Climate Change on Agriculture in 2050: A CGE Approach

Geoffrey Musyoki Kitetu[1]
Ph.D. Candidate, Division of International and Area Studies, Pukyong National University

Jong-Hwan Ko[2]
Professor, Division of International and Area Studies, Pukyong National University

Contents

Abstract

Agriculture plays a very critical role in terms of global food security and provides livelihood to over 30 percent of the world population. However, agricultural activities and related firm production processes heavily rely on the prevailing climatic conditions to produce. This study investigates the economic impact of climate change on agriculture in 2050. We employ the multi-sector multi-region computable general equilibrium (CGE) based approach. Using the latest GTAP Version 10 database (whose base year is 2014), we project the global economy to 2050 relative to 2014. The main interests of this study are findings concerning the role of economic players adaptation response to climate change, the potential regional impacts, and the possible changes in production quantities and market prices. Two simulations are implemented: a baseline growth path simulation (scenario) that does not account for climate change effects and a counterfactual policy simulation accounting for the impacts that accrue due to climate change. Simulation results reveal that climate change will make China's GDP grow by -0.21%, Brunei's by -0.7%, Malaysia's by -0.06 %, Singapore's by -0.05%, Korea's by -0.03%, India's by -0.1% and rest of the world by -0.2 % relative to RCP 2.6 scenario. All other regions have positive GDP growth. Welfare in the USA is projected to decline by 25.85 US$ billion, in Canada by 20.85 US$ billion, in Chile by 4.64 US$ billion, in New Zealand by 4.43 US$ billion, and in Japan by 0.66 US$ billion. Furthermore, the trade balance is found to decline in ten regions with the USA's decreasing by 7.29 US$ billion and that of Korea by 0.30US$ billion. The study concludes that climate change adaptation and mitigation policies should be specific to every stage in the food value chain (FVC) with more emphasis on production and market integration segments.

Keywords: Agriculture, Integrated Approach, Climate Change, CGE Model, CPTPP, RCEP, USA, India

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[1] First author, e-mail: geoffreykitetu.m@gmail.com
[2] Corresponding author, e-mail: jonghko@pknu.ac.kr

I. Introduction

Agriculture plays a central role in terms of global food security and provides livelihood to over 30 percent of the global population. However, agricultural production and related firm activities heavily rely on the state of the climate in their production process. Strikingly, the effects of climate change on the agricultural sector are immediate and more pronounced than on other sectors of the economy. Numerous incidences confirm that the world climate is changing very fast. Recently in an unprecedented occurrence on August 10th, 2019, lighting[3] struck 48 times in the north pole within 85^0 N and 126^0E, meaning that the north pole is warming up faster than anticipated (Andrew, 2019). During the same period, the Korean peninsula experienced several typhoons, which have adversely affected agricultural production and the general livelihoods of many people, a phenomenon attributed to climate change by many climate experts (Ko, 2019). There is adequate literature on climate change, highlighting the evidence that the atmosphere and the oceans have been getting warmer, the snow is melting faster, the sea level has risen, and the amount of greenhouse gas (GHG) emission has increased tremendously hence, and therefore the climate system is in distress (IPCC, 2013). To formulate appropriate climate change adaptation and mitigation policies, understanding the effects of climate change is paramount.

The agricultural sector, which is mostly affected by climatic change, contributes significantly to the economic growth of many developing nations, by addressing food security and unemployment concerns. According to the International Labor Organization (ILO) (2014), agriculture employs 31.3 % of the world's labor force in 2013 (a decline of 29.7 % since 1991), 39.3% of the labor force of South-East Asia and the Pacific, 14.8% of that of Latin America, 3.6%

[3] Lightning strikes in the North pole is a sign that the north pole is also warming up. https://www.nationalgeographic.com/environment/2019/08/lightning-struck-near-north-pole-why-strange/

of the developed economies and the European Union and 46.3 % of that of South Asia. Therefore, appropriate climate adaptation measures must be implemented to ensure sustainability in global food security and private household livelihoods.

Agricultural production is sensitive to weather fluctuations. Hence, climate change poses a food security threat due to its broad negative impact on agricultural production. Therefore, it is necessary to empirically quantify the impact of climate change on agricultural productivity and the economy to guide climate policy formulation. To bring out plausible empirical results, the use of the CGE model is most appropriate due to its capacity to isolate the response mechanisms by various economic agents to adapt and mitigate the impacts of climate change. Furthermore, an integrated assessment approach produces reliable estimates of the impacts of climate change on agriculture. The integrated approach involves evaluating the actual impact of climate change on agricultural production at every stage of the agricultural production value chain. This captures in detail the effects of climate change on production. A study on the effects of climate change on agriculture considering the response by economic agents shows that (average) biophysical yield effect without carbon fertilization leads to a 17% reduction in global crop yield by 2050 with an unchanging climate. Further, the study finds that endogenous economic adjustments reduce the yield decline to 11%, lead to an increase in the cultivated land area of major crops by 11%, and reduce consumption by 3% Nelson et al. (2014).

Numerous studies are reviewing the economic impact of climate change through crop yield. However, most of the previous studies on climate change in the Asia-Transpacific region focus on the economic impact of climate change through GHG emissions but not through crop yield reduction. Furthermore, we feel that this study is necessary as it relooks at the response of economic agents on a wider scope to changes in crop yield due to climate, using the most current

GTAP version 10 database, whose base year is 2014. This study analyzes the impact of climate change in 2050 relative to 2014 under two GGCM scenarios, the RCP 2.6 and RCP 8.5.

This paper is structured as follows: after the introduction, section II provides a review of the mainstream literature related to the topic and the objectives of this study. The methodology description is presented in Section III, while data and simulation procedures are examined in section IV. Section V discusses simulation results, and section VI provides concluding remarks and policy implications.

II. Literature Review

With the projected increase in the world population to 10.08 billion in 2050, the demand for agricultural commodities is expected to increase exponentially in 2050 (UN, 2017). Given the expected increase in population and the improved purchasing power by private households, the question then arises whether agricultural production can meet world food demand by the year 2050 (United Nations, 2015; Bruinsma, 2011; and Foure, et al., 2012). Furthermore, food demand within the Sub-Saharan African (SSA) and the South Asian region is estimated to increase by about 70 % (Alexandratos and Bruinsma, 2012; Hunter et al., 2017; Zeshan and Ko 2017).

