissions scenario that is viewed as most likely. We apply A1B scenario in this projection.

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999) [a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations [b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:
[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity (EMICs), and a large number of Atmosphere-Ocean Global Circulation Models (AOGCMs).
[b] Year 2000 constant composition is derived from AOGCMs only.

Figure 3 Projected global average surface warming and sea level rise at the end of the 21st century

Source: Intergovernmental Panel on Climate Change (2007)

3.2 IPCC Climate Model

IPCC have confidence in model estimates of future climate evolution, which are based on well-established physical principles and have been demonstrated to reproduce observed features of recent climate and past climate changes. There is considerable confidence that Atmosphere-Ocean General Circulation Models (AOGCMs) provide credible quantitative estimates of future climate change, particularly at continental and larger scales. Confidence in these estimates is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation). There are 23 AOGCMs used widely in AR4 report.

Due to nonlinearities in the processes governing climate, the climate system response to perturbations depends to some extent on its basic state (Spelman and Manabe, 1984).Consequently, for models to predict future climatic conditions reliably, they must simulate the current climatic state with some as yet unknown degree of fidelity. Poor model skill in simulating present climate could indicate that certain physical or dynamical processes have been misrepresented. The better a model simulates the complex spatial patterns and seasonal and diurnal cycles of present climate, the more confidence there is that all the important processes have been adequately represented. However, there still lots of way to evaluated ‘’which one’’ is the best suitable model.

Here, the models have understated the problem. In reality the events are all within the upper range of the model’s predictions. There are other examples of models being too conservative, rather than alarmist as some portray them. All models have limits - uncertainties - for they are modeling chaotic systems. However, all models improve over time, and with increasing sources of real-world information such as satellites, the output of climate models can be constantly refined to increase their power and usefulness.

Ho. et al apply the technique of virtual reality based on the results of numerical simulations for describing the effects due to climate changes and sea level rising resulted from global warming as well as extreme climate. The project adopted HADCM3 climate model ,which Ho pointed out that from 23 IPCC climate models it has the highest correlation coefficient (Temperature 0.99, Precipitation 0.77)with Taiwan climate in the simulation for the short-period (in 2025 year), middle-period (in 2055 year), and the long-period (in 2085 year) of climate changes. Regarding to this, we chose HADCM3 for our climate factor simulation, and selected the other four models-MIROC3.2(MEDRES), ECHAM5, CSIRO-MK3.0, CNRM-CM3 to analyze various result from different predicted climate scenarios.

Table 9 shows five selected models features. the AOGCMs participating in the

MMD at PCMDI are listed by IPCC identification (ID) along with the calendar year (‘vintage’) of the first publication of results from each model. And their respective sponsoring institutions, the pressure at the top of the atmospheric model, the horizontal and vertical resolution of the model atmosphere and ocean models, as well as the oceanic vertical coordinate type and the characteristics of sea ice dynamics/ structure, and whether adjustments of surface momentum, heat or freshwater fluxes are applied in coupling the atmosphere, ocean and sea ice components. Land features such as the representation of soil moisture.

Table 9 The Features of the five climate models this study adopted

Model ID, Vintage	**Sponsor(s), Country**	Atmosphere Top Resolution[a] References	Ocean Resolution[b] Z Coord., Top BC References	**Sea Ice** **Dynamics, Leads** **References**	**Coupling** **Flux Adjustments** **References**	**Land** **Soil, Plants, Routing** **References**
CNRM-CM3, 2004	Météo-France/Centre National de Recherches Météorologiques, France	top = 0.05 hPa T63 (~1.9° x 1.9°) L45 Déqué et al., 1994	0.5°–2° x 2° L31 depth, rigid lid Madec et al., 1998	rheology, leads Hunke-Dukowicz, 1997; Salas-Mélia, 2002	no adjustments Terray et al., 1998	layers, canopy,routing Mahfouf et al., 1995; Douville et al., 1995; Oki and Sud, 1998
CSIRO-MK3.0, 2001	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research, Australia	top = 4.5 hPa T63 (~1.9° x 1.9°) L18 Gordon et al., 2002	0.8° x 1.9° L31 depth, rigid lid Gordon et al., 2002	rheology, leads O'Farrell, 1998	no adjustments Gordon et al., 2002	layers, canopy Gordon et al., 2002
ECHAM5, 2005	Max Planck Institute for Meteorology, Germany	top = 10 hPa T63 (~1.9° x 1.9°) L31 Roeckner et al., 2003	1.5° x 1.5° L40 depth, free surface Marsland et al., 2003	rheology, leads Hibler, 1979; Semtner, 1976	no adjustments Jungclaus et al., 2005	bucket, canopy, routing Hagemann, 2002; Hagemann and Dümenil-Gates, 2001

Model ID, Vintage	**Sponsor(s), Country**	Atmosphere Top Resolution[a] References	Ocean Resolution[b] Z Coord., Top BC References	**Sea Ice** **Dynamics, Leads** **References**	**Coupling** **Flux Adjustments** **References**	**Land** **Soil, Plants, Routing** **References**
MIROC3.2(hires), 2004	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	top = 40 km T106 (~1.1° x 1.1°) L56 K-1 Developers, 2004	0.2° x 0.3° L47 sigma/depth, free surface K-1 Developers, 2004	rheology, leads K-1 Developers, 2004	no adjustments K-1 Developers, 2004	layers, canopy, routing K-1 Developers, 2004; Oki and Sud, 1998
UKMO-HadCM3, 1997	Hadley Centre for Climate Prediction and Research/Met Offi ce, UK	top = 5 hPa 2.5° x 3.75° L19 Pope et al., 2000	1.25° x 1.25° L20 depth, rigid lid Gordon et al., 2000	free drift, leads Cattle and Crossley, 1995	no adjustments Gordon et al., 2000	layers, canopy, routing Cox et al., 1999

Predicted Climate Data

Five climate models Predict Future Global Temperature and Precipitation Changes in A1B scenario (year 2030, 2040 and 2050).

Table 10 Five climate models Predict Future Global Temperature and Precipitation Changes in A1B scenario

Unit: %

Climate Model		**2030**	**2040**	**2050**
HadCM3	Temperature	0.395	0.490	0.633
	Precipitation	0.824	1.131	1.377
MIROC3.2(MEDRES)	Temperature	0.389	0.525	0.620
	Precipitation	1.033	1.400	1.919
ECHAM5	Temperature	0.316	0.430	0.580
	Precipitation	1.054	1.638	2.331
CSIRO-MK3.0	Temperature	0.315	0.382	0.440
	Precipitation	1.518	1.817	2.210
CNRM-CM3	Temperature	0.486	0.618	0.752
	Precipitation	1.322	1.913	2.729

Note: 2000 data is the average between 1960-2000, 2030 data is the average between 2021-2030, 2040 data is the average between 2031-2040, 2050 data is the average between 2041-2050.

4. Prediction of the impacts of future climate change on crop yield distribution

This study utilizes the simulated annual mean temperature and annual total precipitation data under A1B Scenario from five climate models, including HadCM3, Miroc3.2 (medres), ECHAM5, CSIRO-MK3.0, and CNRM-CM3 to connect our estimated results. We use 2000 (the average value from 1961 to 2000) as baseline to calculate corresponding percentage change of mean temperature and precipitation in 2030 (the average value from 2021 to 2030), 2040 (the average value from 2031 to 2040), and 2050 (the average value from 2041 to 2050).

These five climate models belong to Atmosphere Ocean General Circulation Model (hereafter AOGCMs) is a numerical representation model of the general circulation of atmosphere and ocean and based on physics, chemistry, and biology to construct past and future global atmospheric circulation characteristic and climate change. AOGCMs conclude twenty three climate models from fourteen climate research centers, and HadCM3, Miroc3.2 (medres), ECHAM5, CSIRO-MK3.0, and

CNRM-CM3 is built by Hadley Centre for Climate Prediction and Research/Met Office, Center for Climate System Research (University of Tokyo), Max Planck Institute for Meteorology, Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research, Météo-France/Centre National de Recherches Météorologiques, respectively. The relative introduction of these five climate models is shown 1n Table 11. Then, this study combine the estimated results and percentage change of mean temperature and precipitation in 2030, 2040, and 2050 to predict the influences of future climate change on three crop yield distribution. In 2030, 2040, and 2050, future global mean temperature and annual precipitation in five climate models for A1B scenario will all be increased, and we sum up the effects of future temperature and precipitation change on mean yield as the effects of future climate change on mean yield.

For maize, future climate change under A1B scenario cause the mean yield of maize in these ten main producing maize countries to decrease, and India has the biggest decreased degrees, which is -2.137~-3.312% in 2030, -2.593~-4.211% in 2040, and -2.989~-5.114% in 2050. For rice, future climate change under A1B scenario make the mean yield of rice in these ten main producing rice countries declined, and the decline level is bigger and bigger. Future climate change effects the mean yield of rice in Philippines most, and the influence scope is -0.315~-0.497% in 2030, -0.382~-0.630% in 2040, and -0.439~-760% in 2050. For wheat, future climate change under A1B scenario will reduce the mean yield of wheat in these ten main producing wheat countries, and the deduced magnitude rises gradually. Future climate change is predicted to affect the mean yield of wheat in Australia most, and the influence scope is -2.246~-3.487% in 2030, -2.726~-4.432% in 2040, and -3.141~-5.380% in 2050.

Table 11 Predicted variations in crop mean and variance yield to variations in climate factors

Maize	Climate Model	2030	2040	2050	Rice	2030	2040	2050	Wheat	2030	2040	2050
Argentina	HadCM3	-1.619	-2.011	-2.596	Bangladesh	-0.346	-0.420	-0.549	Australia	-2.84	-3.52	-4.55
	MIROC3.2(MEDRES)	-1.607	-2.166	-2.574		-0.324	-0.437	-0.497		-2.79	-3.77	-4.44
	ECHAN5	-1.316	-1.802	-2.438		-0.248	-0.322	-0.426		-2.26	-3.07	-4.15
	CSIRO-MK3.0	-1.338	-1.622	-1.877		-0.213	-0.260	-0.292		-2.25	-2.73	-3.14
	CNRM-CM3	-1.857	-2.349	-2.833		-0.403	-0.495	-0.573		-3.49	-4.43	-5.38
Brazil	HadCM3	-1.799	-2.227	-2.881	Brazil	-0.230	-0.281	-0.366	Canada	-1.69	-2.09	-2.71
	MIROC3.2(MEDRES)	-1.769	-2.384	-2.814		-0.219	-0.294	-0.338		-1.66	-2.24	-2.64
	ECHAN5	-1.434	-1.948	-2.627		-0.170	-0.223	-0.297		-1.35	-1.83	-2.47
	CSIRO-MK3.0	-1.423	-1.727	-1.991		-0.152	-0.185	-0.210		-1.34	-1.62	-1.87
	CNRM-CM3	-2.276	-2.893	-3.513		-0.272	-0.337	-0.396		-2.08	-2.64	-3.20
Canada	HadCM3	-1.618	-2.004	-2.591	China	-0.275	-0.333	-0.436	China	-2.21	-2.73	-3.53
	MIROC3.2(MEDRES)	-1.595	-2.150	-2.542		-0.256	-0.344	-0.388		-2.17	-2.93	-3.46
	ECHAN5	-1.296	-1.765	-2.383		-0.193	-0.248	-0.327		-1.76	-2.39	-3.23
	CSIRO-MK3.0	-1.296	-1.572	-1.813		-0.160	-0.196	-0.218		-1.75	-2.12	-2.45
	CNRM-CM3	-1.991	-2.535	-3.086		-0.318	-0.389	-0.446		-2.71	-3.45	-4.19
China	HadCM3	-1.550	-1.918	-2.481	India	-0.302	-0.376	-0.485	France	-2.30	-2.84	-3.67
	MIROC3.2(MEDRES)	-1.525	-2.055	-2.427		-0.302	-0.406	-0.485		-2.26	-3.04	-3.60
	ECHAN5	-1.237	-1.682	-2.269		-0.249	-0.342	-0.464		-1.83	-2.49	-3.36
	CSIRO-MK3.0	-1.231	-1.493	-1.722		-0.257	-0.311	-0.361		-1.82	-2.21	-2.55
	CNRM-CM3	-1.904	-2.421	-2.942		-0.377	-0.484	-0.596		-2.83	-3.60	-4.38

