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IMPACTS OF CLIMATE CHANGE ON FOOD PRODUCTION

— AN ECONOMIC ASSESSMENT —

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Abstract

The impact of climate change on crop production may be one of the most serious problems of the next century. In order to evaluate this problem quantitatively, we developed a modeling framework to estimate the economic impact caused by climate change. The framework comprises two main models; a GIS-based potential crop productivity model and an international trade model of 30 regions. Without considering the direct impact of an increase in atmospheric CO_2 concentration (CO_2 fertilization), the potential crop productivity of winter wheat is estimated to decrease 45% in India and increase 25% in Canada by the end of the next century, while that of rice and maize will not decrease significantly in any region. Taking these regional changes in potential productivity as technical changes in the production function of the international trade model, social welfare in India is seen to decrease considerably, 4.89%, while that in Canada and Japan will increase 0.34% and 0.02%, respectively. Globally, the social welfare will decrease 0.046%, which is valued at a loss of $9.5 billion under the climate in 2100. If consideration of the direct impact of CO_2 increase is included, the potential productivity of rice and maize will increase in most regions of the world. Although the potential productivity of winter wheat will still decrease in some regions, global social welfare will increase 0.41%, $84.4 billion gain under the climate in 2100.

KEYWORDS: *ClimateChange Impact, Food Production, Applied General Equilibrium Model*

1. Introduction

There has been active discussion in nearly every country on how to achieve reductions in greenhouse gas (GHG) emissions to prevent global warming. Reduction of GHG emissions requires

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considerable effort, and will affect the domestic and international economy. In order to make appropriate policies for each country, quantitative estimates of the impacts caused by the global warming as a result of insufficient GHG reduction is necessary.

Climate change have many effects; on water resources, human health, sea levels and natural ecosystems. Its effect on agriculture will also be of prime importance, and that has been selected as the subject of investigation for this study. Agricultural production is highly dependent on climatic conditions such as temperature, precipitation and evapotranspiration, and is influenced by climate change directly. There have been many studies estimating the changes in crop productivity caused by climate change. The studies often estimate the yield of crops per unit area using climate data such as temperature, precipitation, solar radiation, humidity and wind speed, as well as the land features such as slope, soil texture and pH, considered together with fertilizer input and irrigation. For the estimation of crop yield under a changed climate, the calculated results of general circulation models (GCMs) are usually used as the future climate condition. Although the estimations of crop production change still have large uncertainties, we expect these methods of evaluation will be improved in the future.

Furthermore, to propose promising policies for mitigation and adaptation to these changes, it is very important to understand how the direct impact of climate change on natural systems, such as change in crop productivity, influence human beings. For that purpose, an understanding of the social and economic systems, which relate the natural system to human activity, is essential. In this study, we estimated the impact of climate change on economy through the changes in crop productivity, while developing an assessment framework which integrates crop productivity and global trade models. In the next section, the framework for the assessment is explained and the resulting estimates are reported. In the final section, we discuss the results and the expected improvements in the research method.

2. Agricultural Impact Model

2.1 Outline of the model

Figure 1 shows the framework for the assessment in this report. Global-averaged temperatures from 1990 to 2100 are projected under the assumed GHG emission scenarios using the temperature increase module. The climate distribution module then predicts monthly temperature and precipitation in 2100 with a resolution of 0.5 ° by using the global temperature increase estimated in the previous module, the current monthly temperature and precipitation, and the future spatial pattern of the climate produced by the GCMs. Other climate-related data such as potential evapotranspiration (PET) and photosynthetically active radiation (PAR) are also calculated here with the water balance model. The potential crop productivity model simulates the process of crop growth, and estimates the potential crop productivity of the three representative grains under the current and the future climate conditions in each cell grid. The estimated productivity is aggregated for each of the 30 regions in the world, and the change in potential crop productivity between the present and future is assumed as the change in production technology in the following global trade model. The global trade model estimates the economic impact of climate change, with the assumption that, except for the technology change in the agricultural production sector, there will be no change in the surrounding conditions. In