According to IPCC (2018, & 2019), reports on the effects of climate change, physical land provides the principal basis for human livelihoods, and wellbeing including the supply of food, domestic water, and multiple other ecosystem services, including biodiversity. The reports find climate change to create additional stress on land, exacerbating existing risks to human livelihood, biodiversity, ecosystem, and human health, infrastructure, and food systems. According to the reports, Land surface air temperature has risen nearly twice as much as the global average temperature since the pre-industrial period. As a result, food security and environmental ecosystem have negatively been affected. Conversely, agriculture, forestry, and Other land use (AFOLU) human operations contribute about 13% of carbon, 44% of methane (CH4), and 82% of nitrous oxide (N2O) emissions globally during the period 2000-2016, a 23% (12.0 +/- 3.0 GtCo2e year-1) of the total net anthropogenic emissions of GHGs. During the same period, the natural response of land to human-induced environmental change resulted in a net sink of about 11.2 GtCo2 yr-1, equivalent to 29% of the total carbon emissions. However, due to climate change, the consistency of the sink is not certain. The reports conclude that the level of risk from climate change depends on the magnitude in the rise in temperature and how population growth, consumption, production technology development, and land management patterns evolve.

A study on farmers' short-run response to extreme heat due to climate change applied the production function approach. The study finds that extreme temperatures induce farmers to increase land use acreage and the crop mix during the farming cycle and reduces agricultural output. Furthermore, the study shows that land adjustments play a very critical role as an adaptive measure to climate change. The study suggests the application of these estimated values in general equilibrium models to quantitatively ascertain the magnitude of their impact on the economy (Arangon et al. 2018).

A biophysical study by Birthal et al. (2014), undertaken to analyze India's food security concerning climate change evaluated climate variables vis-à-vis temperature and rainfall and their impact on crop yields. The study observed a significant increase in mean monthly temperatures during the post-rain season but a marginal increase in rainfall. Further, the study finds that an increase above the maximum monthly temperature leads to a decline in the crop yield, while a similar rise in the minimum monthly temperature has a positive effect on crop yield. However, the increase in yield from a rise in the minimum temperature is not sufficient to compensate for the loss of crop yield from a rise in the maximum monthly temperature.

Available literature confirms that climate change has already impacted crop yields. Ray et al., (2019) study employ the biophysical approach to empirically evaluate the potential effect of actual climate change on the productivity of 10 crops which include barley, cassava, maize, oil palm, rapeseed, rice, sorghum, soybeans, sugarcane, and wheat using weather and reported crop data at 20,000 political units. The findings of the study show that the global climate change effect on yield ranges between -13.4 percent for oil palm to 3.5 for soybean. Geographically Europe, Southern Africa, and Australia are negatively affected while Latin America is positively impacted. The Asian region, and North and Central America show mixed responses to climate change. This aggravates food security concerns in the majority of the food-insecure regions.

Extreme temperatures reduce agricultural productivity through reduced crop yields, which eventually leads to price fluctuations (Zeshan and Ko, 2017 and Birth et al., 2014). Since food demand is projected to increase with an increased world population of 10.078 billion by 2050 as projected by the United Nations (2015), improved farming methods to adapt or mitigate the negative effects of climate change need to be developed to address global food security. Climate change-induced temperature rise has a negative supply effect on agricultural commodities. Analyzing the economy-wide effects, the findings of several studies find that most of the East Asian and South Asian countries will have welfare loss and decline in GDP (Zeshan and Ko, 2017; Bandra and Cai, 2014).

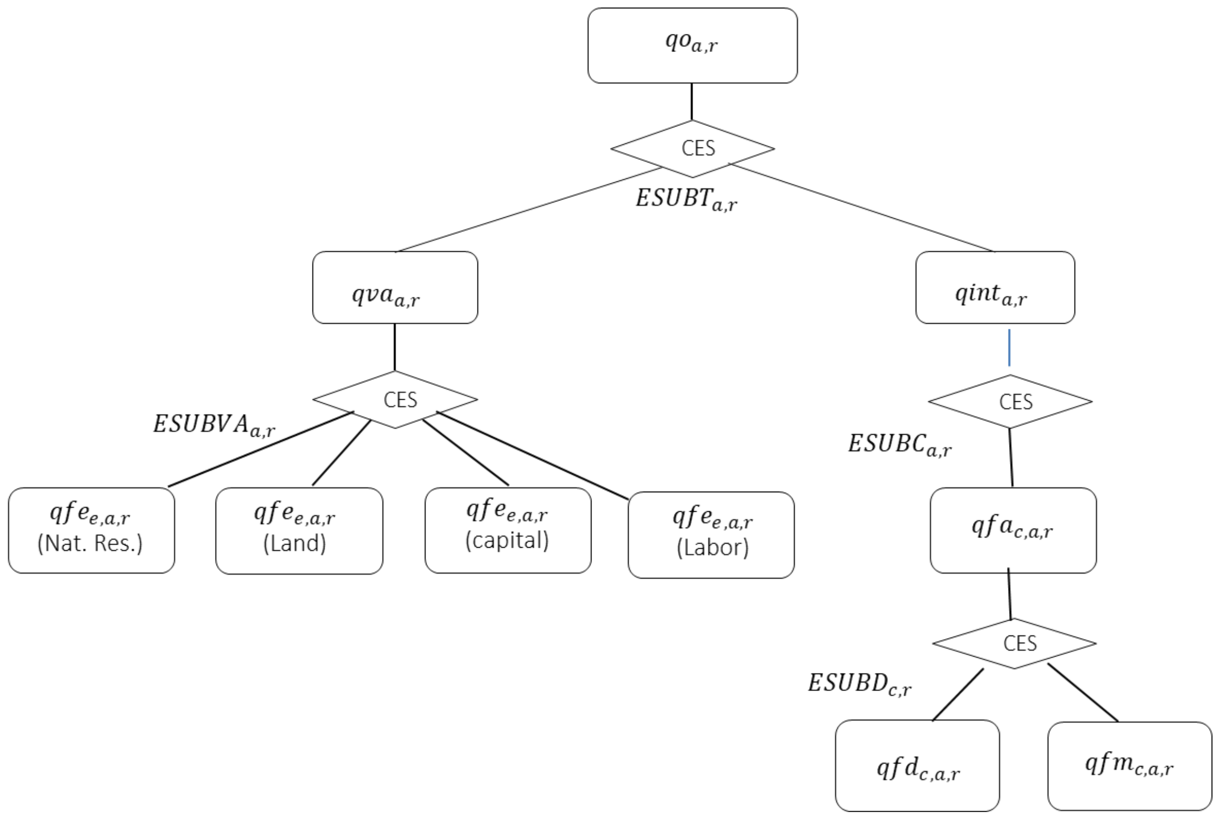
An extensive study on the impact of climate change on labor productivity finds that excessive heat in the workplace to be an occupational hazard and lowers labor productivity. To adapt to extreme heat, human beings tend to slow down work or reduce working hours. Hence, extreme heat lowers labor productivity, monthly incomes, and overall national output. Therefore, since agricultural production relies heavily on human labor, an increase in temperature due to climate change will have a direct impact on agricultural output. The reduced production and purchasing power have a direct and indirect negative impact on the economic growth of a nation, finds UNDP (2016).