Maize	Climate Model	2030	2040	2050	Rice	2030	2040	2050	Wheat	2030	2040	2050
France	HadCM3	-1.647	-2.041	-2.638	Indonesia	-0.374	-0.458	-0.596	Germany	-2.12	-2.63	-3.40
	MIROC3.2(MEDRES)	-1.625	-2.190	-2.592		-0.358	-0.482	-0.557		-2.09	-2.81	-3.32
	ECHAN5	-1.322	-1.802	-2.434		-0.280	-0.371	-0.495		-1.69	-2.30	-3.10
	CSIRO-MK3.0	-1.325	-1.608	-1.856		-0.257	-0.313	-0.355		-1.68	-2.04	-2.35
	CNRM-CM3	-2.029	-2.585	-3.150		-0.445	-0.555	-0.656		-2.61	-3.31	-4.02
India	HadCM3	-2.698	-3.339	-4.320	Japan	-0.182	-0.213	-0.285	India	-2.69	-3.33	-4.31
	MIROC3.2(MEDRES)	-2.654	-3.576	-4.222		-0.155	-0.209	-0.218		-2.65	-3.57	-4.21
	ECHAN5	-2.151	-2.923	-3.943		-0.103	-0.118	-0.147		-2.15	-2.92	-3.94
	CSIRO-MK3.0	-2.137	-2.593	-2.989		-0.052	-0.066	-0.064		-2.14	-2.59	-2.99
	CNRM-CM3	-3.312	-4.211	-5.114		-0.191	-0.218	-0.221		-3.30	-4.20	-5.11
Indonesia	HadCM3	-2.473	-3.073	-3.966	Myanmar	-0.343	-0.428	-0.551	Iran	-1.98	-2.45	-3.17
	MIROC3.2(MEDRES)	-2.457	-3.312	-3.940		-0.344	-0.464	-0.555		-1.94	-2.62	-3.09
	ECHAN5	-2.016	-2.762	-3.739		-0.285	-0.394	-0.535		-1.57	-2.13	-2.88
	CSIRO-MK3.0	-2.055	-2.490	-2.883		-0.297	-0.360	-0.418		-1.55	-1.89	-2.17
	CNRM-CM3	-3.071	-3.929	-4.817		-0.430	-0.554	-0.685		2.49	3.17	3.86
Mexico	HadCM3	-2.068	-2.558	-3.310	Philippines	-0.407	-0.503	-0.652	Pakistan	-2.63	-3.26	-4.21
	MIROC3.2(MEDRES)	-2.031	-2.738	-3.229		-0.364	-0.491	-0.568		-2.58	-3.48	-4.11
	ECHAN5	-1.644	-2.233	-3.010		-0.321	-0.434	-0.585		-2.09	-2.84	-3.82
	CSIRO-MK3.0	-1.629	-1.977	-2.278		-0.315	-0.382	-0.439		-2.07	-2.51	-2.89
	CNRM-CM3	-2.535	-3.221	-3.907		-0.497	-0.630	-0.761		-3.23	-4.10	-4.97

Maize	Climate Model	2030	2040	2050	Rice	2030	2040	2050	Wheat	2030	2040	2050
South Africa	HadCM3	-1.900	-2.350	-3.041	Thailand	-0.125	-0.143	-0.194	Turkey	-2.41	-2.98	-3.85
	MIROC3.2(MEDRES)	-1.865	-2.514	-2.963		-0.100	-0.134	-0.130		-2.36	-3.19	-3.76
	ECHAN5	-1.509	-2.047	-2.759		-0.058	-0.058	-0.066		-1.91	-2.60	-3.50
	CSIRO-MK3.0	-1.492	-1.810	-2.085		-0.010	-0.014	-0.004		-1.89	-2.30	-2.65
	CNRM-CM3	-2.328	-2.956	-3.583		-0.121	-0.130	-0.116		-2.95	-3.75	-4.55
USA	HadCM3	-2.287	-2.831	-3.662	Vietnam	-0.217	-0.259	-0.342	USA	-1.81	-2.24	-2.90
	MIROC3.2(MEDRES)	-2.250	-3.033	-3.581		-0.195	-0.262	-0.288		-1.78	-2.40	-2.83
	ECHAN5	-1.825	-2.481	-3.347		-0.140	-0.174	-0.225		-1.44	-1.96	-2.64
	CSIRO-MK3.0	-1.815	-2.202	-2.539		-0.101	-0.125	-0.134		-1.43	-1.73	-2.00
	CNRM-CM3	-2.809	-3.572	-4.340		-0.241	-0.287	-0.315		-2.22	-2.82	-3.42

5. GTAP Model and Simulation Results

This study uses the soft link approach, combining crop yield model and GTAP model to form our project empirical and simulated aggregation model. About our scenarios setting, we adopt IPCC five Atmosphere-Ocean General Circulation Models (AOGCMs)-hadcm3, MIROC3_2_MEDRES, ECHAM5, CSIRO-MK30, and CNRM_CM3 to evaluate the production negative effect from 2030, 2040, 2050 average temperature and Precipitation variation on major producing countries. Furthermore, we insert the result into GTAP model to realize crop price fluctuation and impact on countries' economic condition.

The GTAP database we consult here is the newest edition-2008 Published Edition7. This database is fully documented and continuously updated. The data set used in this study is the GTAP database Version 7 that refers to the base year 2004. The database provides disaggregated data from up to 113 regions across 57 sectors. All monetary values of the data are expressed in U.S. dollar (millions). The GTAP global database consists of an input-output structure that links industries together in a value-added chain, from primary goods to goods for consumption. It contains information based on individual countries' input-output (I/O) tables, bilateral commodity trade between regions, as well as data on international transportation and protection (Hertel & Tsigas, 1997)

According to this project purpose for evaluating the climate change impact on rice, wheat, maize productions and prices, we classified the whole world into 24 regions. Table 12 presents a complete list of country classification and codes in version 7 of the GTAP database.

Table 12 GTAP Country Classification and Codes

No.	GtapCode	Country	No.	GtapCode	Country
1	CHIN	China	13	MEX	Mexico
2	JPN	Japan	14	ARG	Argentina
3	IDN	Indonesia	15	BRA	Barzil
4	MMR	Myanmar	16	TUR	Turkey
5	PHL	Philippine	17	FRA	France
6	THA	Thailand	18	DEU	Germany
7	VNM	Vietnam	19	Other_EU	Other EU
8	BGD	Bangladesh	20	ZAF	South Africa
9	IND	Indonesia	21	AUS	Australia
10	PAK	Pakistan	22	IRN	Iran
11	CAN	Canada	23	TWN	Taiwan
12	USA	USA	24	RestofWorld	Rest of World

Note: Other EU include Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.

Source:

This study uses five climate change models (hadcm3, MIROC3_2_MEDRES, ECHAM5, CSIRO-MK30, and CNRM_CM3) to simulate the prediction of average temperature and average rainfall in 2030, 2040, and 2050. Using these prediction results and the estimated grain production variations in major countries, which were outlined in the previous chapter, this study further simulates changes in GDP and social welfare resulting from climate change impacts on the production of rice, wheat, and other coarse grain (i.e. maize) by incorporating the GTAP model. In addition, impact assessment on production and price variation of rice, wheat, and other coarse grain (i.e. maize) will be provided.

The simulation results indicate that there are adverse impacts on GDP and social welfare in various countries. Under the CNRM_CM3 model simulation global average temperature will decrease by 0.486%, 0.618%, and 0.752% in year 2030, 2040, and 2050 respectively. The drop in average rainfall is predicted to be 1.322%, 1.913%, and 2.729% for year 2030, 2040, and 2050. These numbers indicate the largest possible impact on each country. Among these countries, India, Mexico and Indonesia experience larger magnitude of adverse impact on GDP in three out of five climate models (the MIROC3_2_MEDRES, ECHAM5, and CNRM_CM3). In these three models, the simulated GDP of India decreases between 0.457~0.611% in 2030;0.70~1.031% in 2040; and 1.284~1.57% in 2050. The simulated Mexican GDP decreases between 0.315~0.384% in 2030; 0.423~0.548% in 2040; and 0.519~0.607% in 2050. The simulated Indonesian GDP decreases between 0.162~0.202% in 2030; 0.218~0.282% in 2040; and 0.288~0.325% in 2050. In hadcm3 model, Indonesia is replaced by Bangladesh and in CSIRO-MK30 model Myanmar takes over Indonesia's place.

On the other hand, India, Mexico, and USA experience larger magnitude of adverse impact on social welfare in three out of five models (the hadcm3, MICROC3_2_MEDRES, and CNRM_CM3; however, in hadcm3 model, China experiences greater drop in social welfare than USA in 2030 with a 576 million US dollars difference). The simulated India social welfare decreases between 3,902~5,625 million US dollars in 2030; 5,723 ~10,031 million US dollars in 2040; and 10,970~32,699 million US dollars in 2050. The simulated Mexican social welfare decreases between 3,328~4,179 million US dollars in 2030; 4,223~5,254 million US dollars in 2040; and 5,269~6,438 million US dollars in 2050. The simulated US social welfare decreases between 2,036~2,505 million US dollars in 2030; 2,530~3,062 million US dollars in 2040; and 2,977~3,460 million US dollars in 2050. In both ECHAM5 model and CSIRO-MK30 model, China suffers from greater decline in social welfare than USA. In conclusion, we can find that the major producing countries experience the most serious GDP and social welfare loss, especially in India. The other simulation results are shown in Tables24~ 25.

Table 13 Simulation prediction of GDP variation caused by the reduction of primary food production in five climate models

Unit：%

GDP variation	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Taiwan	-0.001	-0.002	-0.002	-0.001	-0.002	-0.002	-0.001	-0.001	-0.002	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002
China	-0.159	-0.154	-0.144	-0.159	-0.158	-0.144	-0.164	-0.153	-0.118	-0.158	-0.153	-0.149	-0.159	-0.158	-0.144
Japan	-0.017	-0.020	-0.025	-0.016	-0.021	-0.022	-0.012	-0.015	-0.017	-0.01	-0.011	-0.012	-0.016	-0.021	-0.022
Indonesia	-0.207	-0.258	-0.338	-0.202	-0.282	-0.325	-0.162	-0.218	-0.288	-0.156	-0.19	-0.219	-0.202	-0.282	-0.325
Myanmar	-0.219	-0.267	-0.346	-0.216	-0.286	-0.339	-0.177	-0.237	-0.32	-0.174	-0.211	-0.242	-0.216	-0.286	-0.339
Philippines	-0.107	-0.130	-0.167	-0.097	-0.13	-0.146	-0.085	-0.111	-0.146	-0.081	-0.098	-0.111	-0.097	-0.13	-0.146
Thailand	-0.026	-0.028	-0.030	-0.024	-0.027	-0.025	-0.018	-0.02	-0.02	-0.012	-0.015	-0.015	-0.024	-0.027	-0.025
Vietnam	-0.118	-0.129	-0.143	-0.109	-0.128	-0.128	-0.084	-0.099	-0.107	-0.062	-0.078	-0.082	-0.109	-0.128	-0.128
Bangladesh	-0.259	-0.313	-0.414	-0.243	-0.329	-0.376	-0.188	-0.242	-0.318	-0.162	-0.197	-0.222	-0.243	-0.329	-0.376
India	-0.625	-0.893	-1.702	-0.611	-1.031	-1.57	-0.457	-0.71	-1.284	-0.454	-0.59	-0.737	-0.611	-1.031	-1.57
Pakistan	-0.121	-0.150	-0.194	-0.119	-0.161	-0.189	-0.096	-0.131	-0.175	-0.095	-0.116	-0.133	-0.119	-0.161	-0.189
Canada	-0.028	-0.034	-0.041	-0.028	-0.038	-0.041	-0.024	-0.03	-0.033	-0.024	-0.027	-0.031	-0.028	-0.038	-0.041
USA	-0.030	-0.037	-0.045	-0.03	-0.044	-0.044	-0.026	-0.033	-0.032	-0.026	-0.03	-0.033	-0.03	-0.044	-0.044
Mexico	-0.391	-0.487	-0.623	-0.384	-0.548	-0.607	-0.315	-0.423	-0.519	-0.314	-0.376	-0.432	-0.384	-0.548	-0.607
Argentina	-0.103	-0.127	-0.151	-0.102	-0.155	-0.149	-0.088	-0.112	-0.106	-0.089	-0.102	-0.116	-0.102	-0.155	-0.149
Brazil	-0.051	-0.062	-0.076	-0.05	-0.071	-0.074	-0.041	-0.053	-0.059	-0.04	-0.048	-0.054	-0.05	-0.071	-0.074
Turkey	-0.147	-0.181	-0.230	-0.144	-0.193	-0.225	-0.118	-0.158	-0.209	-0.116	-0.141	-0.161	-0.144	-0.193	-0.225
France	-0.010	-0.013	-0.016	-0.01	-0.014	-0.015	-0.009	-0.011	-0.013	-0.009	-0.01	-0.011	-0.01	-0.014	-0.015
Germany	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Rest of EU	0.000	0.001	0.001	0	0.001	0.001	0	0.001	0.001	0	0	0.001	0	0.001	0.001
South Africa	-0.058	-0.072	-0.087	-0.058	-0.085	-0.086	-0.049	-0.063	-0.064	-0.049	-0.057	-0.064	-0.058	-0.085	-0.086
Australia	-0.015	-0.019	-0.025	-0.015	-0.021	-0.025	-0.012	-0.017	-0.023	-0.012	-0.015	-0.017	-0.015	-0.021	-0.025
Iran	-0.125	-0.148	-0.182	-0.123	-0.157	-0.178	-0.103	-0.132	-0.168	-0.101	-0.12	-0.134	-0.123	-0.157	-0.178
Rest of the World	-0.009	-0.011	-0.012	-0.009	-0.012	-0.012	-0.007	-0.009	-0.01	-0.006	-0.008	-0.008	-0.009	-0.012	-0.012