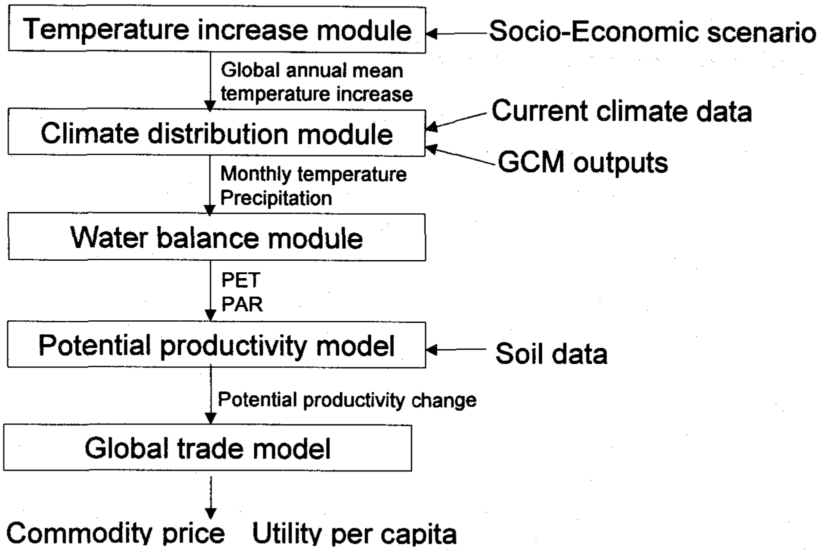

Fig. 1 Framework for the assessment

Table 1 30 regions in this assessment

Country	Code
Australia	AUS
New Zealand	NZL
Japan	JPN
South Korea	KOR
Indonesia	IDN
Malaysia	MYS
Philippines	PHL
Singapore	SGP
Thailand	THA
China	CHN
Hong Kong	HKG
Taiwan	TWN
India	IDI
Other South Asia	RAS
Canada	CAN
U.S.A.	USA
Mexico	MEX
Central America and Caribbean	CAM
Argentina	ARG
Brazil	BRA
Chile	CHL
Other South America	RSM
EU	E_U
Austria, Finland, Sweden	EU3
Europian Free Trade Area	EFT
Central European Associates	CEA
Former USSR	FSU
Middle East and North Africa	MEA
South Africa	SSA
Rest of the world	ROW

the following paragraphs, the modules and results are explained.

Several previous studies have estimated the impact of climate change on the economy through crop production using approaches similar to this one (Fischer *et al.*, 1994; Kane *et al.*, 1992; Darwin *et al.*, 1995). These studies adopted a common assessment framework, which integrated a crop model estimating the direct impact of climate change (productivity change) with an economic model for global trade simulation. The result of these studies were reviewed by the authors in a previous report (Takahashi *et al.*, 1997a).

In this study, we developed a potential crop productivity model with the parameters of crop growth reported by FAO (FAO, 1978-1981) to estimate the change in crop productivity under the given climate change. The result from this model was then put into the global trade model, after aggregated for each of the 30 regions of the study (Table 1). The advantage of this study over previous ones is the fine resolution of the crop model and the large number of regions included.

2.2 Potential crop productivity model

We will give only a brief explanation of the potential crop productivity model here. For a more detailed explanation, refer to the previous reports by the authors (Takahashi *et al.,* 1997a and Takahashi *et al.,* 1997b). This model requires daily mean temperature, mean daytime temperature, precipitation, PET, photosynthetically active radiation, and soil characteristics in order to simulate the growth of crops and to estimate the potential crop productivity. Twelve crops were estimated with this model, including rice, winter and spring wheat, and tropical and temperate maize, which are considered to be the most important from the nutritional point of view. Since the estimates are executed in high-resolution grids (5-minute resolution), the results can be aggregated into the appropriate spatial level.