Climate change affects the overall food value chain from production through consumption. In addition to the significant negative effect on agricultural production, climate change also affects storage, processing, distribution, marketing, supply prices, and the quality of the final commodity and consumption patterns. Hence, the cumulative negative effect of climate change on global food security and employment is significantly wide. Tumwesigye et al. (2019) study recommend innovating adaptation and mitigation climate change policies reflecting each stage of the food value chain, such as at the farm level.

III. CGE Model Specification

In evaluating the potential global economic impact of climate change on agriculture, this study employs a multi-sector multi-region CGE model. There is no standard definition of a CGE model. However, a CGE model constitutes a system of non-linear simultaneous equations that describe the constrained optimizing behavior of economic agents such as the savers, investors, producers, exporters, importers, consumers, the government etc. (Ko,1993). The model characteristic provides an appropriate framework by which the impact of policies and the efficiency in resource allocation within an economy can be evaluated. The standard GTAP model contains five primary factors of production, which include skilled-labor, unskilled-labor, capital, land, and natural resources. However, unlike capital and labor, land is immobile, and therefore less substitutable for other primary factors in the production process. More so, land is a major factor in the agricultural production process, together with the other primary factors of production. It's worth noting that energy use, climate change, and agricultural production are intricately interlinked.

<Figure >Top Production Nest



Source: Adapted from the standard GTAP model, version 7 Corong et al. (2017)

According to Corong et al., (2017) and Hertel, (1997), the standard GTAP approach applies the Cobb-Douglas utility (CES) structure. In this model, the regional household income is distributed among the three components of final demand, which include the private household, government expenditure, and investment. To produce a commodity, the value-added composite, is combined with the intermediate composites under a CES production structure while imported intermediate commodities are differentiated from their source through the Armington CES structure. The consumption behavior of private households in the standard GTAP is addressed differently from the two other factors of final demand (government expenditure and private savings). Consumption of all goods by the private households is assumed to be of a constant-difference elasticity (CDE) form see<Figure 1>.

IV. Data and Simulation Procedures

The primary database applied in this study is the GTAP version 10 database, whose base year is 2014. This database is composed of data for 141 regions in 65 sectors. For the sake of this study, we aggregate the database into 16 regions and 17 sectors. To analyze the impact of climate change in 2050, we project the global economy to 2050 relative to 2014, using macroeconomic data drawn from numerous data sources. The macroeconomic projections include forecasts for real GDP, population, skilled labor, and unskilled labor, physical capital stock, and arable land on each of the 16 regions for the year 2050 relative to 2014. Regional and sectoral data aggregation is presented in <Table 1>.

<Table 1> Regional and Sectoral Aggregation

No.	Region	Description	Sector	Description
1	AUS	Australia	PDR	Rice
2	BRN	Brunei Darussalam	WHT	Wheat
3	CAN	Canada	OGR	Other grains
4	CHL	Chile	VGF	Vegetable & fruits
5	JPN	Japan	OSD	Oil seeds
6	MYS	Malaysia	OAG	Other agriculture
7	MEX	Mexico	Coal	Coal
8	NZL	New Zealand	Oil	Oil
9	PER	Peru	Gas	Gas
10	SGP	Singapore	OXT	Other extraction
11	VNM	Vietnam	PrcFood	Processed food
12	USA	United States of America	Oil-pcts	Oil products
13	KOR	Korea	ENT	Energy intensive
14	CHN	China	OMF	Other Manufacture
15	IND	India	Electricity	Electricity
16	ROW	Rest of the World	Transport	Transport
17	-	-	OSVC	Other Services

Source: GTAP database version 10 (August 2019)

Simulation Procedures

This section describes the simulation design applied in quantifying the global impact of climate change on agriculture in 2050 under two climatic scenarios. Through an integrated research framework, physical and social scientists collaboratively explore the enormous implications of climate change on humanity. The integrated research approach involves linking the impacts of climate change from global climate models (GCMs), through global gridded crop models (GGCMs) to a global economic model (GEM). The approach applied in this study is at the tail end of this framework.

The GCMs simulate the interactions of the atmosphere, oceans, land surface, snow ice, and permafrost and their responses to the increase in GHG emissions by the use of chemical, physical, and biological principles. These GCMs consider projections of all variables (including socio-economic pathway variables) that affect the amount of GHS emissions. These models provide a range of projections showing the expected global climate changes, which are used as input into biophysical crop models. Applying several technics (mechanical or statistical), the biophysical models carry out simulations to evaluate the effects of projected climate change on physical and biological processes, and systems including crop yield, water supply, and human health and productivity. Finally, findings from the biophysical models are applied as inputs into the GEMs, such as the CGE models, to evaluate the economic responses to the effects of change in climate, including the review of alternative policies' effectiveness to either adapt or mitigate climate change.