Table 14 Simulation prediction of social welfare variation caused by the reduction of primary food production in five climate models

Unit：Million US dollars

social welfare variation	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Taiwan	-132.074	-159.45	-187.125	-130.431	-192.848	-183.36	-113.3	-140.742	-131.157	-113.1	-128.6	-143.5	-158	-183	-214
China	-2633.65	-2526.9	-2433.64	-2619.43	-2464.02	-2433.92	-2696.13	-2527.44	-2306.09	-2595.0	-2518.9	-2458.8	-2521	-2436	-2231
Japan	-1332.25	-1568.88	-1861.1	-1259.25	-1781.16	-1694.22	-1026.23	-1236.38	-1200.91	-897.9	-1036.7	-1127.0	-1509	-1694	-1757
Indonesia	-543.328	-678.172	-887.411	-529.852	-742.63	-854.83	-424.412	-575.426	-756.505	-411.8	-501.2	-578.4	-668	-852	-1057
Myanmar	-14.297	-17.423	-22.41	-14.124	-18.4	-22.097	-11.534	-15.589	-21.376	-11.4	-13.9	-16.0	-17	-22	-30
Philippines	-115.872	-141.443	-180.392	-106.497	-144.151	-161.77	-92.129	-121.567	-157.449	-89.2	-107.0	-121.8	-139	-174	-213
Thailand	-38.524	-40.897	-43.863	-34.565	-37.815	-36.107	-25.455	-28.313	-30.367	-16.1	-20.1	-19.8	-38	-36	-10
Vietnam	-60.159	-67.097	-76.887	-56.074	-66.904	-69.56	-43.271	-52.299	-59.773	-33.4	-41.7	-44.8	-64	-70	-55
Bangladesh	-187.149	-227.59	-301.33	-176.924	-240.639	-276.048	-137.294	-178.943	-235.07	-120.7	-147.3	-166.3	-220	-275	-378
India	-3993.89	-5723.14	-10970.2	-3902.42	-6607.7	-10109.3	-2910.53	-4537.58	-8258.57	-2889.3	-3768.6	-4714.8	-5625	-10031	-32700
Pakistan	-152.806	-189.919	-246.366	-149.881	-203.604	-240.107	-121.045	-165.005	-221.441	-119.9	-145.6	-168.0	-188	-240	-290
Canada	-146.865	-175.98	-205.62	-145.655	-209.182	-202.636	-128.619	-156.354	-149.255	-129.9	-145.4	-161.2	-175	-202	-228
USA	-2057.93	-2530.44	-3028.79	-2036.49	-3062.4	-2977.1	-1741.5	-2226.75	-2116.47	-1757.2	-2026.8	-2289.9	-2506	-2967	-3460
Mexico	-3384.83	-4223.76	-5405.64	-3328.48	-4777.26	-5269.86	-2729.67	-3661.99	-4461	-2716.3	-3253.9	-3744.5	-4180	-5254	-6439
Argentina	15.236	17.957	25.186	14.287	15.687	22.913	10.789	14.287	27.698	9.0	11.5	13.0	19	25	36
Brazil	-191.009	-234.837	-289.316	-187.114	-268.322	-280.601	-154.302	-201.805	-223.276	-151.0	-178.9	-203.5	-235	-285	-318
Turkey	-497.261	-611.203	-778.331	-487.584	-656.964	-761.065	-397.077	-535.375	-702.681	-393.3	-475.5	-545.6	-605	-759	-898
France	-62.443	-75.141	-86.218	-61.587	-83.358	-85.966	-50.858	-67.213	-71.414	-50.7	-60.7	-68.8	-75	-86	-67
Germany	48.624	63.867	94.716	47.735	79.491	89.881	40.431	53.208	71.347	40.7	47.1	54.8	63	89	188
Rest of EU	-2.642	12.913	82.951	-3.247	0.781	73.466	-10.167	3.387	108.094	-8.8	-3.0	5.7	12	72	306
South Africa	-115.826	-142.996	-174.846	-114.237	-169.811	-170.998	-96.254	-124.821	-128.729	-96.3	-112.5	-127.7	-141	-170	-203
Australia	82.924	94.784	108.072	81.292	106.974	104.102	73.425	84.357	84.769	71.4	77.3	83.1	93	104	119
Iran	-220.615	-263.147	-322.502	-216.821	-281.256	-315.537	-181.729	-233.912	-291.414	-179.5	-211.6	-237.2	-106	-315	-367
Rest of the World	-1084.57	-1284.28	-1466.4	-1061.48	-1540.74	-1420.97	-908.221	-1114.81	-977.043	-872.4	-1002.0	-1108.6	-1263	-1418	-1613

The results of this study indicate that under the hadcm3 model, in year 2030 the top three countries with the greatest impact of climate change on production reduction are Mexico (-3.062%), the Philippines(-0.407%), and Canada (-0.399%). The top three countries with increasing unit production cost due to climate change are the Philippines (6.529%), China (4.704%), and Indonesia (4.430%). These three countries are also the top three with the largest reduction in productivity with a 5.539% decrease for China, 4.4135% decrease for Indonesia and 4.321% decrease in the Philippines. The above-mentioned countries are the major rice producing countries in the world. As a result, it can be observed from the hadcm3 model that each producing country in average will have a 1% to 6.5% increase in production cost and the productivity will drop by 1% to 5.55%.

Using the same model for year 2040, Mexico, Canada, and other EU experience the greatest impact of climate change on rice production. The production in each declines by 3.944%, 1.198%, and 0.734% respectively. In all nations, the rise in production cost is the result of climate change. The top three countries with the greatest variation are the Philippines (7.963%), Indonesia (6.73%), and Bangladesh (4.839%). On the other hand, severe drop in productivity can be seen in Indonesia (-6.491%), China (-5.645%), and the Philippines (-5.224%); these countries also rank among the top for global rice production. In sum, the observation for year 2040 under the hadcm3 model is that production cost in each producing country is likely to increase between 1%~7.9% and the productivity will drop from 1% to 6.5%. In 2050, hadcm3 model suggests that the increase in rice production cost in both the Philippines and Indonesia soars above 10% with 10.446% in the Philippines and 10.218% in Indonesia. In these two countries, productivity drops by 9.996% in Indonesia and 6.616% in the Philippines. This phenomenon will cause an over 10% reduction in rice production in other southeastern countries, resulting in decline in productivity and increase in production cost.

Under the other four climate-change models, it can also be observed that the variation results predicted for year 2030, 2040, and 2050 in the affected countries are parallel to the hadcm3 model used in Taiwan. The main finding is that with the impact of climate change, each country will experience rise in rice production cost. Under the model of CNRM_CM3, in year 2050, India will have the greatest variation in production cost which is predicted to have a 29.366% increase. In terms of productivity, India will drop 33.916%, following by the Philippines and Indonesia. These countries are the main rice producing countries in the southeastern region and in facing the impacts of future climate change, these countries are inevitably more prone to be affected.

Table 15 Simulation prediction of 2030 rice production, production cost, and productivity variation in five climate models Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity
Taiwan	-0.037	0.096	0.000	-0.044	0.091	0.000	-0.039	0.077	0.000	-0.062	0.068	0.000	-0.074	0.105	0.000
China	-0.275	4.704	-5.539	-0.256	4.515	-5.201	-0.193	4.122	-4.216	-0.160	3.112	-3.040	-0.318	4.124	-5.443
Japan	-0.182	3.777	-3.148	-0.155	3.400	-2.833	-0.103	2.547	-2.120	-0.052	1.806	-1.490	-0.191	4.048	-3.372
Indonesia	-0.374	4.430	-4.413	-0.358	4.623	-4.524	-0.280	3.585	-3.513	-0.257	4.199	-3.955	-0.445	6.900	-6.606
Myanmar	-0.343	1.862	-1.095	-0.344	1.828	-1.080	-0.285	1.497	-0.885	-0.297	1.457	-0.875	-0.430	2.241	-1.326
Philippines	-0.407	6.529	-4.321	-0.364	5.913	-3.918	-0.321	5.159	-3.440	-0.315	4.955	-3.309	-0.497	7.837	-5.145
Thailand	-0.125	1.535	-0.766	-0.100	1.406	-0.677	-0.058	1.089	-0.493	-0.010	0.786	-0.280	-0.121	1.562	-0.731
Vietnam	-0.217	2.577	-1.587	-0.195	2.397	-1.464	-0.140	1.878	-1.118	-0.101	1.434	-0.824	-0.241	2.701	-1.672
Bangladesh	-0.346	3.998	-2.442	-0.324	3.759	-2.296	-0.248	2.903	-1.780	-0.213	2.502	-1.529	-0.403	4.655	-2.822
India	-0.302	1.357	-2.120	-0.302	1.295	-2.044	-0.249	0.744	-1.345	-0.257	0.748	-1.336	-0.377	2.503	-3.480
Pakistan	0.193	-0.008	0.000	0.179	-0.011	0.000	0.168	0.002	0.000	0.112	-0.015	0.000	0.100	-0.055	0.000
Canada	-0.399	0.930	0.000	-0.508	0.915	0.000	-0.484	0.790	0.000	-0.945	0.778	0.000	-1.243	1.086	0.000
USA	1.693	0.670	0.000	1.555	0.646	0.000	1.225	0.542	0.000	0.776	0.480	0.000	1.490	0.727	0.000
Mexico	-3.062	1.367	0.000	-3.038	1.338	0.000	-2.467	1.099	0.000	-2.571	1.067	0.000	-3.971	1.648	0.000
Argentina	2.029	0.541	0.000	1.897	0.518	0.000	1.440	0.416	0.000	1.154	0.375	0.000	2.249	0.629	0.000
Brazil	-0.230	2.022	-1.606	-0.219	1.918	-1.522	-0.170	1.492	-1.177	-0.152	1.292	-1.011	-0.272	2.327	-1.845
Turkey	0.749	0.143	0.000	0.710	0.139	0.000	0.587	0.118	0.000	0.478	0.111	0.000	0.778	0.164	0.000
France	1.351	0.076	0.000	1.220	0.073	0.000	1.290	0.068	0.000	0.748	0.056	0.000	0.020	0.055	0.000
Germany	0.753	0.094	0.000	0.675	0.090	0.000	0.805	0.086	0.000	0.420	0.071	0.000	-0.372	0.065	0.000
Rest of EU	0.161	0.107	0.000	0.124	0.103	0.000	0.304	0.098	0.000	0.068	0.084	0.000	-0.723	0.078	0.000
South Africa	8.864	0.692	0.000	8.297	0.654	0.000	6.580	0.524	0.000	4.904	0.422	0.000	8.949	0.735	0.000
Australia	1.325	0.433	0.000	1.238	0.420	0.000	0.976	0.366	0.000	0.703	0.334	0.000	1.293	0.468	0.000
Iran	-0.071	0.309	0.000	-0.075	0.303	0.000	-0.067	0.256	0.000	-0.083	0.250	0.000	-0.102	0.360	0.000
Rest of the World	0.846	0.697	0.000	0.780	0.668	0.000	0.585	0.541	0.000	0.402	0.474	0.000	0.869	0.785	0.000

