Measurement of the long-term flood damage cost in Japan: Dynamic multi-regional computable general equilibrium analysis[1]

Kazunori Nakajima[2], Masa Morisugi[3] and Naoki Sakamoto[4]

Abstract

In order to examine regional economic impacts of the long-term flood damage due to climate change in Japan, we develop a dynamic multi-regional computable general equilibrium (CGE) model and measure flood damage costs and adaptation benefits by some numerical experiments. As a result, the findings of this study are as follows. (1) By our numerical simulation analyses, the total amount of flood damage cost in Japan was estimated to be from about 0.26 billion US dollars per year to about 2.05 billion US dollars per year in the 50th period. (2) The decrease in the rate of investment return by the long-term increase in flood damage causes decreases in savings and consumption, so that the dynamic multiplier of damage cost was estimated to be from 1.211 times to 1.248 times.

Keywords: *flood, damage cost, climate change, forward-looking dynamic, computable general equilibrium model*

JEL Classification: C68, D58, D61, H54, Q54

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[2] School of Human Science and Environment, University of Hyogo (nakajima@shse.u-hyogo.ac.jp)

[3] Faculty of Urban Science, Meijo University

[4] Faculty of Literature and Social Sciences, Yamagata University

1. Introduction

In order to explain economic impacts of flood damages due to climate change over time in Japan, we develop a dynamic multi-regional computable general equilibrium (CGE) model, and measure flood damage costs through some numerical experiments.

It is inferred that the frequency and the intensity of flood are on the long-term increase. In the category of flood damage in Japan, there are serious flood damages to social capital, including in houses, buildings, roads and so on. These economic damages have been measured by a variety of methods, such as an econometric approach, a general equilibrium approach and an engineering approach. However, there remain questions regarding each approach. For instance, as a computable general equilibrium approach that is assumed to be a static economy does not consider a capital accumulation, it is inappropriate for traditional CGE model to evaluate the "long-term" flood damages due to climate change.

On the other hand, Morisugi *et al*. (2012) theoretically derived the long-term flood damage cost based on a Ramsey growth model. It was assumed that the depreciation rate of capital stock includes the annual disaster physical damage of capital stock loss and climate change increases in the depreciation rate. Compared to two steady-states with or without flood due to climate change, the relations among a direct damage cost, a dynamic damage cost and a dynamic multiplier of damage cost were shown. Then, it was ensured that a dynamic multiplier of dynamic cost that was the proportion of a dynamic damage cost to a direct damage cost was always over 1 theoretically, and the dynamic multiplier was calculated as 1.357 by a tentative numerical analysis. Therefore, it is necessary to develop a dynamic model that has an endogenous capital stock, and to evaluate economic impacts of flood damages.

We develop a dynamic multi-regional CGE model that consists of 8 regions (Hokkaido, Tohoku, Kanto, Chubu, Kinki, Shikoku, Chugoku and Kyushu), 20 sectors and some economic agents (representative household, government, investment and import-export) in each region of Japan, based on that of Nakajima et al. (2017). Our dynamic model structure is a forward-looking type based on a Ramsey model, and our simulation periods are assumed to be 50 periods. Nakajima et al. (2017) showed that the forward-looking dynamic model, despite strict constraints and unrealistic assumptions, could show some realistic results. Also, in dynamic analysis with the long-term perspectives, it is important to obtain various impacts of the change in economic and environmental situation in the future on not only the economy after the change but also the economy before the change. Therefore, by using the forward-looking dynamic model, we can show the economic impacts that the backward-looking dynamic model cannot analyze. We employ four scenarios in our numerical experiments. The flood damage rates of the four scenarios are calculating by four climate models that are CSIRO, GFDL, MIROC and MRI, respectively.

According to Morisugi *et al*. (2012), we define two economic indices as "direct damage cost" and "dynamic damage cost". The direct damage cost is defined as damages like the flood observations mentioned above. On the other hand, the dynamic damage cost is defined as a discounted present value of a decrease in consumption with flood due to climate change in each period, compared to consumption without flood. And, the dynamic multiplier of damage cost is defined as the proportion of these damage costs. In addition, we consider the transition dynamics that is defined as the differences between flood damage costs by a baseline scenario and by a flood scenario, on the transition path to new steady-state equilibrium. As we could describe the transition path, we show possible dynamic spillover effects of flood damage due to climate change over time.

2. Model and scenarios

2.1. Structure of multi-regional CGE model

We use the 2000 Inter-regional Input-Output Table (47 prefectures and 45 sectors) that was created by Miyagi *et al.* (2003) and Ishikawa and Miyagi (2004) as the reference data set. **Figure.1**, **Table.1** and **Table.2** show that we integrated 47 prefectures into 8 regions and 45 sectors into 20 sectors. Economic agents in our model consist of household, production sector, investment sector, export and import, and government. Based on the model developed by Ban (2007), we modified our multi-regional CGE model.