The experiment design for the analysis of the impact of climate change on agriculture in 2050, is implemented using two main scenarios: a baseline simulation and counterfactual simulation. Using the macroeconomic projections, the baseline scenario reflects the global economy in 2050 without climate change, while the counterfactual (policy) scenario is applied to empirically quantify the potential global economic effects of climate change in 2050 relative to 2014. The difference in results between the baseline scenario and the climate change scenario describes the effects of climate change in 2050 compared to 2014.

Baseline Scenario

<Table 2> Projected Macroeconomic Parameters in Percent

Region	Code	GDP	Population	Skilled labor	Unskilled labor	Capital stock	Arable land
Australia	AUS	127.04	37.05	44.73	6.6	109.65	3.36
Brunei	BRN	62.63	27.92	58.79	-5.40	42.05	2.02
Canada	CAN	116.69	24.27	43.88	13.4	91.58	4.48
Chile	CHL	121.39	13.66	42.95	37.70	73.6	3.36
Japan	JPN	64.70	-14.30	-0.94	-11.2	46.48	-0.44
Malaysia	MYS	190.22	35.96	70.00	35.00	217.31	2.02
Mexico	MEX	190.32	33.23	32.00	36.27	152.56	3.36
New Zealand	NZL	116.27	21.63	54.71	8.51	132.23	-0.44
Peru	PER	177.21	34.33	28.29	37.70	258.64	3.36
Singapore	SGP	80.45	17.98	12.20	3.35	53.4	2.02
Vietnam	VNM	185.77	22.42	68.84	40.40	242.43	2.18
United States	USA	87.11	20.65	62.96	11.1	61.6	-0.91
Korea, Rep.	KOR	177.20	-1.49	20.80	6.6	192.71	0.70
China	CHN	284.50	-1.03	11.05	-6.49	264.00	3.36
India	IND	325.72	25.27	57.33	37.60	281.95	2.02
Rest of the World	ROW	183.56	36.10	49.80	35.99	233.4	3.36

Source: SSP2, UN Population, Bruinsma (2011), Four'e et al (2012) and WDI

The baseline experiment defines the 11 CPTTP members, 2 RCEP members (Korea and China), India, the USA, and ROW economies in 2050 with a constant unchanged climate. In developing the benchmark scenario, we update our model with the projected values of the five macroeconomic variables: real GDP, population, skilled and unskilled labor force, physical capital stock, and arable land. All macroeconomic projections are benchmarked to 2014. Real GDP projections are drawn from the SSP2 database (Keywan et al. 2017), while the projected population values are taken from the UN (2017) labor projections. The projected values for labor and physical capital stock supply growth are sourced from Foure et al., (2012), while the projected growth in arable land is from Bruinsma (2011). Macroeconomics projections data applied in this study is presented in <Table 2>.

Policy Scenario

The counterfactual simulation describes the 11 CPTTP members, the 2 RCEP members (Korea and China), India, and the USA economies in 2050 with climate change. We impose the same factor endowment and productivity projections as in the baseline experiment, including the effects of climate change on land supply, agricultural productivity, and labor productivity. The effects of climate change in 2050 result from the difference in results between the baseline scenario and the counterfactual experiment. For this study, agricultural productivity is endogenously estimated. This study analyzes the impact of climate change in 2050 relative to 2014 using climate change projected crop yields. We apply the RCP 2.6 and RCP 8.5 projected crop yields as applied in Xie et al. (20180.) as presented in <Table 3>.

<Table 3>Climate Change Projected Crop Yield in 2050, under RCP 2.6 and RCP 8.5 in Percent

Region	Rice		Wheat		Other grain		Oil seeds		Vegetable & fruit		Other Agriculture	
	RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5
Australia	-0.02	-0.19	-0.27	-0.40	-0.12	-0.28	-0.09	-0.28	-0.13	-0.29	-0.15	-0.31
Brunei	-0.27	-0.55	-0.93	-1.81	-0.11	-0.30	0.06	0.01	-0.31	-0.66	-0.32	-0.69
Canada	0.00	0.00	0.05	-0.03	0.15	0.05	0.17	0.14	0.09	0.04	0.12	0.05
Chile	-0.19	-0.43	-0.60	-1.18	-0.11	-0.34	0.02	-0.09	-0.22	-0.51	-0.22	-0.53
Japan	0.15	0.16	-0.09	0.09	-0.04	-0.18	0.01	-0.01	0.01	0.02	-0.03	-0.02
Malaysia	-0.04	-0.08	0.00	0.00	-0.17	-0.42	0.12	-0.05	-0.02	-0.14	-0.02	-0.15
Mexico	-0.19	-0.43	-0.60	-1.18	-0.11	-0.34	0.02	-0.09	-0.22	-0.51	-0.22	-0.53
New Zealand	-0.02	-0.19	-0.27	-0.40	-0.12	-0.28	-0.09	-0.28	-0.13	-0.29	-0.15	-0.31
Peru	-0.19	-0.43	-0.60	-1.18	-0.11	-0.34	0.02	-0.09	-0.22	-0.51	-0.22	-0.53
Singapore	-0.27	-0.55	-0.93	-1.81	-0.11	-0.30	0.06	0.01	-0.31	-0.66	-0.32	-0.69
Vietnam	-0.09	-0.18	0.03	0.03	-0.22	-0.57	-0.12	-0.26	-0.10	-0.25	-0.10	-0.26
United States	-0.09	-0.27	0.06	0.07	-0.22	-0.63	-0.03	-0.21	-0.07	-0.26	-0.07	-0.26
Korea	-0.01	-0.06	0.23	0.24	-0.35	-0.66	-0.03	-0.07	-0.04	-0.14	-0.05	-0.16
China	-1.34	-2.60	-4.83	-9.39	0.25	0.31	0.31	0.42	-1.40	-2.82	-1.42	-2.87
India	-0.27	-0.55	-0.93	-1.81	-0.11	-0.30	0.06	0.01	-0.31	-0.66	-0.32	-0.69
Rest of World	-0.07	-0.20	0.05	-0.01	-0.13	-0.37	-0.15	-0.37	-0.08	-0.24	-0.08	-0.25

Sources: Wei et al (2018); Bruinsma (2011)

V. Simulated results

This section presents simulated results for the impact of climate change on agriculture in 2050 relative to 2014. A comparative analysis of the key results from the simulated results is discussed, with emphasis on the potential regional economic impact, changes in welfare, domestic production, consumption, terms of trade, and changes in commodity prices. Any climate shock propagates through the economic modeling options whereby the economic models transfer the shock effect to the response variables.