Table 16 Simulation prediction of 2040 rice production, production cost, and productivity variation in five climate models Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity
Taiwan	-0.069	0.108	0.000	-0.112	0.116	0.000	-0.073	0.089	0.000	-0.075	0.077	0.000	-0.116	0.114	0.000
China	-0.333	4.205	-5.645	-0.344	3.936	-5.563	-0.248	3.946	-4.661	-0.196	3.522	-3.804	-0.389	3.312	-5.192
Japan	-0.213	4.346	-3.620	-0.209	4.483	-3.747	-0.118	2.970	-2.468	-0.066	2.165	-1.789	-0.218	4.495	-3.738
Indonesia	-0.458	6.730	-6.491	-0.482	8.340	-7.925	-0.371	6.187	-5.846	-0.313	5.571	-5.206	-0.555	10.857	-10.267
Myanmar	-0.428	2.262	-1.332	-0.464	2.436	-1.419	-0.394	1.984	-1.187	-0.360	1.760	-1.062	-0.554	2.841	-1.685
Philippines	-0.503	7.963	-5.224	-0.491	7.975	-5.211	-0.434	6.794	-4.489	-0.382	5.949	-3.951	-0.630	9.782	-6.350
Thailand	-0.143	1.658	-0.798	-0.134	1.655	-0.733	-0.058	1.231	-0.526	-0.014	0.950	-0.354	-0.130	1.530	-0.652
Vietnam	-0.259	2.826	-1.760	-0.262	2.848	-1.759	-0.174	2.204	-1.330	-0.125	1.762	-1.034	-0.287	2.824	-1.779
Bangladesh	-0.420	4.839	-2.933	-0.437	5.096	-3.076	-0.322	3.750	-2.282	-0.260	3.053	-1.860	-0.495	5.791	-3.474
India	-0.376	2.587	-3.577	-0.406	3.283	-4.400	-0.342	1.710	-2.539	-0.311	1.211	-1.933	-0.484	6.358	-7.867
Pakistan	0.105	-0.054	0.000	0.047	-0.068	0.000	0.119	-0.040	0.000	0.113	-0.031	0.000	-0.240	-0.185	0.000
Canada	-1.198	1.099	0.000	-1.839	1.244	0.000	-1.041	0.968	0.000	-1.053	0.886	0.000	-3.495	1.236	0.000
USA	1.567	0.744	0.000	1.345	0.815	0.000	1.271	0.640	0.000	0.989	0.561	0.000	0.911	0.732	0.000
Mexico	-3.994	1.669	0.000	-4.547	1.872	0.000	-3.477	1.442	0.000	-3.107	1.275	0.000	-5.338	1.998	0.000
Argentina	2.350	0.642	0.000	2.316	0.686	0.000	1.812	0.529	0.000	1.442	0.450	0.000	2.593	0.744	0.000
Brazil	-0.281	2.404	-1.907	-0.294	2.481	-1.951	-0.223	1.914	-1.513	-0.185	1.580	-1.243	-0.337	2.772	-2.200
Turkey	0.804	0.167	0.000	0.875	0.185	0.000	0.667	0.145	0.000	0.565	0.129	0.000	0.724	0.184	0.000
France	0.056	0.057	0.000	-0.789	0.047	0.000	0.458	0.059	0.000	0.568	0.057	0.000	-4.937	-0.045	0.000
Germany	-0.367	0.066	0.000	-1.085	0.052	0.000	0.081	0.073	0.000	0.240	0.072	0.000	-4.581	-0.077	0.000
Rest of EU	-0.734	0.079	0.000	-1.292	0.064	0.000	-0.313	0.087	0.000	-0.130	0.087	0.000	-3.925	-0.075	0.000
South Africa	9.299	0.760	0.000	9.189	0.775	0.000	7.552	0.622	0.000	6.118	0.517	0.000	8.724	0.785	0.000
Australia	1.343	0.478	0.000	1.316	0.513	0.000	1.103	0.420	0.000	0.893	0.375	0.000	1.082	0.489	0.000
Iran	-0.099	0.363	0.000	-0.114	0.392	0.000	-0.098	0.322	0.000	-0.097	0.291	0.000	-0.151	0.422	0.000
Rest of the World	0.913	0.806	0.000	0.883	0.876	0.000	0.697	0.670	0.000	0.533	0.572	0.000	0.889	0.883	0.000

Table 17 Simulation prediction of 2050 rice production, production cost, and productivity variation in five climate models Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Productio n Cost	Productivity	Production	Production Cost	Productivity
Taiwan	-0.103	0.123	0.000	-0.118	0.113	0.000	-0.066	0.096	0.000	-0.097	0.082	0.000	-0.148	0.118	0.000
China	-0.436	3.344	-5.512	-0.388	3.293	-5.165	-0.327	3.249	-4.585	-0.218	3.389	-3.921	-0.446	2.014	-3.150
Japan	-0.285	5.363	-4.457	-0.218	4.486	-3.731	-0.147	3.380	-2.790	-0.064	2.255	-1.860	-0.221	4.387	-3.663
Indonesia	-0.596	10.446	-9.996	-0.557	10.950	-10.351	-0.495	9.582	-9.034	-0.355	7.200	-6.662	-0.656	14.751	-14.317
Myanmar	-0.551	2.928	-1.719	-0.555	2.845	-1.688	-0.535	2.629	-1.608	-0.418	2.009	-1.216	-0.685	4.139	-2.376
Philippines	-0.652	10.218	-6.616	-0.568	8.982	-5.847	-0.585	8.927	-5.850	-0.439	6.765	-4.471	-0.761	12.273	-7.876
Thailand	-0.194	1.763	-0.820	-0.130	1.521	-0.645	-0.066	1.237	-0.519	-0.004	0.971	-0.331	-0.116	0.699	0.007
Vietnam	-0.342	3.133	-2.008	-0.288	2.816	-1.775	-0.225	2.346	-1.455	-0.134	1.863	-1.096	-0.315	2.172	-1.337
Bangladesh	-0.549	6.402	-3.833	-0.497	5.812	-3.486	-0.426	4.900	-2.955	-0.292	3.428	-2.080	-0.573	8.002	-4.717
India	-0.485	7.263	-8.900	-0.485	6.435	-7.954	-0.464	4.758	-6.004	-0.361	1.825	-2.672	-0.596	29.336	-33.916
Pakistan	-0.295	-0.200	0.000	-0.249	-0.187	0.000	-0.149	-0.170	0.000	0.070	-0.058	0.000	-2.322	-0.767	0.000
Canada	-3.737	1.260	0.000	-3.552	1.237	0.000	-2.712	0.999	0.000	-1.476	0.981	0.000	-15.457	1.085	0.000
USA	0.966	0.754	0.000	0.890	0.731	0.000	0.967	0.582	0.000	0.940	0.603	0.000	-2.351	0.366	0.000
Mexico	-5.486	2.056	0.000	-5.361	2.002	0.000	-4.646	1.687	0.000	-3.654	1.452	0.000	-7.568	2.188	0.000
Argentina	2.879	0.787	0.000	2.599	0.740	0.000	2.350	0.641	0.000	1.590	0.504	0.000	2.517	0.805	0.000
Brazil	-0.366	3.004	-2.387	-0.338	2.773	-2.200	-0.297	2.439	-1.951	-0.210	1.770	-1.392	-0.396	2.945	-2.323
Turkey	0.766	0.189	0.000	0.721	0.184	0.000	0.526	0.150	0.000	0.593	0.142	0.000	0.180	0.164	0.000
France	-5.791	-0.063	0.000	-5.054	-0.048	0.000	-3.451	-0.028	0.000	-0.093	0.047	0.000	-36.254	-0.743	0.000
Germany	-5.377	-0.104	0.000	-4.679	-0.080	0.000	-3.247	-0.048	0.000	-0.317	0.059	0.000	-31.411	-1.067	0.000
Rest of EU	-4.565	-0.106	0.000	-3.997	-0.078	0.000	-2.824	-0.039	0.000	-0.577	0.074	0.000	-24.123	-1.177	0.000
South Africa	9.396	0.847	0.000	8.682	0.783	0.000	7.543	0.677	0.000	6.401	0.554	0.000	6.031	0.685	0.000
Australia	1.138	0.506	0.000	1.072	0.488	0.000	0.977	0.412	0.000	0.919	0.400	0.000	-0.293	0.378	0.000
Iran	-0.148	0.432	0.000	-0.152	0.422	0.000	-0.145	0.378	0.000	-0.115	0.324	0.000	-0.268	0.460	0.000
Rest of the World	0.997	0.936	0.000	0.883	0.882	0.000	0.743	0.715	0.000	0.563	0.631	0.000	0.602	0.882	0.000

The results of this study indicate that under the hadcm3 model, in year 2030 the top three countries with the greatest impact of climate change on production reduction are Australia (-2.84%), India (-2.69%), and Pakistan (-2.63%). The top three countries with increasing unit production cost due to climate change are India (20.729%), Iran (19.249%), and Turkey (11.802%). These three countries are also the top three with the largest reduction in productivity with a 14.098% decrease for Iran, 13.055% decrease for India and 9.244% decrease in Turkey. The variation results for year 2040 and 2050 depict similar pattern with 2030; however, the magnitude of impact is greater especially in 2050 the predicted unit production cost of wheat in India will increase by 70.062% while productivity drops 36.194%.

Under the other four climate-change models, it can be observed that the variation results predicted for year 2030, 2040, and 2050 in the affected countries depict similar patterns with the hadcm3 model used in Taiwan. Among the five models, the CNRM_CM3 climate-change model depicts the greatest variation. The results from the five models all show that in Year 2030, India, Iran, and Turkey will experience the greatest rise in production cost with 14.282%~31.113% increase in India, 15.620%~22.797% in Iran, and 9.283%~14.412% in Turkey. These three countries are also the top three with the greatest reduction in productivity with 9.411%~18.457% decrease in India, 11.839%~16.150% decrease in Iran, and 7.420%~11.008% decrease in Turkey.

The results for 2040 show that unit production cost of wheat in India, Iran, and Turkey rises dramatically with an increase of 19.377%~62.888%, 18.492%~27.689%, and 11.268%~18.200% respectively. The top three countries with the greatest drop in productivity are India (-12.319%~-33.105%), Iran (-13.641%~-18.742%), and Turkey (-8.85%~-13.453%). Predictions for year 2050 show similar pattern with previous results in that India, Iran, and Turkey rank as the top three for highest increase in production cost. India is predicted to increase 25.232%~1465, Iran with 20.779%~32.066%, and Turkey 12.963%~21.650%. The top three with the greatest reduction in productivity are India (-15.468%~-96.7%), Iran (-15.003%~-20.837%), and Turkey (-10.03%~-15.537%). According to FAO (2009), India ranks as the second largest wheat producing country with the annual production of 80.68 million metric ton. As a result, under the CNRM_CM3 model, the impact of climate change on wheat production can be observed through a 146% increase in production cost. This dramatic increase will then cause a sharp decline in productivity.

Table 18 Simulation prediction of 2030 wheat production, production cost, and productivity variation in five climate models Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity
Taiwan	5.190	1.840	0.000	5.103	1.804	0.000	4.094	1.452	0.000	4.087	1.436	0.000	6.452	2.267	0.000
China	-2.210	7.075	-5.476	-2.170	6.937	-5.377	-1.760	5.480	-4.283	-1.750	5.472	-4.286	-2.710	8.901	-6.796
Japan	5.683	0.764	0.000	5.609	0.738	0.000	4.501	0.587	0.000	4.546	0.556	0.000	7.141	0.923	0.000
Indonesia	7.826	1.238	0.000	7.772	1.204	0.000	6.253	0.969	0.000	6.422	0.930	0.000	9.910	1.495	0.000
Myanmar	4.142	2.299	0.000	4.075	2.256	0.000	3.237	1.803	0.000	3.239	1.785	0.000	5.210	2.864	0.000
Philippines	3.948	2.005	0.000	3.931	1.950	0.000	3.111	1.587	0.000	3.124	1.567	0.000	4.910	2.459	0.000
Thailand	1.002	1.830	0.000	0.995	1.796	0.000	0.820	1.452	0.000	0.838	1.436	0.000	1.201	2.247	0.000
Vietnam	12.755	0.644	0.000	12.580	0.624	0.000	9.947	0.515	0.000	10.105	0.481	0.000	16.247	0.750	0.000
Bangladesh	8.820	1.782	0.000	8.676	1.735	0.000	6.885	1.370	0.000	6.872	1.328	0.000	11.136	2.213	0.000
India	-2.690	20.729	-13.055	-2.650	20.181	-12.757	-2.150	14.389	-9.470	-2.140	14.282	-9.411	-3.300	31.113	-18.457
Pakistan	-2.630	7.955	-6.319	-2.580	7.805	-6.208	-2.090	6.300	-5.075	-2.070	6.246	-5.037	-3.230	9.805	-7.671
Canada	-1.690	3.042	-2.497	-1.660	2.985	-2.449	-1.350	2.389	-1.947	-1.340	2.372	-1.931	-2.080	3.780	-3.100
USA	-1.810	2.850	-2.259	-1.780	2.797	-2.218	-1.440	2.245	-1.768	-1.430	2.227	-1.755	-2.220	3.527	-2.793
Mexico	3.224	1.443	0.000	3.165	1.417	0.000	2.541	1.143	0.000	2.515	1.135	0.000	3.898	1.793	0.000
Argentina	4.108	0.979	0.000	4.036	0.960	0.000	3.217	0.779	0.000	3.203	0.767	0.000	5.099	1.204	0.000
Brazil	7.457	0.643	0.000	7.318	0.631	0.000	5.853	0.512	0.000	5.808	0.505	0.000	9.259	0.787	0.000
Turkey	-2.410	11.802	-9.224	-2.360	11.566	-9.058	-1.910	9.379	-7.489	-1.890	9.283	-7.420	-2.950	14.412	-11.008
France	-2.300	2.205	-2.080	-2.260	2.165	-2.044	-1.830	1.750	-1.656	-1.820	1.737	-1.644	-2.830	2.711	-2.549
Germany	-2.120	2.575	-2.409	-2.090	2.531	-2.370	-1.690	2.042	-1.917	-1.680	2.027	-1.904	-2.610	3.174	-2.957
Rest of EU	3.646	0.324	0.000	3.581	0.319	0.000	2.885	0.261	0.000	2.862	0.258	0.000	4.493	0.395	0.000
South Africa	5.118	0.293	0.000	5.022	0.288	0.000	4.025	0.237	0.000	3.991	0.234	0.000	6.332	0.358	0.000
Australia	-2.840	3.719	-3.114	-2.790	3.649	-3.057	-2.260	2.917	-2.433	-2.250	2.896	-2.419	-3.490	4.626	-3.871
Iran	-1.980	19.249	-14.098	-1.940	18.921	-13.901	-1.570	15.796	-11.952	-1.550	15.620	-11.839	-2.425	22.797	-16.150
Rest of the World	3.711	0.730	0.000	3.647	0.715	0.000	2.928	0.583	0.000	2.918	0.573	0.000	4.593	0.886	0.000