Table 2 shows the estimated change in potential productivity of rice, winter wheat and tropical maize at the end of the next century, assuming the IS92a scenario (medium rates of economic development and population increase) as the socio-economic scenario. According to the IPCC (1996), the atmospheric CO_2 concentration will increase to about 710 ppm, and the global averaged temperature will increase about 2.0 °C under the IS92a scenario. To obtain the seasonal and spatial distributions of temperature increase and precipitation, the averaged temperature increase was combined with the GCM outputs interpolated spatially. To consider the range of estimates from the results of different GCMs, the change in productivity was estimated with the 11 GCMs, and the median value of the regional aggregates of these estimates was selected as the representative value. The columns under IS92a* in Table 2 show the estimates without considering the CO_2 fertilization effect. Though some research results at the laboratory level indicate that crop productivity increases with the increased concentration of atmospheric CO_2, there is also the view that the CO_2 fertilization effect will not be so large on actual farmland due to mitigating factors such as competition with weeds. In this report, we estimated the change in potential productivity in two cases, with consideration of the CO_2 fertilization effect, as surveyed by Cure et al. (1986), and without. According to the survey by Cure, yields of rice, wheat and maize increase 15%, 35% and 29%, respectively, under the doubling concentration of atmospheric CO_2. To obtain the potential productivity

Table 2 Median of the potential productivity changes in the three crops in 2100 under the IS92a scenario (%)

	Rice		Winter wheat		Maize	
	IS92a	IS92a*	IS92a	IS92a*	IS92a	IS92a*
AUS	27	9	18	−15	42	8
NZL	14	−2	36	−1	40	7
JPN	17	0	31	−5	26	−4
KOR	13	−2	29	−7	26	−4
IDN	13	−2	−22	−44	30	−1
MYS	11	−4	−	−	28	−3
PHL	12	−4	−	−	29	−2
SGP	−	−	−	−	−	−
THA	10	−5	−	−	37	4
CHN	18	1	28	−7	30	−1
HKG	−	−	−	−	−	−
TWN	26	9	24	−10	28	−2
IDI	4	−11	−24	−45	31	0
RAS	14	−2	−12	−36	51	15
CAN	105	76	72	25	140	83
USA	17	0	33	−4	33	1
MEX	11	−4	−19	−41	24	−5
CAM	14	−2	−42	−58	29	−2
ARG	12	−3	27	−8	30	−1
BRA	13	−3	−21	−43	29	−2
CHL	50	29	37	−1	72	31
RSM	14	−2	0	−27	31	0
E_U	22	5	27	−8	35	3
EU3	109	80	74	26	166	102
EFT	55	34	66	21	84	41
CEA	20	3	29	−6	29	−2
FSU	85	59	66	20	74	33
MEA	25	9	24	−10	43	9
SSA	12	−3	−19	−41	28	−3
ROW	17	1	26	−9	44	10

considering CO_2 fertilization effect, the increase ratios were multiplied to the estimated potential productivity without consideration of it (Takahashi *et al.,* 1997b).

2.3 Global trade model

To evaluate the economic impact of climate change through the changes in crop potential productivity in each region, we employed a global trade model based on the GTAP general equilibrium model developed at Purdue University (Hertel, 1997), with an aggregation of commodities (Table 3).

Figure 2 shows the flow of value in the model. Income in each region is added into the region's household, and distributed to the three purposes; private consumption, governmental consumption and savings. Under an equilibrium condition, the summation of savings in the world equals the summation of investments. Three factors are composed to produce intermediate and final commodities; land, labor and capital. Household possesses land and labor, and it provides the factors to the producer of commodities in the same region with the return of land rent and wage.

Table 3 Production sectors in the global trade model

Production sectors	Description
Paddy	Paddy
Wheat	Wheat
Other grains	Other grains
Other crops	Non-grain crops
Livestock	Wool Other livestock
Other agricultural products	Processed rice Meat products Milk products Other food products Beverages and tobacco Textiles Leather
Manufacture	Apparels Lumber Pulp paper Petroleum and coal Chemicals, rubbers and plastics Nonmetallic minerals Primary ferrous metals Nonferrous metals Fabricated metal products Transport industiries Machinery and equipment Other manufacturing
Services	Electricity, water and gas Construction Trade and transport Other private services Other governmental services Ownership of dwellings