<Table 4> Impact of Climate Change on Market prices in Percent

Region	Effect on Market prices (RCP8.5-RCP 2.6)					
	Rice	Wheat	Other Grains	Vegetable fruits	Oil seeds	Other Agriculture
Australia	0.49	1.04	0.83	1.17	1.13	1.40
Brunei	0.79	1.36	0.76	1.11	0.78	1.29
Canada	0.29	0.85	0.71	0.90	0.77	1.04
Chile	0.50	1.14	0.86	1.25	0.88	1.56
Japan	0.09	0.32	0.45	0.21	0.41	0.82
Malaysia	0.59	1.14	1.62	1.22	0.94	1.71
Mexico	0.31	1.02	1.05	1.05	0.90	1.16
New Zealand	1.26	0.89	0.91	1.01	1.19	1.60
Peru	0.65	1.41	1.11	1.15	0.98	1.43
Singapore	0.45	1.70	1.20	1.42	1.23	1.64
Vietnam	0.62	1.03	1.61	1.31	1.07	1.36
United States	0.46	0.97	1.29	1.03	1.03	1.13
Korea	0.72	0.72	1.10	0.97	0.74	1.13
China	2.02	9.51	0.80	3.06	0.70	4.56
India	0.66	1.81	0.93	1.49	0.92	1.59
Rest of World	0.61	0.71	0.81	0.78	0.98	1.30
Av Price Change	0.66	1.60	1.00	1.20	0.91	1.55

Source: Authors' estimations

A review of the simulation results shows that the impact of change climate on macroeconomic variables is at most non-linear. Hence, the economic impacts of climate change between different regions (sectors) vary significantly. The CGE model in build capacity can capture the internal responses by economic agents caused by any external shock, including climatic change. Theoretically, climatic changes reduce crop productivity (ceteris paribus), leading to a shift of the supply curve to the left and thereby reduce the supply capacity leading to an increase in market prices of agricultural commodities. Under budget constraints, private households respond to the market price increase by reducing the consumption of expensive agricultural commodities while shifting into the consumption of substitute commodities. Likewise, in response to climate change, agricultural producers adapt by adjusting their farm-level management operations or by increasing the farming area under each crop. Additionally, international trade plays a major role in the reallocation of production and consumption of produced agricultural commodities within the global community.

<Table 5> Impact of Climate Change on Production in Percent

Region	Effect on Production (RCP8.5- RCP 2.6) (%)					
	Rice	Wheat	Other Grains	Vegetable fruits	Oil seeds	Other Agriculture
Australia	0.37	1.46	0.54	0.07	0.20	0.89
Brunei	-0.67	-4.08	0.02	-0.46	0.37	-0.30
Canada	0.24	1.28	0.80	0.50	0.53	0.90
Chile	0.16	-0.80	0.15	-0.08	0.03	-0.19
Japan	0.10	3.24	0.86	0.77	1.26	0.76
Malaysia	0.00	-0.40	-0.67	0.45	-0.25	0.03
Mexico	0.40	-2.32	0.25	-0.10	0.25	-0.16
New Zealand	-2.56	-1.31	-0.37	-0.21	-2.16	0.23
Peru	-0.09	-0.89	-0.02	-0.14	-0.07	-0.22
Singapore	0.88	-1.58	0.16	-0.25	0.45	-0.37
Vietnam	0.25	-4.95	-0.15	0.18	-0.37	-0.10
United States	0.55	0.79	-0.03	-0.11	-0.59	0.30
Korea	0.24	0.14	-0.24	0.17	0.23	0.03
China	-0.16	-1.53	-0.28	-1.34	-0.27	-1.33
India	-0.14	-1.05	-0.21	-0.50	-0.26	-0.35
Rest of World	0.05	0.38	-0.04	0.07	-0.20	-0.03

Source: Authors' estimations

A decline in the production of major food crops together with an increase in population, a rise in disposable income will increase agricultural commodity prices. Usually, when prices increase, consumers adjust by substituting expensive commodities with cheaper commodities. <Table 4>

confirms that extreme climate will lead to an increase in the prices of all crops in all regions. On average, the prices of wheat and sector other-agriculture are projected to increase the highest by 1.6 percent and 1.55 percent, respectively. Rice and Oilseeds are expected to have the lowest price increase of 0.66 percent and 0.91 percent, respectively, while the global prices of Othergrains and vegetables and fruits increase by 1 percent and 1.2 percent, respectively.

An increase in market prices, as shown in <Table 4>, motivates the farmers to increase the production of crops, which have higher profit margins. Assessment of simulation results show that production under extreme climate has mixed results with production in some sectors declining in other sectors production takes an upward trajectory. The production of rice in Brunei declined by 0.67 percent, in New Zealand by 2.56 percent, in Peru by 0.09 percent, in China by 0.16 percent, and in India by 0.14 percent. Rice Crop production is found to do better under extreme climatic conditions compared to other crops. Under the RCP 8.5 scenario, crop yield improves on all crops in Australia, Canada, and Japan. However, crop yield for all sectors decreases for China, India, and Peru.

With an increase in the market prices of agricultural commodities, private households adjust by substituting high-cost food items with less expensive commodities, as shown in <Table 4> and <Table 6>. Private household consumption of rice, other grains, vegetable fruits, and oilseeds decline in Australia, Brunei, and Japan. However, the consumption of wheat and sector other-agriculture is projected to increase. Strikingly, wheat, and sector Other-agriculture production is projected to increase, compared to the output of other sectors. Furthermore, the domestic market comprises of domestically produced goods and imported commodities. It's worth noting that the domestic agricultural commodity basket is composed of domestically produced agricultural commodities and imported agricultural commodities. Hence, imported agricultural commodities can be substituted for locally produced agricultural commodities. In this model, internationally traded goods are subjected to the Armington assumption whereby goods are differential from their source. A vital assumption is that there are no market distortions except those caused by climate change. Comparing results as presented in <Table 4 and Table 6>, it shows that agricultural production is projected to decline by a bigger percentage compared to the decline in demand for agricultural commodities by the private household.