2.1.1. Production sector

As shown in **Figure.2**, all production functions in the domestic production sector are assumed to be the nested CES (constant elasticity of substitution) style. For the first step, labor L_j^s and capital K_j^s are aggregated into the composite production factor VA_j^s using a Cobb-Douglas production function, and the composite inputs N_{ij}^s are made up of intermediate inputs X_{ij}^{rs} from all regions using a CES production function. For the second step, in order to produce the gross domestic output Y_j^s for the j-th production sector in the s-th region, the composite production factor is combined with the composite inputs, using a Leontief production function.

2.1.2. Household consumption

Figure.3 shows the structure of household consumption. We assume that there is one representative household in each region. In order to yield utility U_H^s under a budget constraint, a household demands composite household consumption goods N_{iH}^s that are made up of intermediate household consumptions X_{iH}^{rs} from all regions using a CES function.

2.1.3. Government sector

According to Ban (2007), the structure of government expenditure is assumed to be divided into government consumption and government investment. The government in each region earns revenue from income tax, production tax, and indirect tax, and under budget constraint, it determines the optimal consumption and investment. In addition, the government in each region is assumed to be myopic for investment, and it demands investment goods in its own region. For the structure of government behavior, see details in Ban (2007).

2.1.4. Private investment

The structure of the private investment sector is the same as that of the household consumption sector in **Figure.3**. We assume that there is a virtual investment sector in each region. While the government sector invests in sectors in its own region, the private investment sector demands investment goods over the region.

2.1.5. Export and import

In accordance with Hosoe *et al.* (2010), **Figure.4** shows the structure of the substitution between imports and domestic goods and that of the transformation between exports and domestic goods. About imperfect substitution between imports and domestic goods, we assume the Armington's assumption (Armington (1969)). The i-th Armington-composite-good-producing sector in the s-th region aggregates domestic goods D_i^r and imports IM_i^r into composite goods Q_i^r using a CES function. On the other hand, gross domestic output Y_i^r is transformed into domestic goods D_i^r and exports EX_i^r using a CET (constant elasticity of transformation) function. Both parameters of elasticity of transformation σ_{DEX} and elasticity of substitution σ_{DIM} are assumed to be 2.0 exogenously.

2.1.6. Domestic supply and demand goods

The relationship between the Armington composite goods Q_i^r that are domestically supplied and goods that are demanded in each domestic final demand sector is shown as follows:

$$Q_i^r = \sum_s \sum_j X_{ij}^{rs} + \sum_s X_{iH}^{rs} + \sum_s X_{iG}^{rs} + \sum_s XI_{iH}^{rs} + \sum_s XI_{iG}^{rs} \tag{1}$$

where X_{iG}^{rs} is government consumptions, XI_{iH}^{rs} is private investments, and XI_{iG}^{rs} is government investments.

2.2. Structure of multi-regional CGE model

This study extends the description of the dynamic model structure by Lau *et al.* (2002), Paltsev (2004), and Ban (2007). These studies adopted a Ramsey growth model to develop a dynamic structure.

First, we have three assumptions in describing a neoclassical growth model: 1) over all periods, an economy is on a steady-state equilibrium path, 2) in the initial period, an economy is on a steady state, and 3) in the last period, under constraint that the growth rate of investment is equal to the growth rate of output, an economy is on a steady state.

A representative household maximizes the present value of lifetime utility subject to three constraints, i.e., that a production function in period t is assumed to be constant returns to scale in labor and capital, total output in period t is divided into consumption and investment, and the capital stock in period $t+1$ is equal to the capital stock in period t depreciated at rate δ plus investment in period t.

$$\max_{c(t)} \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho} \right)^t U\left(c(t)\right) \tag{2}$$

$$s.t.\ \ Y(t) = F\left(K(t), L(t)\right) \tag{3}$$

$$c(t) = Y(t) - I(t) \tag{4}$$

$$K(t+1) = K(t) \cdot (1-\delta) + I(t) \tag{5}$$

where $c(t)$ is consumption in period t, $Y(t)$ is output, $I(t)$ is investment, $K(t)$ is capital stock, $L(t)$ is labor, $U(\bullet)$ is utility function, and ρ is the time preference rate. In accordance to Barro and Sala-i-Martin (2004), we assume a neoclassical production function $F(\bullet)$ that satisfies the properties of homogeneity of degree one, positive, and diminishing marginal products, and the Inada conditions with respect to K and L. Solving the utility maximization problem results in the first-order conditions, which can be rewritten as follows:

$$P(t) = \left(\frac{1}{1+\rho}\right)^t \cdot \frac{\partial U\left(c(t)\right)}{\partial c(t)} \tag{6}$$

$$PK(t) = (1-\delta) \cdot PK(t+1) + P(t) \cdot \frac{\partial F(\bullet)}{\partial K(t)} \tag{7}$$

$$PK(t) = PK(t+1) \tag{8}$$

where $P(t)$, $PK(t)$, and $PK(t+1)$ are the values of the corresponding Lagrange multiplier, and they can be interpreted such that $P(t)$ is the output price in period t, $PK(t)$ is the capital price in period t, and $PK(t+1)$ is the capital price in period $t+1$. According to Paltsev (2004), $RK(t)$, $W(t)$, and M represent rental rate of capital, wage rate, and consumer's income, respectively. Unit cost function $C(\bullet)$ and demand function $D(\bullet)$ are represented as $C\left(RK(t), W(t)\right)$ and $D\left(P(t), M\right)$. Then, we can formulate the equilibrium conditions in terms of three classes of equations: i) zero profit conditions, ii) market clearance conditions, and iii) income balance conditions, as the mixed complementarity problem.