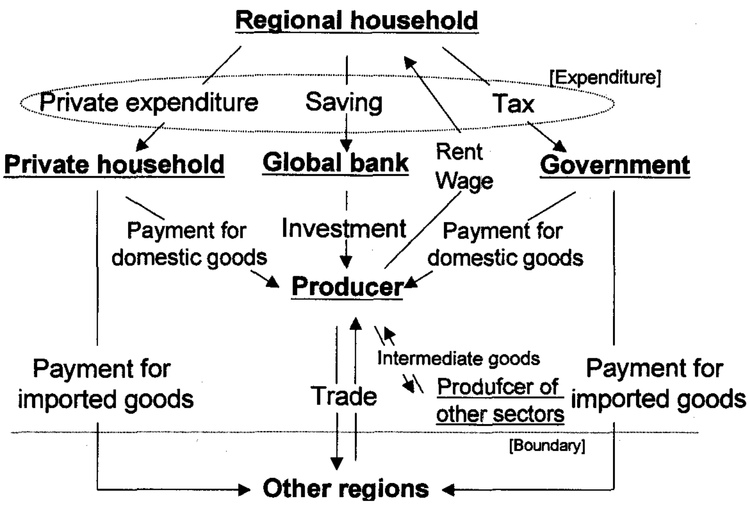

Fig. 2 Flow of value in global trade model (Hertel, 1997)

In the model, each producer produces commodities with the objective of maximizing profit. In all production sectors, constant returns to scale are assumed. Figure 3 shows the structure of substitution in the production sectors in the model. A firm combines certain composed factors and composed intermediate goods with the constant ratio (Leontief technology) to produce the goods. For the formation of the composed factors, the composed imported intermediate goods, and the composed intermediate goods, the CES (Constant Elasticity of Substitution) production function is assumed.

Household consumes the goods in order to maximize its utility. The shares of private consumption, governmental consumption, and saving are dependent on the Cobb-Douglas utility function. Thus, the share of expenditures in total income is constant and independent of the amount of income. The CDE (Constant Difference of Elasticity) utility function and the Cobb-Douglas utility function are assumed for private and governmental consumption, respectively.

In this global trade model, the potential productivity changes in rice, winter wheat, and tropical maize, which were estimated in the previous section, are taken as the changes in the Hicks-neutral technology parameters of the production sectors of rice, wheat, and other grains respectively. If it is assumed that a production Q is the function of two variables X_1 and X_2, the exogenous change in technology is described in the production function using the parameters of technology change A_0, A_1, and A_2,

$$Q = A_0 \times f(X_1 \times A_1, X_2 \times A_2)$$

Here, the parameter A_0 corresponds to the Hicks-neutral technology change. Table 4 shows the estimated changes in producer price, production, consumer price index and income per capita, under the given climate change.