Table 19 Simulation prediction of 2040 wheat production, production cost, and productivity variation in five climate models Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity
Taiwan	6.505	2.289	0.000	7.031	2.465	0.000	5.664	1.986	0.000	4.996	1.749	0.000	8.232	2.869	0.000
China	-2.730	8.979	-6.848	-2.930	9.702	-7.314	-2.390	7.738	-5.971	-2.120	6.774	-5.269	-3.450	11.620	-8.700
Japan	7.180	0.941	0.000	7.781	1.010	0.000	6.296	0.786	0.000	5.578	0.676	0.000	9.251	1.153	0.000
Indonesia	9.914	1.521	0.000	10.709	1.639	0.000	8.854	1.289	0.000	7.908	1.123	0.000	12.755	1.867	0.000
Myanmar	5.254	2.894	0.000	5.644	3.135	0.000	4.555	2.495	0.000	3.999	2.187	0.000	6.789	3.707	0.000
Philippines	4.942	2.484	0.000	5.333	2.663	0.000	4.334	2.155	0.000	3.832	1.901	0.000	6.258	3.094	0.000
Thailand	1.202	2.268	0.000	1.218	2.452	0.000	1.100	1.973	0.000	1.000	1.743	0.000	1.428	2.824	0.000
Vietnam	16.342	0.764	0.000	17.522	0.842	0.000	14.227	0.651	0.000	12.521	0.570	0.000	21.354	0.887	0.000
Bangladesh	11.242	2.248	0.000	12.174	2.427	0.000	9.698	1.895	0.000	8.488	1.636	0.000	14.685	2.890	0.000
India	-3.330	31.771	-18.783	-3.570	37.615	-21.611	-2.920	24.102	-14.870	-2.590	19.377	-12.319	-4.200	62.888	-33.105
Pakistan	-3.260	9.896	-7.736	-3.480	10.605	-8.235	-2.840	8.605	-6.803	-2.510	7.594	-6.056	-4.100	12.488	-9.565
Canada	-2.090	3.814	-3.125	-2.240	4.117	-3.329	-1.830	3.303	-2.715	-1.620	2.904	-2.381	-2.640	4.848	-3.978
USA	-2.240	3.560	-2.817	-2.400	3.839	-2.968	-1.960	3.089	-2.453	-1.730	2.719	-2.156	-2.820	4.499	-3.583
Mexico	3.922	1.811	0.000	3.976	1.999	0.000	3.470	1.565	0.000	3.071	1.379	0.000	4.844	2.288	0.000
Argentina	5.155	1.214	0.000	5.506	1.327	0.000	4.479	1.051	0.000	3.938	0.928	0.000	6.544	1.514	0.000
Brazil	9.339	0.795	0.000	10.054	0.867	0.000	8.097	0.690	0.000	7.118	0.610	0.000	11.826	0.985	0.000
Turkey	-2.980	14.553	-11.101	-3.190	15.583	-11.777	-2.600	12.720	-9.862	-2.300	11.268	-8.850	-3.750	18.200	-13.453
France	-2.840	2.731	-2.566	-3.040	2.939	-2.753	-2.490	2.383	-2.247	-2.210	2.109	-1.992	-3.600	3.426	-3.206
Germany	-2.630	3.201	-2.981	-2.810	3.443	-3.192	-2.300	2.788	-2.606	-2.040	2.465	-2.310	-3.310	4.026	-3.731
Rest of EU	4.531	0.399	0.000	4.869	0.435	0.000	3.946	0.348	0.000	3.485	0.309	0.000	5.696	0.489	0.000
South Africa	6.389	0.361	0.000	6.861	0.401	0.000	5.546	0.315	0.000	4.881	0.280	0.000	8.068	0.441	0.000
Australia	-3.520	4.671	-3.905	-3.770	5.040	-4.185	-3.070	4.039	-3.388	-2.730	3.550	-2.982	-4.430	5.946	-4.963
Iran	-2.450	22.992	-16.258	-2.620	24.327	-16.984	-2.130	20.462	-14.818	-1.890	18.492	-13.641	-3.079	27.689	-18.742
Rest of the World	4.630	0.896	0.000	4.950	0.979	0.000	4.038	0.779	0.000	3.565	0.689	0.000	5.853	1.096	0.000

Table 20 Simulation prediction of 2050 wheat production, production cost, and productivity variation in five climate models Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity
Taiwan	8.422	2.945	0.000	8.250	2.874	0.000	7.580	2.645	0.000	5.813	2.025	0.000	8.989	3.143	0.000
China	-3.530	11.935	-8.903	-3.460	11.651	-8.721	-3.230	10.552	-7.818	-2.450	7.954	-6.136	-4.190	13.907	-10.222
Japan	9.418	1.211	0.000	9.274	1.154	0.000	8.574	1.030	0.000	6.526	0.775	0.000	10.592	1.270	0.000
Indonesia	12.784	1.952	0.000	12.781	1.871	0.000	12.070	1.681	0.000	9.302	1.283	0.000	12.481	2.202	0.000
Myanmar	6.948	3.817	0.000	6.805	3.716	0.000	6.372	3.410	0.000	4.692	2.550	0.000	7.302	4.283	0.000
Philippines	6.373	3.180	0.000	6.354	3.072	0.000	5.886	2.836	0.000	4.466	2.193	0.000	6.563	3.439	0.000
Thailand	1.426	2.896	0.000	1.428	2.829	0.000	1.463	2.588	0.000	1.138	2.012	0.000	1.076	3.099	0.000
Vietnam	21.760	0.927	0.000	21.406	0.887	0.000	20.141	0.756	0.000	14.778	0.638	0.000	22.627	1.023	0.000
Bangladesh	15.087	3.018	0.000	14.721	2.898	0.000	13.653	2.622	0.000	9.980	1.907	0.000	16.757	3.502	0.000
India	-4.310	70.062	-36.194	-4.210	63.477	-33.361	-3.940	50.062	-27.464	-2.990	25.232	-15.468	-5.110	146.000	-96.700
Pakistan	-4.210	12.824	-9.793	-4.110	12.518	-9.585	-3.820	11.585	-8.952	-2.890	8.773	-6.928	-4.970	14.807	-11.165
Canada	-2.710	4.978	-4.081	-2.640	4.858	-3.985	-2.470	4.453	-3.739	-1.870	3.378	-2.776	-3.200	5.524	-4.513
USA	-2.900	4.618	-3.674	-2.830	4.509	-3.591	-2.640	4.142	-3.423	-2.000	3.157	-2.509	-3.420	5.077	-4.045
Mexico	4.931	2.353	0.000	4.847	2.293	0.000	4.876	2.029	0.000	3.536	1.599	0.000	4.700	2.680	0.000
Argentina	6.721	1.553	0.000	6.578	1.512	0.000	6.150	1.361	0.000	4.591	1.069	0.000	7.065	1.688	0.000
Brazil	12.119	1.012	0.000	11.844	0.987	0.000	10.938	0.891	0.000	8.280	0.702	0.000	12.959	1.087	0.000
Turkey	-3.850	18.671	-13.744	-3.760	18.244	-13.481	-3.500	16.960	-12.678	-2.650	12.963	-10.030	-4.550	21.650	-15.537
France	-3.670	3.505	-3.278	-3.600	3.430	-3.210	-3.360	3.164	-2.977	-2.550	2.435	-2.295	-4.380	3.896	-3.651
Germany	-3.400	4.132	-3.825	-3.320	4.036	-3.739	-3.100	3.727	-3.477	-2.350	2.848	-2.662	-4.020	4.668	-4.322
Rest of EU	5.838	0.501	0.000	5.707	0.490	0.000	5.276	0.438	0.000	4.032	0.354	0.000	6.468	0.531	0.000
South Africa	8.273	0.453	0.000	8.081	0.442	0.000	7.493	0.384	0.000	5.667	0.320	0.000	8.932	0.477	0.000
Australia	-4.550	6.108	-5.088	-4.440	5.960	-4.974	-4.150	5.482	-4.638	-3.140	4.132	-3.472	-5.380	6.735	-5.623
Iran	-3.170	28.345	-19.069	-3.090	27.764	-18.780	-2.880	26.150	-17.962	-2.170	20.779	-15.003	-3.734	32.066	-20.837
Rest of the World	5.990	1.126	0.000	5.865	1.097	0.000	5.493	0.979	0.000	4.138	0.789	0.000	6.419	1.196	0.000

The results of this study indicate the hadcm3 model simulation of 2030 coarse grain production reduction. The top five countries, which have the most magnitude of production reduction, are India (-2.698%), Indonesia (-2.473%), USA (-2.287%), Mexico (-2.068%), and Brazil(-1.799%). The countries, whose coarse grain production cost per unit increases over 10%, are Indonesia (53.793%), Mexico (26.044%), India (22.363%), China (16.671%), USA (13.623%), and Canada (11.993%). And the other countries, whose coarse grain productivity decreases over 10%, are Indonesia (-25.305%), China (-20.658%), Mexico (-16.416%), India (-13.902%), Canada (-10.11%), and USA (-11.148%). We can found that the above-mentioned countries are currently global maize major producing countries, which includes USA, China, Brazil, Mexico, Argentina, France, India, Indonesia, South Africa, and Canada. The hadcm3 model simulation outcomes of 2040 and 2050 are similar to the 2030 simulation, but the magnitudes of impact are larger.

Under the other four modes, it is predicted that variation magnitude in 2030, 2040 and 2050 are similar to the result from hadcm3, while in CNRM_CM3 model shows the largest range. Production cost will increase 42.009~71.374%, 20.722%~32.390 and 17.708%~27.567% in Indonesia, Mexico and India, respectively in 2030. The above countries production costs are predicted to rise seriously, all of their range exceed 20% (Indonesia 54.152%~99.379%, Mexico21.537%~32.641%, India21.537%~32.641%).

And about coarse grain productivity, top six countries are expected to decrease more than 10%, those are Indonesia (-25.112%~-37.551%), China (-15.123% ~ -29.147%), Mexico (-15.871%~-23.337%), India (-13.509%~-17.747%), USA (-10.885%~-15.483%) and Canada (-10.237%~-14.047%). In conclusion, the impact on coarse grain (maize) is higher than rice and wheat.