<Table 6 > Impact of Climate Change on Private Household Consumption in Percent

Region	Effect om Private Household Consumption (%) (RCP 8.5-RCP 2.6)					
	Rice	Wheat	Other Grains	Vegetable fruits	Oil seeds	Other Agriculture
Australia	0.09	0.00	0.09	0.03	-0.13	-1.72
Brunei	-0.71	-0.23	-0.09	-0.18	-0.19	-1.08
Canada	0.24	-0.02	0.44	0.17	0.25	-0.74
Chile	-0.03	-0.06	-0.05	-0.38	-0.04	-0.80
Japan	0.03	0.00	0.49	0.32	0.09	-0.49
Malaysia	-0.04	-0.59	-0.56	0.58	0.04	-0.39
Mexico	-0.04	-0.08	0.05	-0.08	-0.06	-0.67
New Zealand	-1.06	-0.01	-0.06	-0.10	-0.02	-1.03
Peru	-0.23	-1.66	-0.13	-0.19	-0.14	-0.44
Singapore	0.00	-1.99	-0.31	-0.30	-0.56	-0.81
Vietnam	-0.18	-4.76	-0.94	-0.05	-0.34	-0.33
United States	0.39	-0.01	-0.27	-0.06	-0.02	-1.00
Korea	0.12	0.07	-0.16	0.10	0.07	-0.55
China	-0.59	-2.03	-0.25	-0.73	0.29	-1.90
India	-0.27	-0.48	-0.27	-0.46	-0.24	-0.51
Rest of World	-0.14	-0.11	-0.18	-0.13	-0.20	-0.50

Source: Authors' estimation

<Table 7> Impact of Climate Change on Imports in Percent

Region	Effect on Imports Percent US$ Million					
	Rice	Wheat	Other Grains	Vegetable fruits	Oil seeds	Other Agriculture
Australia	-1.00	0.57	-0.15	-0.10	0.41	-0.81
Brunei	0.15	0.02	0.02	0.01	0.01	-0.03
Canada	-1.49	0.68	-0.25	-0.03	-0.22	-0.56
Chile	0.01	1.35	0.00	0.45	0.15	0.77
Japan	-0.66	-0.08	0.04	-0.61	0.00	-0.49
Malaysia	-0.46	-0.31	-0.13	-0.44	-0.63	-1.19
Mexico	-0.21	0.18	-0.30	0.23	0.06	-0.20
New Zealand	-0.45	-0.39	-0.66	-0.13	-0.49	0.10
Peru	0.51	2.61	-0.14	0.26	-0.08	0.27
Singapore	1.28	0.67	0.10	0.04	0.16	0.22
Vietnam	-6.33	-0.32	-0.10	-0.37	0.01	-0.58
United States	-0.78	0.42	0.99	0.13	0.38	-0.14
Korea	-5.64	-0.51	-0.42	0.11	-0.01	-0.80
China	6.20	75.12	-0.45	3.73	-0.58	10.76
India	-2.24	6.15	-0.15	0.82	-0.95	-0.14
Rest of World	-0.46	-0.17	-0.13	-0.15	-0.02	-0.39

Source: Authors estimation

Climate change lowers the productive capacity of many crops. Through international trade, countries meet excess demand for agricultural commodities through the importation of commodities from bilateral trading partners. Simulation results in <Table 7> show that regional imports of agricultural commodities decrease significantly, especially rice, other grains, and sector other-agriculture. Rice imports decrease in many economies except for China, where rice imports increase by 6.20 percent, followed by Singapore by 1.28 percent, in Peru by 0.51 percent, in Brunei by 0.15 percent, and in Chile by 0.01 percent, respectively. Wheat imports by China increased by 75.12 percent, while, for India, wheat imports increased by 6.15 percent. Rice imports by Korea and the USA are expected to decline by 5.64 percent and 0.78 percent, respectively. Wheat imports are expected to increase in the USA by 0.42 percent but decrease for Korea by 0.51 percent. Changes in both domestic production capacity and private household consumption patterns will significantly affect the nature and quantities of agricultural imports.

< Table 8> Impact of Climate Change on Self Sufficiency in Percent

Region	Effect on Self sufficiency						
	Rice	Wheat	Other Grains	Vegetabl e fruits	Oil seeds	Other Agricultur e	Agricultur e
Australia	0.002	0.046	-0.005	0.000	-0.006	0.009	0.046
Brunei	0.000	0.000	0.000	-0.001	0.000	0.000	-0.001
Canada	0.001	0.027	0.001	0.002	0.006	0.010	0.048
Chile	0.000	-0.003	0.003	0.007	0.000	0.000	0.008
Japan	0.000	0.001	0.000	0.003	0.000	0.005	0.011
Malaysia	0.000	0.000	0.000	0.001	0.000	0.001	0.002
Mexico	0.001	-0.005	0.000	-0.003	0.000	0.000	-0.007
New Zealand	-0.001	-0.001	0.001	0.006	-0.002	0.012	0.014
Peru	0.000	-0.003	0.000	0.000	0.000	0.000	-0.004
Singapore	-0.002	-0.001	0.000	0.000	0.000	-0.001	-0.004
Vietnam	0.002	0.000	0.001	0.001	0.000	0.001	0.004
United States	0.004	0.015	-0.003	0.000	-0.008	0.004	0.011
Korea	0.001	0.001	0.000	0.001	0.000	0.001	0.003
China	-0.001	-0.007	0.000	-0.005	0.000	-0.003	-0.015
India	0.000	-0.003	0.000	-0.001	0.001	0.000	-0.003
Rest of World	0.000	0.002	0.000	0.001	0.000	0.001	0.004
Global	0.006	0.070	-0.001	0.012	-0.009	0.039	0.117