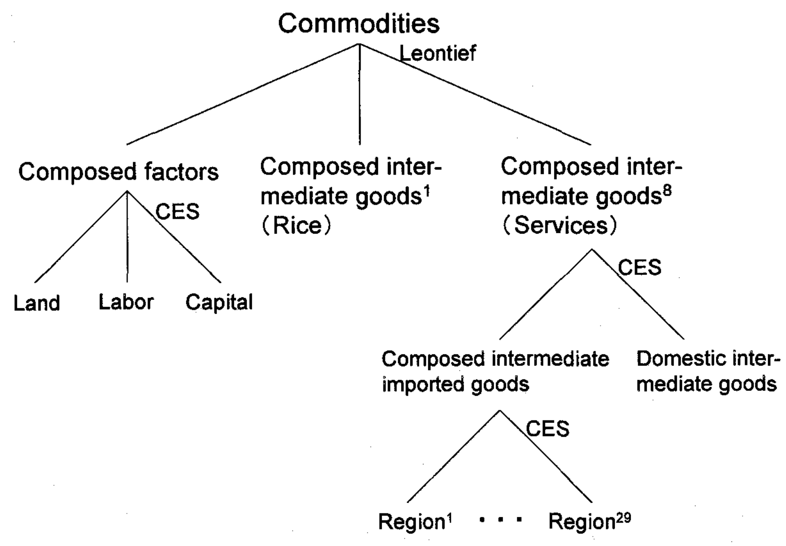

Fig. 3 Structure of substitution in production sectors

3. Discussions

In Table 4, we will first look at the results estimated without consideration of the CO_2 fertilization effect. In Canada, the productivity of crops will increase generally (Table 2), causing a significant decrease in the producer price of crops. The amount of crop production will increase, while the production of manufactured goods and services will decrease. Although the consumer price index will increase, reflecting the price increases in non-agricultural sectors, the increase in income will exceed the increase in prices, and social welfare will increase by 0.3%. Canada is found to be the country gaining the most benefit of these listed in Table 4. In India, the producer price of wheat will be more than double, and the amount of production will decrease in all sectors. Since the consumption of agricultural products and processed agricultural commodities accounts for a large part of private expenditure in India, social welfare will decrease drastically, by 4.8%. Considering the poorly nourished lower classes in India, a decrease in agricultural consumption could cause a severe hunger problem. In Japan, the anticipated decrease in crop productivity will cause an increase in the price of wheat and other grains and a decrease in the production of the crops, however, the effect will not be so large and social welfare will increase by 0.02%. The same tendency is found in the results for the U.S.A. Social welfare will decrease 0.046%, or 9.5 \$US billion, in the world under the climate conditions in 2100.

With the assumption that the economic impact is proportional to the change in temperature, the accumulated economic impact in the world during the period from 1992 to 2100 under the IS92a scenario is estimated to be –480.2 \$US billion, without considering the discount rate. With a discount rate of 3%/year, it would be –75.1 \$US billion. The accumulated welfare loss under the IS92a scenario is calculated as follows:

Table 4 Impact of climate change on economy through the change in crop productivity in 6 regions

	IS92a (With CO2 fertilization)						IS92a* (Without CO2 fertilization)					
	JPN	CHN	IDI	CAN	USA	E_U	JPN	CHN	IDI	CAN	USA	E_U
Producer price change (%)												
Rice	-18.24	-19.71	-6.64	-51.76	-17.07	-19.16	-0.01	-1.58	17.96	-40.16	-0.06	-4.93
Wheat	-28.61	-27.47	38.64	-41.18	-28.27	-22.82	4.91	8.47	125.11	-13.10	4.76	8.92
Other grains	-26.26	-29.14	-29.80	-59.35	-27.83	-27.51	1.81	0.79	1.80	-43.59	-1.46	-3.36
Other crops	-1.68	-1.43	-1.75	-0.35	-1.57	-0.62	-0.01	-0.28	1.90	2.76	-0.10	-0.05
Livestock	-3.16	-5.81	-2.49	-6.21	-8.80	-1.48	-0.19	-0.09	2.84	-1.22	-0.59	-0.04
Other agricultural products	-3.30	-5.21	-1.22	-2.24	-2.16	-1.14	-0.15	-0.01	0.30	-0.35	-0.07	0.04
Manufacture	0.10	0.12	-0.92	0.14	-0.11	-0.17	0.03	-0.12	-1.10	0.61	0.03	-0.02
Services	0.14	0.38	-1.09	0.17	-0.10	-0.17	0.03	-0.16	-0.93	0.69	0.02	-0.02
Production change (%)												
Rice	1.88	2.48	-0.26	113.40	-0.51	0.82	0.11	-0.25	-1.76	105.99	0.23	2.03
Wheat	-0.53	0.53	-6.22	105.10	-0.64	-7.20	-6.60	-3.97	-7.64	115.07	2.87	-3.64
Other grains	-8.30	-0.09	-1.73	82.94	-3.69	-8.03	-15.56	-1.39	-1.33	89.41	-4.04	-6.50
Other crops	1.39	4.47	-0.02	-0.81	0.56	-0.57	0.11	-0.07	-4.25	-2.26	0.25	-0.03
Livestock	1.31	6.88	-0.49	0.16	0.90	-0.60	0.09	-0.24	-2.27	0.94	0.03	-0.22
Other agricultural products	1.94	7.79	-0.63	0.53	0.38	-0.46	0.11	-0.27	-4.73	0.69	0.04	-0.22
Manufacture	-0.03	1.08	1.63	-0.46	0.19	0.26	-0.01	0.31	-0.37	-1.62	0.03	0.05
Services	0.08	1.65	0.37	0.10	0.09	0.15	0.00	0.00	-2.62	-0.02	0.01	0.01
Consumer price index (%)	-0.439	-5.131	-1.698	-0.156	-0.286	-0.393	0.001	0.001	6.047	0.513	0.017	-0.010
Income change per capita (%)	0.054	0.296	-1.474	0.259	-0.013	-0.086	0.026	-0.236	-0.617	0.833	0.026	-0.009
Social welfare change (%)	0.333	3.685	-0.077	0.334	0.232	0.224	0.022	-0.219	-4.892	0.343	0.009	0.003