Table 21 Simulation prediction of 2030 Coarse grains production, production cost, and productivity variation in five climate models

Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity
Taiwan	6.201	1.071	0.000	6.119	1.057	0.000	5.258	0.911	0.000	5.233	0.906	0.000	7.600	1.308	0.000
China	-1.550	15.907	-20.055	-1.525	16.111	-20.149	-1.237	19.789	-21.769	-1.231	19.711	-21.683	-1.904	12.527	-12.261
Japan	12.240	1.248	0.000	12.092	1.233	0.000	10.583	1.077	0.000	10.533	1.072	0.000	14.920	1.520	0.000
Indonesia	-2.473	53.793	-25.371	-2.457	53.301	-25.201	-2.016	41.907	-21.112	-2.055	42.763	-21.430	-3.071	71.657	-30.976
Myanmar	5.584	2.863	0.000	5.506	2.822	0.000	4.596	2.361	0.000	4.581	2.352	0.000	6.854	3.507	0.000
Philippines	0.932	0.563	0.000	0.924	0.557	0.000	0.816	0.485	0.000	0.819	0.485	0.000	1.126	0.679	0.000
Thailand	6.577	2.178	0.000	6.507	2.155	0.000	5.442	1.819	0.000	5.474	1.828	0.000	8.352	2.726	0.000
Vietnam	4.815	1.816	0.000	4.759	1.797	0.000	4.057	1.550	0.000	4.059	1.552	0.000	5.985	2.211	0.000
Bangladesh	10.641	2.760	0.000	10.482	2.719	0.000	8.594	2.231	0.000	8.558	2.222	0.000	12.949	3.362	0.000
India	-2.698	22.533	-14.061	-2.654	22.169	-13.881	-2.151	17.903	-11.637	-2.137	17.824	-11.600	-3.312	27.866	-16.566
Pakistan	2.296	0.604	0.000	2.267	0.596	0.000	1.929	0.509	0.000	1.925	0.507	0.000	2.803	0.730	0.000
Canada	-1.618	11.869	-10.346	-1.595	11.727	-10.229	-1.296	10.246	-8.990	-1.296	10.206	-8.958	-1.991	14.223	-12.356
USA	-2.287	13.527	-11.110	-2.250	13.337	-10.965	-1.825	11.304	-9.389	-1.815	11.248	-9.347	-2.809	16.657	-13.546
Mexico	-2.068	25.999	-16.420	-2.031	25.534	-16.181	-1.644	20.719	-13.602	-1.629	20.550	-13.509	-2.535	32.501	-19.673
Argentina	-1.619	7.536	-5.978	-1.607	7.453	-5.915	-1.316	6.342	-5.053	-1.338	6.356	-5.066	-1.857	9.216	-7.268
Brazil	-1.799	7.436	-6.366	-1.769	7.328	-6.277	-1.434	6.137	-5.292	-1.423	6.104	-5.265	-2.276	9.308	-7.897
Turkey	0.604	0.104	0.000	0.596	0.103	0.000	0.511	0.088	0.000	0.509	0.088	0.000	0.737	0.125	0.000
France	-1.647	3.560	-3.384	-1.625	3.515	-3.342	-1.322	2.964	-2.828	-1.325	2.962	-2.825	-2.029	4.382	-4.150
Germany	1.820	0.162	0.000	1.798	0.160	0.000	1.545	0.137	0.000	1.542	0.136	0.000	2.232	0.196	0.000
Rest of EU	1.787	0.274	0.000	1.765	0.271	0.000	1.519	0.232	0.000	1.515	0.232	0.000	2.190	0.333	0.000
South Africa	-1.900	9.972	-8.838	-1.865	9.820	-8.712	-1.509	8.238	-7.381	-1.492	8.183	-7.335	-2.328	12.298	-10.785
Australia	10.356	1.804	0.000	10.295	1.790	0.000	9.896	1.661	0.000	9.854	1.654	0.000	11.470	2.049	0.000
Iran	0.835	0.110	0.000	0.824	0.109	0.000	0.700	0.093	0.000	0.697	0.093	0.000	1.030	0.133	0.000
Rest of the World	2.303	0.563	0.000	2.276	0.557	0.000	1.992	0.484	0.000	1.984	0.483	0.000	2.815	0.680	0.000

Table 22 Simulation prediction of 2040 Coarse grains production, production cost, and productivity variation in five climate models

Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity
Taiwan	7.705	1.325	0.000	6.180	1.069	0.000	6.636	1.145	0.000	6.012	1.039	0.000	8.647	1.484	0.000
China	-1.918	12.409	-10.962	-2.055	12.667	-60.340	-1.682	14.468	-18.913	-1.493	16.268	-20.172	-2.421	9.237	-27.974
Japan	15.146	1.542	0.000	11.048	1.148	0.000	13.024	1.329	0.000	11.894	1.213	0.000	16.334	1.671	0.000
Indonesia	-3.073	71.956	-31.084	-3.312	75.589	-31.290	-2.762	61.818	-27.957	-2.490	54.014	-25.427	-3.929	99.383	-37.630
Myanmar	6.925	3.544	0.000	6.334	3.256	0.000	6.034	3.087	0.000	5.415	2.772	0.000	7.781	4.026	0.000
Philippines	1.140	0.687	0.000	0.809	0.554	0.000	0.996	0.602	0.000	0.920	0.552	0.000	1.180	0.751	0.000
Thailand	8.446	2.755	0.000	7.269	2.386	0.000	7.248	2.383	0.000	6.489	2.147	0.000	10.177	3.271	0.000
Vietnam	6.059	2.236	0.000	5.031	1.897	0.000	5.222	1.955	0.000	4.713	1.782	0.000	7.026	2.546	0.000
Bangladesh	13.048	3.388	0.000	13.089	3.403	0.000	11.507	2.984	0.000	10.288	2.668	0.000	14.813	3.886	0.000
India	-3.339	28.090	-16.660	-3.576	28.604	-16.579	-2.923	24.526	-15.041	-2.593	21.726	-13.670	-4.211	32.602	-17.720
Pakistan	2.836	0.738	0.000	2.440	0.641	0.000	2.468	0.645	0.000	2.234	0.586	0.000	3.222	0.830	0.000
Canada	-2.004	14.378	-12.496	-2.150	12.669	-10.525	-1.765	12.626	-10.980	-1.572	11.547	-10.081	-2.535	16.544	-14.029
USA	-2.831	16.873	-13.719	-3.033	14.452	-11.373	-2.481	14.537	-11.888	-2.202	13.089	-10.776	-3.572	19.544	-15.471
Mexico	-2.558	32.871	-19.857	-2.738	32.826	-19.402	-2.233	28.202	-17.542	-1.977	24.878	-15.843	-3.221	41.202	-23.375
Argentina	-2.011	9.451	-7.462	-2.166	7.910	-6.161	-1.802	8.179	-6.477	-1.622	7.396	-5.875	-2.349	10.740	-8.361
Brazil	-2.227	9.277	-7.874	-2.384	8.420	-7.083	-1.948	8.016	-6.841	-1.727	7.186	-6.161	-2.893	11.176	-9.336
Turkey	0.748	0.126	0.000	0.622	0.112	0.000	0.648	0.111	0.000	0.587	0.101	0.000	0.847	0.143	0.000
France	-2.041	4.428	-4.193	-2.190	3.931	-3.702	-1.802	3.847	-3.652	-1.608	3.470	-3.301	-2.585	5.183	-4.873
Germany	2.259	0.199	0.000	1.819	0.172	0.000	1.953	0.173	0.000	1.773	0.157	0.000	2.537	0.226	0.000
Rest of EU	2.218	0.337	0.000	1.777	0.283	0.000	1.917	0.293	0.000	1.741	0.267	0.000	2.487	0.379	0.000
South Africa	-2.350	12.475	-10.934	-2.514	11.024	-9.472	-2.047	10.725	-9.465	-1.810	9.607	-8.535	-2.956	14.623	-12.538
Australia	11.574	2.068	0.000	9.417	1.804	0.000	10.650	1.879	0.000	10.199	1.768	0.000	12.082	2.264	0.000
Iran	1.031	0.134	0.000	0.910	0.121	0.000	0.896	0.118	0.000	0.810	0.107	0.000	1.209	0.153	0.000
Rest of the World	2.860	0.689	0.000	2.033	0.543	0.000	2.455	0.600	0.000	2.242	0.548	0.000	3.058	0.750	0.000

Table 23 Simulation prediction of 2050 Coarse grains production, production cost, and productivity variation in five climate models

Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity	Production	Production Cost	Productivity
Taiwan	8.848	1.517	0.000	8.673	1.488	0.000	8.143	1.399	0.000	6.777	1.168	0.000	9.986	1.698	0.000
China	-2.481	8.909	-28.066	-2.427	9.198	-27.987	-2.269	10.154	-28.341	-1.722	13.999	-18.297	-2.942	6.012	-30.690
Japan	16.690	1.706	0.000	16.379	1.675	0.000	15.426	1.579	0.000	13.283	1.355	0.000	18.680	1.876	0.000
Indonesia	-3.966	100.962	-37.982	-3.940	99.933	-37.751	-3.739	92.545	-36.064	-2.883	65.294	-29.014	-4.817	130.246	-43.227
Myanmar	7.819	4.065	0.000	7.798	4.036	0.000	7.531	3.871	0.000	6.180	3.158	0.000	2.102	1.869	0.000
Philippines	1.192	0.763	0.000	1.183	0.753	0.000	1.137	0.716	0.000	1.021	0.616	0.000	1.103	0.782	0.000
Thailand	10.368	3.330	0.000	10.232	3.287	0.000	9.571	3.086	0.000	7.516	2.464	0.000	12.024	3.772	0.000
Vietnam	7.168	2.593	0.000	7.056	2.556	0.000	6.621	2.415	0.000	5.372	2.005	0.000	8.085	2.828	0.000
Bangladesh	14.801	3.896	0.000	14.827	3.890	0.000	14.469	3.775	0.000	11.770	3.052	0.000	0.678	0.739	0.000
India	-4.320	32.611	-17.468	-4.222	32.639	-17.716	-3.943	31.702	-17.758	-2.989	25.137	-15.335	-5.114	-1.407	5.892
Pakistan	3.282	0.845	0.000	3.231	0.831	0.000	3.055	0.789	0.000	2.525	0.658	0.000	3.349	0.809	0.000
Canada	-2.591	16.915	-14.318	-2.542	16.592	-14.067	-2.383	15.615	-13.289	-1.813	12.877	-11.194	-3.086	19.295	-16.141
USA	-3.662	20.029	-15.815	-3.581	19.605	-15.514	-3.347	18.342	-14.600	-2.539	14.859	-12.138	-4.340	23.063	-17.947
Mexico	-3.310	42.443	-23.884	-3.229	41.325	-23.426	-3.010	38.251	-22.121	-2.278	28.841	-17.865	-3.907	50.830	-27.117
Argentina	-2.596	11.135	-8.670	-2.574	10.970	-8.551	-2.438	10.318	-8.068	-1.877	8.419	-6.665	-2.833	12.422	-9.573
Brazil	-2.881	11.269	-9.406	-2.814	11.026	-9.217	-2.627	10.307	-8.653	-1.991	8.198	-6.990	-3.513	13.257	-10.924
Turkey	0.868	0.146	0.000	0.852	0.144	0.000	0.800	0.136	0.000	0.662	0.113	0.000	1.004	0.144	0.000
France	-2.638	5.291	-4.972	-2.592	5.198	-4.887	-2.434	4.885	-4.601	-1.856	3.947	-3.745	-3.150	6.076	-5.707
Germany	2.589	0.230	0.000	2.544	0.226	0.000	2.395	0.214	0.000	1.999	0.177	0.000	2.927	0.228	0.000
Rest of EU	2.540	0.387	0.000	2.495	0.380	0.000	2.348	0.360	0.000	1.962	0.300	0.000	2.883	0.397	0.000
South Africa	-3.041	15.034	-12.855	-2.963	14.694	-12.592	-2.759	13.716	-11.821	-2.085	10.954	-9.657	-3.583	17.167	-14.490
Australia	12.266	2.304	0.000	12.113	2.270	0.000	11.659	2.168	0.000	10.741	1.901	0.000	12.967	2.419	0.000
Iran	1.222	0.155	0.000	1.198	0.153	0.000	1.125	0.145	0.000	0.915	0.120	0.000	1.415	0.151	0.000
Rest of the World	3.124	0.765	0.000	3.070	0.753	0.000	2.896	0.713	0.000	2.507	0.612	0.000	3.406	0.790	0.000

The predicted results derived from the five climate-change models are shown in Tables 24~26. The results represent the FOB price variation of rice, wheat, and other coarse grain (maize) exported from the major grain producing countries in year 2030, 2040, and 2050. It can be observed that under hadcm33 model (as shown in Figure 4.29), the top three countries with the largest variation in rice export price are the Philippines (6.529%), China (4.704%), and Indonesia (4.443%). As for variations in wheat export price, India, Iran, and Turkey rank as the top three with 20.729% increase for India, 19.249% for Iran, and 11.802% for Turkey. The top three countries with the greatest variation in other coarse grain (maize) export price are Indonesia (53.759%), Mexico (26.044%), and India (22.63%). It can be analyzed that in the GTAP model and without taking export tax into consideration, product export FOB price equal to the variation in producing supply price.