Source: Authors Estimations

The agricultural sector plays a critical role in addressing a country’s food security concerns. The ability of climatic change to affect crop productivity has a direct impact on food self-sufficiency capacity. <Table 8> shows the effect of climate on self-sufficiency in agricultural commodities. Extreme climate change is projected to significantly affect global food supply by decreasing the capacity of domestic production to meet local demand for some agricultural commodities in 2050. Simulation results show that global self-sufficiency is to improve in several sectors', such as in rice by 0.006 units, in wheat by 0.070 units, in vegetable and fruit by 0.012 units and in sector other-agriculture by 0.039 units. However, a decline in sector other-grains and sector oilseeds by 0.001units and 0.009 units, respectively, relative to scenario RCP 2.6, is detected. Self-sufficiency for Four CPTPP members are projected to have positive self -sufficiency, Brunei, Mexico, Peru, and Singapore will decline by 0.001units, 0.007units, 0.004 units, and 0.004 units, respectively. Self-sufficiency in all sectors for Canada, Japan, and Korea will improve significantly, with overall self-sufficiency of 0.048 units, 0.011 units, and 0.003 units, respectively. Self-sufficiency for the USA will improve for rice by 0.004 units, wheat by 0.015units, and sector other-agriculture by 0.004 units.

<Table 9 > Impact of Climate Change on Trade Balance in US$ millions.

Region	Effects on Sectoral Trade Balance in US$ Million						
	Rice	Wheat	Other Grains	Vegetable fruits	Oil seeds	Other Agriculture	Agriculture Trade
Australia	1.99	171.84	27.07	5.18	14.75	710.48	931.31
Brunei	-0.54	-0.02	-0.06	-0.44	-0.01	-0.37	-1.44
Canada	2.34	234.99	27.09	-2.38	164.28	590.08	1016.41
Chile	-0.15	-5.76	4.29	107.21	1.15	47.53	154.26
Japan	8.44	-14.45	-53.35	33.26	-31.94	360.32	302.29
Malaysia	-2.60	-3.61	-7.85	-25.73	-4.08	-16.80	-60.68
Mexico	-2.07	-31.39	-44.68	90.90	-52.55	37.93	-1.85
New Zealand	-0.35	-0.89	-0.12	31.03	-0.12	403.00	432.55
Peru	-1.52	-29.35	-9.39	27.65	-2.08	27.76	13.08
Singapore	-3.57	-1.40	-0.29	-9.71	-0.60	-26.53	-42.09
Vietnam	74.42	-5.41	-13.17	-6.23	-13.18	64.30	100.74
United States	36.84	202.13	93.24	-35.53	157.09	1755.22	2208.98
Korea	8.43	-8.37	-23.42	-21.46	-14.06	-31.36	-90.23
China	-208.38	-771.82	-41.79	-995.05	-221.20	-6821.25	-9059.49
India	78.21	-99.98	13.49	-158.82	21.53	49.14	-96.43
Rest of World	9.09	322.67	40.99	944.10	0.38	2653.60	3970.84
Net Trade Balance	0.60	-40.81	12.06	-16.02	19.35	-196.94	-221.76

Source: Authors estimation

Several factors contribute to dampening the negative impact of climate change. These include the increase of acreage under crop, change of management practices by farmers, such as farm automation and agricultural innovation. Control of food wastage through improved storage practices will minimize the negative effects of extreme climate change (Tumwesigye et al., 2019). <Table 9 > presents a summary of the sectoral trade balance in US$ millions. Trading in agricultural commodities is projected to contribute positively to the overall trade balance of the majority of countries. Four CPTPP countries are expected to have a negative agricultural trade balance while the rest will have a positive trade balance from agricultural trade. Korea and China, as RCEP members, including India, will have a negative trade balance.

<Table 10> Impact of Climate Change on GDP in Percentage

Region	Climate Change Effect on GDP (%)					
	Consumption	Investment	Government Expenditure	Exporting	Import	Real GDP
Australia	0.10	0.17	0.10	-0.03	0.12	0.10
Brunei	-0.06	-0.01	-0.07	-0.08	-0.02	-0.07
Canada	0.23	0.31	0.23	-0.07	0.24	0.23
Chile	0.09	0.10	0.08	0.02	0.05	0.09
Japan	0.01	0.09	0.00	-0.19	-0.01	0.00
Malaysia	-0.03	-0.38	-0.10	-0.03	-0.08	-0.06
Mexico	0.02	0.08	0.00	-0.08	0.01	0.02
New Zealand	0.21	0.12	0.20	0.18	0.19	0.19
Peru	0.07	-0.10	-0.04	0.07	0.04	0.03
Singapore	-0.04	-0.02	-0.06	-0.07	-0.06	-0.05
Vietnam	0.13	-0.14	-0.01	0.00	-0.02	0.10
United States	0.06	0.13	0.05	-0.06	0.13	0.05
Korea	-0.02	0.00	-0.04	-0.07	-0.05	-0.03
China	-0.11	-0.41	-0.32	0.34	-0.06	-0.21
India	0.03	-0.12	-0.09	-0.04	-0.08	-0.01
Rest of World	-0.01	-0.03	-0.05	-0.04	-0.03	-0.02

Source: Authors estimation

Real GDP is an essential statistical tool applied by economists to evaluate the performance of the economy of a country. Without intervention by economic agents, climate change will harm the real GDP growth of any economy. <Table 10> shows the percentage change in real GDP due to climate change. The Real GDP for three CPTPP members, is negative with Brunei's real GDP falling by 0.07 percent, that of Malaysia by 0.06 percent, and that of Singapore by 0.05 percent. The real GDP for Korea and China (who are RCEP members) is projected to fall by 0.03 percent and 0.21 percent, respectively, with that of India expected to fall by 0.01 percent and that of the

ROW regions by 0.02 percent. The fall in private consumption, government expenditure, and exports contribute to the fall of Korea's real GDP. The fall in real GDP for China stems from the decline in private consumption, investment, and government expenditure. Real GDP for the USA increased by 0.05 percent, supported by improved private consumption, investment, and government expenditure. However, a fall in exports and increase in imports in the USA dampens the rate of real GDP growth. Real GDP growth for Canada is the highest by 0.23 percent supported by private consumption, investment, and government.