$$AWL = \sum_{i=1992}^{2100} \left(\frac{WL_{2100}}{(1+r)^{i-1992}} \times \frac{\Delta T_i}{\Delta T_{2100}} \right)$$

AWL Accumulated global welfare loss during the period from 1992 to 2100 ($US million 1992)

WL_{2100} Global welfare loss under the climate conditions in 2100 from the IS92a scenario ($US million 1992)

ΔT_i Global temperature increase in the year i under the IS92a scenario (°C)

r Discount rate

If CO_2 fertilization is taken into account, the productivity of rice and maize increases all over the world, while the productivity of winter wheat increases in some regions and decreases in others (Table 2). Social welfare increases by 0.41% (84.4 $US billion) in the world under the climate conditions in 2100. The accumulated (positive) economic impact in the world, including the consideration of the CO_2 fertilization effect during the period from 1992 to 2100 under the IS92a scenario is 6663.3 and 4240.3 $US billion, respectively, with and without considering the discount rate of 3%/year. Comparing the results regionally, the social welfare increases in China and South Asia are large, where the consumer price index will decrease significantly. As shown in Table 5, the reason for this reduction is that the share of rice and other grains, whose prices will decrease, in the total private consumption is larger in these regions than in the others. Although in India there is also a positive effect because of the price decrease in rice and other grains, the price increase in wheat will cancel it. In the developed countries, although the price of agricultural and processed agricultural products will decrease, social welfare will not increase substantially, since the share of consumption of manufactured goods and services in the total private expenditure is much larger than that of agricultural products.

Comparing the results with and without the CO_2 fertilization effect in Table 4, it is found that the impact of climate change on agriculture is highly dependent on the degree of the CO_2 fertilization effect. However, there exists a large uncertainty in the effect, thus the impact assessment considering the uncertainty should be continued.

In this report, the impact of climate change on the economy was estimated under the assumption that factors other than the productivity change in crops will not change. The results of this study

Table 5 Share of consumption of each product in the total private expenditure in 6 regions (%)

	JPN	CHN	IDI	CAN	USA	E_U
Rice	0.001	5.026	8.481	0.001	0.001	0.004
Wheat	0.001	2.131	3.842	0.001	0.001	0.107
Other grains	0.002	5.511	4.446	0.002	0.006	0.079
Other crops	1.002	11.195	8.223	1.027	0.597	0.700
Livestock	0.178	10.636	9.212	0.233	0.097	0.804
Other agricultural products	16.090	27.074	21.394	11.345	8.289	15.566
Manufacture	12.068	17.752	11.596	16.985	15.377	18.265
Services	70.658	20.675	32.806	70.406	75.632	64.474
Total	100.000	100.000	100.000	100.000	100.000	100.000

provide the basic information for discussion on how each regional economy will be affected by the crop productivity change particular to that region. For the assessed result with the model is used as the basis of policy making, the future impact should be estimated in more realistic ways. Consideration of changes in factors other than the change in crop productivity is necessary. Technology improvements, population changes, policies for trade among regions, and changes in dietary habits must be taken into account.

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