The results gained from the other four models predicting the results of climate change on rice, wheat, and other coarse grain (maize) in major grain producing countries in year 2030, 2040, and 2050. It is evident that in the future with the influence of climate change India, Indonesia, and China are the three countries facing severe impacts. Thus, this study aim to use enhanced techniques (2%, 4%, 6%, and 8%) to increase production and to facilitate free trade agreement (10%, 20%, and 30% in tax reduction) as the basis for possible adaptation strategies.

Table 24 Simulation prediction of 2030 agriculture-related products' FOB price variation in five climate models Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains
Taiwan	0.064	1.435	1.071	0.064	1.412	1.057	0.058	1.143	0.911	0.058	1.138	0.906	0.071	1.766	1.308
China	4.262	6.125	15.907	4.322	6.008	16.111	4.606	4.734	19.789	4.712	4.703	19.711	3.723	7.707	12.527
Japan	0.101	0.422	1.248	0.100	0.416	1.233	0.085	0.338	1.077	0.085	0.337	1.072	0.120	0.519	1.520
Indonesia	5.273	2.029	53.793	5.175	1.995	53.301	3.751	1.619	41.907	3.778	1.610	42.763	7.612	1.735	71.657
Myanmar	0.325	1.470	2.863	0.321	1.448	2.822	0.275	1.179	2.361	0.272	1.175	2.352	0.390	1.806	3.507
Philippines	0.263	1.408	0.563	0.260	1.386	0.557	0.223	1.126	0.485	0.223	1.120	0.485	0.316	1.728	0.679
Thailand	0.524	1.305	2.178	0.519	1.285	2.155	0.467	1.050	1.819	0.467	1.046	1.828	0.585	1.596	2.726
Vietnam	0.469	0.459	1.816	0.467	0.453	1.797	0.424	0.389	1.550	0.428	0.389	1.552	0.513	0.548	2.211
Bangladesh	0.176	1.302	2.760	0.174	1.281	2.719	0.143	1.022	2.231	0.143	1.018	2.222	0.218	1.639	3.362
India	2.117	20.136	22.533	2.208	19.628	22.169	1.622	13.930	17.903	1.939	13.874	17.824	3.684	30.637	27.866
Canada	1.141	2.274	11.869	1.110	2.235	11.727	1.035	1.797	10.246	0.976	1.787	10.206	0.988	2.817	14.223
USA	1.428	2.181	13.527	1.410	2.145	13.337	1.287	1.730	11.304	1.269	1.721	11.248	1.414	2.692	16.657
Mexico	1.278	2.243	25.999	1.252	2.204	25.534	1.160	1.779	20.719	1.142	1.768	20.550	1.237	2.765	32.501
Argentina	2.328	2.542	7.536	2.248	2.500	7.453	1.841	2.020	6.342	1.718	2.011	6.356	2.616	3.137	9.216
Brazil	3.048	1.972	7.436	2.938	1.940	7.328	2.384	1.574	6.137	2.210	1.566	6.104	3.458	2.424	9.308
Turkey	0.156	0.095	0.104	0.155	0.093	0.103	0.136	0.079	0.088	0.135	0.079	0.088	0.173	0.114	0.125
France	0.088	1.610	3.560	0.061	1.585	3.515	0.122	1.286	2.964	0.050	1.279	2.962	-0.214	1.979	4.382
Germany	0.074	0.187	0.162	0.069	0.184	0.160	0.073	0.153	0.137	0.059	0.152	0.136	0.028	0.227	0.196
Rest of EU	0.053	0.218	0.274	0.047	0.215	0.271	0.056	0.178	0.232	0.041	0.177	0.232	-0.002	0.265	0.333
South Africa	1.693	2.534	9.972	1.690	2.488	9.820	1.524	2.013	8.238	1.543	1.999	8.183	1.801	3.118	12.298
Australia	0.574	1.289	1.804	0.568	1.269	1.790	0.503	1.037	1.661	0.501	1.032	1.654	0.645	1.583	2.049
Iran	0.100	0.095	0.110	0.099	0.094	0.109	0.086	0.081	0.093	0.085	0.080	0.093	0.119	0.114	0.133
Rest of the World	0.634	0.565	0.563	0.630	0.557	0.557	0.550	0.461	0.484	0.553	0.459	0.483	0.724	0.687	0.680

Table 25 Simulation prediction of 2040 agriculture-related products' FOB price variation in five climate models Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains
Taiwan	0.072	1.780	1.325	0.065	1.885	1.069	0.066	1.558	1.145	0.063	1.380	1.039	0.074	2.214	1.484
China	3.692	7.749	12.409	3.441	8.354	12.667	4.117	6.697	14.468	4.443	5.857	16.268	2.705	10.023	9.237
Japan	0.121	0.523	1.542	0.121	0.548	1.148	0.108	0.457	1.329	0.098	0.406	1.213	0.141	0.648	1.671
Indonesia	7.685	2.510	71.956	8.078	2.653	75.589	6.204	2.197	61.818	5.143	1.950	54.014	11.433	2.144	99.383
Myanmar	0.395	1.821	3.544	0.373	1.918	3.256	0.344	1.596	3.087	0.312	1.417	2.772	0.485	2.251	4.026
Philippines	0.319	1.741	0.687	0.293	1.826	0.554	0.281	1.526	0.602	0.256	1.355	0.552	0.371	2.149	0.751
Thailand	0.590	1.608	2.755	0.520	1.677	2.386	0.544	1.412	2.383	0.514	1.258	2.147	0.599	1.974	3.271
Vietnam	0.515	0.553	2.236	0.477	0.522	1.897	0.487	0.490	1.955	0.467	0.447	1.782	0.520	0.646	2.546
Bangladesh	0.221	1.655	3.388	0.223	1.782	3.403	0.190	1.428	2.984	0.169	1.252	2.668	0.287	2.157	3.886
India	3.641	31.260	28.090	4.538	37.373	28.604	3.070	23.631	24.526	2.664	18.940	21.726	8.205	64.334	32.602
Canada	1.007	2.838	14.378	0.843	3.022	12.669	1.007	2.473	12.626	0.996	2.182	11.547	0.185	3.581	16.544
USA	1.425	2.713	16.873	1.361	2.883	14.452	1.395	2.369	14.537	1.358	2.094	13.089	1.043	3.402	19.544
Mexico	1.246	2.787	32.871	1.179	2.972	32.826	1.236	2.433	28.202	1.212	2.150	24.878	0.840	3.498	41.202
Argentina	2.674	3.164	9.451	2.822	3.365	7.910	2.285	2.759	8.179	2.006	2.444	7.396	2.928	3.970	10.740
Brazil	3.541	2.442	9.277	3.729	2.586	8.420	2.990	2.138	8.016	2.600	1.896	7.186	3.941	3.039	11.176
Turkey	0.174	0.115	0.126	0.164	0.109	0.112	0.161	0.101	0.111	0.151	0.092	0.101	0.169	0.134	0.143
France	-0.198	1.995	4.428	-0.418	2.109	3.931	-0.113	1.746	3.847	-0.055	1.549	3.470	-1.297	2.484	5.183
Germany	0.031	0.229	0.199	-0.015	0.230	0.172	0.040	0.201	0.173	0.046	0.180	0.157	-0.163	0.276	0.226
Rest of EU	0.001	0.267	0.337	-0.051	0.269	0.283	0.014	0.235	0.293	0.023	0.210	0.267	-0.219	0.321	0.379
South Africa	1.804	3.146	12.475	1.778	3.345	11.024	1.751	2.745	10.725	1.693	2.429	9.607	1.740	3.944	14.623
Australia	0.650	1.595	2.068	0.627	1.665	1.804	0.597	1.396	1.879	0.558	1.241	1.768	0.688	1.978	2.264
Iran	0.120	0.115	0.134	0.109	0.106	0.121	0.106	0.102	0.118	0.097	0.093	0.107	0.135	0.132	0.153
Rest of the World	0.728	0.692	0.689	0.690	0.701	0.543	0.669	0.609	0.600	0.626	0.546	0.548	0.779	0.833	0.750

Table 26 Simulation prediction of 2050 agriculture-related products' FOB price variation in five climate models Unit：%

	hadcm3			MIROC3_2_MEDRES			ECHAM5			CSIRO-MK30			CNRM_CM3		
Nation	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains	Rice	Wheat	Coarse grains
Taiwan	0.075	2.260	1.517	0.074	2.218	1.488	0.072	2.086	1.399	0.067	1.594	1.168	0.063	2.216	1.698
China	2.591	10.245	8.909	2.689	10.031	9.198	3.008	9.325	10.154	4.074	6.876	13.999	0.836	11.850	6.012
Japan	0.143	0.662	1.706	0.141	0.650	1.675	0.134	0.610	1.579	0.110	0.468	1.355	0.118	0.662	1.876
Indonesia	11.726	3.174	100.962	11.535	3.115	99.933	10.415	2.932	92.545	6.596	2.247	65.294	14.186	1.907	130.246
Myanmar	0.507	2.296	4.065	0.487	2.255	4.036	0.443	2.128	3.871	0.348	1.635	3.158	0.941	2.060	1.869
Philippines	0.379	2.192	0.763	0.371	2.153	0.753	0.349	2.028	0.716	0.286	1.562	0.616	0.445	2.159	0.782
Thailand	0.604	2.014	3.330	0.599	1.978	3.287	0.587	1.865	3.086	0.548	1.445	2.464	0.431	1.961	3.772
Vietnam	0.521	0.660	2.593	0.520	0.648	2.556	0.516	0.611	2.415	0.492	0.500	2.005	0.378	0.786	2.828
Bangladesh	0.300	2.217	3.896	0.288	2.162	3.890	0.262	2.006	3.775	0.195	1.468	3.052	0.505	2.438	0.739
India	8.833	71.764	32.611	8.292	64.984	32.639	6.765	50.693	31.702	3.592	24.870	25.137	39.450	315.723	1.407
Canada	0.104	3.659	16.915	0.165	3.588	16.592	0.425	3.358	15.615	0.910	2.534	12.877	-6.567	3.835	19.295
USA	1.007	3.478	20.029	1.033	3.409	19.605	1.160	3.196	18.342	1.358	2.425	14.859	-2.530	3.588	23.063
Mexico	0.800	3.579	42.443	0.811	3.506	41.325	0.966	3.281	38.251	1.195	2.487	28.841	-2.722	3.771	50.830
Argentina	3.092	4.065	11.135	2.928	3.979	10.970	2.719	3.729	10.318	2.189	2.825	8.419	1.669	4.262	12.422
Brazil	4.179	3.106	11.269	3.943	3.044	11.026	3.631	2.862	10.307	2.860	2.188	8.198	2.645	3.153	13.257
Turkey	0.168	0.136	0.146	0.168	0.134	0.144	0.170	0.127	0.136	0.161	0.103	0.113	-0.050	0.129	0.144
France	-1.427	2.541	5.291	-1.320	2.490	5.198	-0.959	2.336	4.885	-0.236	1.786	3.947	-9.898	2.676	6.076
Germany	-0.186	0.281	0.230	-0.167	0.276	0.226	-0.104	0.261	0.214	0.019	0.206	0.177	-1.694	0.268	0.228
Rest of EU	-0.245	0.327	0.387	-0.224	0.322	0.380	-0.152	0.304	0.360	-0.011	0.240	0.300	-1.954	0.309	0.397
South Africa	1.725	4.037	15.034	1.736	3.953	14.694	1.775	3.699	13.716	1.767	2.807	10.954	0.450	4.304	17.167
Australia	0.694	2.019	2.304	0.688	1.981	2.270	0.673	1.862	2.168	0.602	1.429	1.901	0.383	1.978	2.419
Iran	0.137	0.134	0.155	0.135	0.132	0.153	0.128	0.125	0.145	0.108	0.104	0.120	0.132	0.131	0.151
Rest of the World	0.785	0.849	0.765	0.779	0.835	0.753	0.762	0.789	0.713	0.680	0.623	0.612	0.540	0.818	0.790

5. Concluding Remarks

The Intergovernmental Panel on Climate Change (IPCC, 2007) pointed out that global economic loss of crops, fishery, water resources, and human health induced by climate change in the period of 1991-2005 is approximately US$1,190 billion. Furthermore, according to OECD-FAO 2011-2020 Agricultural outlook, price volatility is driven by a multitude of factors. The most frequent and significant factor causing volatility is the unpredictable weather condition. Climate change is altering weather patterns, however, its impact on extreme weather events is not clear.