<Table 14> Impact of Climate Change on Welfare in US$ Billion

Region	Effect on Welfare US$ Billion					
	Allocative Efficiency	Endowments	Technical Change	Terms of Trade	Investment Savings	Total Welfare
Australia	0.07	0.06	-0.11	-0.35	0.05	-0.28
Brunei	0.00	0.00	0.00	-0.01	0.00	-0.01
Canada	0.31	0.10	0.05	0.50	0.78	1.85
Chile	0.01	-0.01	-0.09	0.23	-0.02	0.13
Japan	-0.07	0.05	-0.01	0.65	-0.32	0.30
Malaysia	-0.03	-0.16	-0.12	-0.06	0.00	-0.40
Mexico	-0.01	-0.06	-0.24	0.27	-0.09	-0.15
New Zealand	0.05	-0.03	-0.05	0.57	-0.02	0.55
Peru	-0.02	-0.06	-0.19	0.05	-0.01	-0.25
Singapore	-0.01	0.00	-0.02	-0.04	-0.04	-0.12
Vietnam	-0.05	-0.08	-0.18	0.05	-0.01	-0.30
United States	0.26	0.06	-0.94	3.48	0.26	3.30
Korea	-0.04	-0.18	-0.12	-0.01	-0.16	-0.50
China	-7.21	-14.34	-36.39	-10.15	1.97	-65.86
India	-0.31	-1.38	-3.31	1.01	-0.28	-4.64
Rest of World	-4.53	-6.61	-9.06	1.64	-2.61	-23.37

Source: Authors Estimation

<Table 14> shows the effects of climate change on welfare across all regions. In our analysis, we compare the differences in effects from the disaster event shocks (crop yield changes due to change in climate) RCP8.5 and RCP 2.6 presented in US$ Billions. Welfare declines for seven

members of the CPTPP trading bloc with Australia's falling by US$ 0.28 billion, Brunei's by US$ 0.01 billion, Malaysia's by US$ 0.40 billion, Mexico's by US$ 0.15 billion, Peru's by US$ 0.25 billion, Singapore's by US$ 0.12 billion, and Vietnam by US$ 0.30 billion, while four members have a positive welfare gain. Among the four, Canada has the highest welfare growth of US$1.85 billion, followed by New Zealand by US$ 0.55 billion, Japan by US$ 0.30 billion, and Chile by US$ 0.13 billion, respectively Korea and China (RCEP members) see a decline in welfare by US$ 0.50 billion and US$ 65.86 billion, respectively. India's welfare falls by US$ 4.64 billion. ROW welfare falls by US$ 23.37 billion, which is the second-highest decline after that of China. Technical change hurts the welfare of the majority of the regions. This means that the existing technology does not have adequate capacity to respond to extreme climatic conditions. A decomposition of the welfare finds that terms of trade play a significant role in stabilizing welfare gains. The USA, India, and ROW see major welfare gains of US$ 3.48 billion, US$ 1.65 billion, and US$ 1.01 billion, respectively. Due to changes in welfare decomposition, the terms of trade for China, Australia, Malaysia, and Singapore, fall by US$10.15 billion, US$ 0.35 billion, US$ 0.06 billion, respectively. Korea's and Brunei's terms of trade fall by US$ 0.01 billion each.

VI. Conclusion

Climate change is a threat to both food security and the source of livelihood to a significant share of the world population. With both the projected increase in the global population and disposable income, food demand is expected to exponentially increase. Numerous studies are reviewing the economic impact of climate change through crop yield. However, most of the previous studies on climate change in the Asia-Transpacific region focus on the economic impact of climate change through GHG emissions but not through crop yield reduction. Furthermore, we feel that this study is necessary as it relooks at the response of economic agents on a wider scope to changes in crop yield due to climate, using the most current GTAP version 10 database, whose base year is 2014. This study analyzes the impact of climate change in 2050 relative to 2014 under two GGCM scenarios, the RCP 2.6 and RCP 8.5. Climate change effects on real GDP, welfare, and other economic variables except, market prices, are heterogeneously distributed. The heterogeneous nature of the effect of climate change on agriculture means policymakers should not use “a one brush fits all” approach. Therefore, based on the findings from our simulations, we find that climate change adaptation and mitigation policy attributes should be facilitative, specific, localized, and innovative.

Climate change policy strategies should revolve around adaptation and mitigation of the effects of climate change. First, increasing acreage under crop, whose productivity is affected by climate change, is one of the climate change adaptation strategies. This can be done by reclaiming the sea, uncultivated fertile land, or reclaiming dry areas through efficient irrigation methods. Since individual farmers cannot implement some of these steps, governments should establish appropriate policies to facilitate the implementation of some of these strategies. More so, adaptation and mitigation policies must be sector-specific such as improving the yields of the crop(s) that have the potential to contribute much towards national food security while at the same time considering dietary requirements. This can be accomplished through capacity-building investments such as training of farmers and agricultural extension officers on the best ways to increase crop yields by improving soil fertility and general management practices, proper pesticide control, crop water requirement, including agricultural farm automation. Investment in agricultural research to address region-specific needs, that may include the provision of suitable farm inputs, and appropriate information to farmers (such as the suitable crop for a specific area, when to plant, etc.), as a way to enhance agricultural productivity. Furthermore, evaluation, improvement, and standardization of climate adaptation practices applied by farmers in each region are more effective and less costly. As shown by our simulation results, trade plays a significant role in the adaptation and mitigation of the effects of climate change. Therefore, the establishment of policies that encourage the free movement of factors of production, including the reduction or removal of trade regulations that hinder trade, is a critical factor in alleviating the negative impacts of climate change.

In conclusion, adaptation and mitigation climate change intervention mechanisms should be specific to every stage in the food value chain from production (farm level) to final consumption (nutritional mix) with more emphasis on production and market integration segments. Due to the nature of the interaction between the different economic agents (private households, business entities, and different government departments) in the food (production) value chain (FVC), this study finds the top down bottom up policy framework most appropriate in terms of cost and response time.

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