The objective of this study is to examine how climatic factors influence crop yield distribution and to predict the degree of climate change inducing variations in crop yield distribution in the future. The first step is to combine the Crop Yield Model estimated results and climate factors data predicted from five climate models (that is, hadcm3, MIROC3_2_MEDRES, ECHAM5,CSIRO-MK30, and CNRM_CM3), and with the assumption that future world is in IPCC (2007) A1B scenario. From these assumptions, we can realize the production impacts in 2030, 2040, 2050 and in cooperation with Global Trade Analysis Model (GTAP) we can further investigate the results. Having GTAP as the final step, analysis can be made on assessing the economic impacts on food price, production power, and macroeconomic aspect-GDP, and social welfare. This study focuses on the impact of climate change on crop production, price, and welfare, hence employment, population growth, and allocation parameters are viewed as external factors that do not impose any change on welfare.

The Crop Yield Model shows that the non-climatic factors including crop planted area and time trend (technical advance) have positive impacts on mean yield for corn, rice, and wheat. However, climate factors impose variations to the production pattern of three main crops. These changes include lower average production and higher variation in crop production. Details of each are described below:

(1) Rice

Increasing mean temperature, temperature variation and total precipitation, precipitation variation lead to a decline in mean yield in rice. The largest impact within major rice producing countries are Japan:-0.637%, Thailand:-0.197%, Myanmar:-0.275% and India:-0.374, respectively. The average temperature, temperature variation and total precipitation, precipitation variation have positive impacts on rice production variation. Japan’s rice production variation will increase 2.525% if temperature increases 1%, and will increase 0.510% if temperature variation increase1%. As for inter-monthly variation in annual precipitation, all of the three crop yields are negatively influenced, and the biggest affected degree on these three crops is in India.

(2) Wheat

The variance in temperature during crop growing season has adverse influences on crop yield. The impacted magnitude of wheat yield in Iran is -0.709%. For wheat, there exist disadvantageous relationships between annual total precipitation and wheat yield in China, India, United State, Canada, Pakistan, France, and Germany. The greatest increased magnitude of annual precipitation affecting wheat yield variance is in Pakistan, where 1% increases in annual precipitation enlarges 0.338% increase in wheat yield variance.

(3) Maize

The average temperature during maize growing season has positive impacts on most of the main producing countries, but has opposite effects on Indonesia. Among them, Canada has the biggest positive impacted degree with rising temperature, and Indonesia has the worst impacted degree, with the elasticity of 0.187 and -0.092 individually. As to maize yield variance, India has the greatest impacted degree, where 1% increases in variance in temperature during crop growing season enlarges 0.417% increase in maize yield variance.

Next we use the soft link approach combining crop yield model and GTAP model to analyze the impacts on crop price, production cost, productivity, GDP and social welfare. From GTAP economical empirical results, the global social welfare will decrease 20,400, 27,177and 51,879 million US dollars in 2030, 2040 and 2050, respectively. Moreover, the regional impacts are:

(1) Rice

The Philippines and Indonesia will experience serious increase in rice production cost and the largest productivity drop. This phenomenon will cause increases in rice supply price in both of the countries, about 6.529% and 4.443%, respectively. The main rice producing countries are located in the southeastern region and facing the impacts of future climate change, these countries are inevitably more prone to be affected.

(2) Wheat

The top three countries with increasing unit production cost and with the greatest drop in productivity due to climate change are India, Iran, and Turkey. Meanwhile, those three countries wheat supply price will increase. According to FAO (2009), India ranks as the second largest wheat producing country with the annual production of 80.68 million metric ton. As a result, under the CNRM_CM3 model, the impact of climate change on wheat production can be observed through a 146% increase in production cost, and 20.729% increase in supply price.

(3) Maize (Coarse grain)

Coarse grain production costs are predicted to rise seriously, with all countries exceeding 20%. In terms of productivity, the top six countries that are expected to decrease more than 10% are Indonesia, China, Mexico, India, USA and Canada. In conclusion, the impacts on coarse grain (maize) are higher than those of rice and wheat.

References

Adams R.M., M.A. McCar, K. Segerson, C. Rosenzweig, K.J. Bryant, B.L. Dixon, R. Conner, R.E. Evenson, and D. Ojima, 1999. "The economic effects of climate change on US agriculture. The impact of climate change on the United States Economy," R. Mendelsohn, J.E. Neumann, Eds., *Cambridge University Press*, *Cambridge*. 18–55.

Adams, R.M., B.A. McCarl, and L.O. Mearns, 2003. "The Effects of Spatial Scale of Climate Scenarios on Economic Assessments: An Example from U.S. Agriculture," *Climatic Change*. 60: 131–148.

Antle, J.M., S.M. Capalbo, E.T. Elliott, and K.H. Paustian, 2004. "Adaptation, Spatial Heterogeneity, and the Vulnerability of Agricultural Systems to Climate Change and CO2 Fertilization: An Integrated Assessment Approach," *Climatic Change*. 64: 289-315.

Bodansky, D., S. Chou and C. Jorge-Tresolini, 2004. "International Climate Efforts Beyond 2012: A Survey of Approaches. Arlington," *VA: Pew Center on Global Climate Change*.

Cabas, J., A. Weersink, and E. Olale, 2010, "Crop yield response to economic, site and climatic variables," *Climatic Change*. 101: 599-616.

CCAF, 2002, "Climate Change Impacts and Adaptation: A Canadian Perspective. Agriculture," Government of Canada, Ottawa.

Chen, C.C. and C.C. Chang, 2005, "The Impact of Weather on Crop Yield Distribution in Taiwan: Some New Evidence from Panel Data Models and Implications for Crop Insurance," *Agricultural Economics*. 33: 503-511.

Chen, C.C., B.A. McCarl, and D.E. Schimmelpfennig, 2004, "Yield Variability as Influenced by Climate: A Statistical Investigation," *Climatic Change*. 66: 239–261.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, W.T. Kwon and Coauthors, 2007, "Regional Climate Projections. Climate Change 2007: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change," S. Solomon, D. Qin, and M. Manning, Eds., *Cambridge University Press*, Cambridge. 847-940.

Darwin, R., 2004,"Effects of Greenhouse Gas Emission on World Agriculture, Food Consumption, and Economic Welfare," *Climatic Change*, 66. 191–238.

Dickey, D. and W. Fuller, 1979, “Distribution of the Estimators for Autoregressive Time Series with a Unit Root,” *Journal of the American Statistical Association*. 74: 427-431.

Dixon, B.L., S.E. Hollinger, P. Garcia, V. Tirupattur, 1994. “Estimating Maize Yield Response Models to Predict Impacts of Climate Change,” *Journal of Agricultural and Resource Economics*. 19: 58–68.

Eitzinger, J., Z. Zalud, V. Alexandrov, C.A. van Diepen, M. Trnka, M. Dubrovsky, D. Semeradova, and M. Oberforster, M., 2001. “A Local Simulation Study on the Impact of Climate Change on Winter Wheat Production in North-East Austria,” *Ecology and Economics*. 52: 199–212.

Foley, J.A., R. DeFries, G.P. Asner, C. Barford, G. Bonan, S.R. Carpenter, F.S. Chapin,M.T. Coe and Co-authors, 2005. “Global Consequences of Land Use. Science,” 309: 570-574.

Gerald C. N, Mark W. R, Amanda P, Ian G, Christina I., Richard R., Simla T., Tingju Z., Timothy B. S., Claudia R, Siwa M., and Liangzhi Y., 2010, “Food Security, Farming, andClimate Change to 2050: Scenarios, Results, Policy Options, *International Food and Policy Research Institution*

Gordon, C., Cooper, C.A. Senior, Banks, H., Gregory, J.M., Johns, T.C., Mitchell, J.F.B., and Wood, R.A., 2000, The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments, Climate Dynamics, 16:147-168.

Granger, O.E., 1980. “The Impact of Climatic Variation on the Yield of Selected Crops in Three California Counties,” *Agricultural Meteorology*. 22: 367–386.

Günther F, 2009 “World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?,.” *International Institute for Applied Systems Analysis*

Hoogenboom, G., 2000. “Contribution of Agrometeorology to the Simulation of Crop Production and its Applications,” Agricultural and Forest Meteorology, 103:137–157.

Intergovernmental Panel on Climate Change (IPCC), 2007. “Climate Change 2007: Impacts, Adaptation and Vulnerability,” Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC), 2007. “Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment

Report of the Intergovernmental Panel on Climate Change," M. Parry et al., Eds., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Isik, M. and S. Devadoss, 2006. "An Analysis of the Impact of Climate Change on Crop Yields and Yield Variability," *Applied Economics*. 38:835-44.

Just, R.E. and R.D. Pope, 1978. "Stochastic Specification of Production Functions and Economic Implications," *Journal of Econometrics*. 7: 67–86.

Just, R.E. and R.D. Pope, 1979. "Production Function Estimation and Related Risk Considerations," *American Journal of Agricultural Economics*. 61:276–284.

Lewandrowski, J. and D. Schimmelpfennig, 1999. "Economic Implications of Climate Change for U.S. Agriculture: Assessing Recent Evidence," *Land Economics*. 75: 39–57.

Lur, H.S., C.L., Hsu1, C.W., Wu, C.Y., Lee1,C.L., Lao1, Wu, Y.C., S.J. Chang,, C.Y. Wang, and M. Kondo, 2009."Changes in Temperature, Cultivation Timing and Grain Quality of Rice in Taiwan in Recent Years,"*Crop, Environment & Bioinformatics*. 6:175-182.

McCarl, B.A., X. Villavicencio, and X. Wu, 2008. "Climate change and future analysis: is stationarity dying?" *American Journal of Agricultural Economics*. 90: 1241–1247.

Mendelsohn, R. and M. Reinsborough, 2007. "A Ricardian Analysis of US and Canadian Farmland," *Climatic Change*, 81: 9–17.

Mendelsohn, R., W.D. Nordhaus, and D. Shaw, 1996. "Climate Impacts on Aggregate Farm Values: Accounting for Adaptation." *Agriculture and Forest Meteorology*. 80: 55–67.

Mendelsohn, R., W.D. Nordhaus, and D. Shaw,1994. "The Impact of Global Warming on Agriculture: A Ricardian Analysis," *American Economic Review*. 84: 753–71.

Olesen, J.E. and M. Bindi, 2002. "Consequences of Climate Change for European Agricultural Productivity, Land Use and Policy," *European Journal of Agronomy*. 16: 239–262.

Parry, M., C. Rosenzweig, A. Inglesias, G. Fischer, and M. Livermore, 1999. "Climate Change and World Food Security: A New Assessment," *Global Environmental Change*. 9: S51–S67.

Pope, V.D., Gallani, M.L., Rowntree, P.R., and Stratton, R.A., 2000, The impact of new physical parametrizations in the Hadley Centre climate model—HadAM3, Climate Dynamics, 16:123-146.

Porter, J.R. and M.A. Semenov, 2005. "Crop Responses to Climatic Variability," P*hilosophical Transactions of the Royal Society B Biological Science*s. 360: 2021–2035.

Rosenzweig, C., F.N. Tubiello, R.A. Goldberg, E. Mills, and J. Bloomfield, 2002. "Increased Crop Damage in the US from Excess Precipitation under Climate Change," *Global Environmental Change*. 12: 197-202.

Rosenzweig, C.E., A. Iglesias, X.B. Yang, P.R. Epstein, and E. Chivian, 2001. "Climate Change and Extreme Weather Events: Implications for Food Production, Plant Diseases, and Pests." *Global Change Human Health*. 2: 90-104.

Schellnhuber, H.J., W. Cramer, N. Nakicenovic, T. Wigley, G. Yohe, 2006. "Avoiding Dangerous Climate Change," Cambridge University Press, Cambridge UK.

Segerson, K. and B.L. Dixon, 1999. "Climate Change and Agriculture: The Role of Farmer Adaptation. The impact of climate change on the United States economy," R. Mendelsohn, J. E. Neumann, Eds., Cambridge University Press, Cambridge, 75–93.

Terjung, W.H., J.T. Hayes, P.A. O'Rourke, and P.E. Todhunter, 1984. "Yield Responses of Crops to Changes in Environment and Management Practices: Model Sensitivity Analysis. II. Rice, Wheat, and Potato," *International Journal of Biometeorology*. 28: 279–92.

Weersink, A., J.H. Cabas, and E. Olale, 2010. "Acreage Response to Weather, Yield, and Price," *Canadian Journal of Agricultural Economics*.

Wu, Y.C., 2008. "Estimating the Economics Impacts of Climate Change on Global Rice Markets," Master thesis, Department of Applied Economics, National Chung Hsing University, Taiwan.