i) zero profit conditions:

$$\begin{aligned} &P(t) \geq PK(t+1), \\ &I(t) \geq 0, \\ &I(t)\left(P(t) - PK(t+1)\right) = 0 \end{aligned} \tag{9}$$

$$\begin{aligned} &PK(t) \geq RK(t) + (1-\delta) \cdot PK(t+1), \\ &K(t) \geq 0, \\ &K(t)\left(PK(t) - RK(t) + (1-\delta) \cdot PK(\bullet)\right) = 0 \end{aligned} \tag{10}$$

$$\begin{aligned} &C(RK(t), W(t)) \geq P(t), \\ &Y(t) \geq 0, \\ &Y(t)\left(C(RK(t), W(t)) - P(t)\right) = 0 \end{aligned} \tag{11}$$

ii) market clearance conditions:

$$\begin{aligned} &Y(t) \geq D(P(t), M) + I(t), \\ &P(t) \geq 0, \\ &P(t)\left(Y(t) - D(P(t), M) - I(t)\right) = 0 \end{aligned} \tag{12}$$

$$
\begin{aligned}
&L(t) \geq Y(t)\frac{\partial C(RK(t),W(t))}{\partial W(t)}, \\
&W(t) \geq 0, \\
&W(t)\left(L(t) - Y(t)\frac{\partial C(RK(t),W(t))}{\partial W(t)}\right) = 0
\end{aligned}
\tag{13}
$$

$$
\begin{aligned}
&K(t) \geq Y(t)\frac{\partial C(RK(t),W(t))}{\partial RK(t)}, \\
&RK(t) \geq 0, \\
&RK(t)\left(K(t) - Y(t)\frac{\partial C(RK(t),W(t))}{\partial RK(t)}\right) = 0
\end{aligned}
\tag{14}
$$

iii) income balance conditions:

$$
M = PK(0)\cdot K(0) + \sum_{t=0}^{\infty} W(t)\cdot L(t),\, M > 0 \tag{15}
$$

In this study, equilibrium conditions in the statics can be shown as equations (9), (11), (12), (13), and (14), while those in the dynamics can be shown as two equations (10) and (15) in addition to these static conditions. In addition, we assume that the depreciation rate of capital stock is 4% per year, interest rate is 5% per year, and population growth rate is 0.1% per year. In the time series data of total population in Japan by MIC (2012), as the annual average growth rate from 2000 to 2010 is 0.089%, we assume the population growth rate of 0.1%.

Second, though our dynamic model needed to converge to a steady-state path, we employed Paltsev (2004) and Ban (2007) who assumed that their models were on a steady-state path in the initial period. If the solution is on a steady state, the following equations hold for any periods:

$$
\begin{aligned}
&PK(t+1) = P(t) \\
&P(t-1) = (1+r)P(t) = (1+\delta)P(t) + RK(t) \\
&(n+\delta)\cdot K(t) = I(t) \\
&RK(t)\cdot K(t) = VK(t)
\end{aligned}
\tag{16}
$$

where $VK(t)$ is capital gain and r is an interest rate. Also, as the initial investment holds as the following equation, we modified our initial investment in accordance with Ban (2007).

$$
I(0) = \frac{(n+\delta)}{(r+\delta)}\cdot VK(0) \tag{17}
$$

Third, we had to solve the infinite horizontal problem numerically. Lau *et al*. (2003) had shown that the terminal condition introduced in (18) could approximate the infinite horizon equilibria with endogenous capital accumulation. In accordance with Lau *et al*. (2003), Paltsev (2004), and Ban (2007), we introduced the level of the post-terminal capital stock as an endogenous variable and added a constraint wherein the growth rate of investment was equal to the growth rate of output in the terminal period. (assumption 3)). We assumed one calculation period as one year and calculated each scenario for 50 periods.

$$
\frac{I(T)}{I(T-1)} = \frac{Y(T)}{Y(T-1)} \tag{18}
$$

Finally, in order to describe the existence of competitive equilibria by multiple agents in a numerical model, we employed the method by Lau *et al*. (2003) in which the existence of equilibria by multiple agents could be ensured by explicitly illustrating a distribution problem of financial assets in the terminal period. Ban (2007) also employed the same method. For these formulations, see Lau *et al*. (2003) and Ban (2007) in detail.

2.3. Setting of flood damage scenarios

We treat the change in flood damages as the change in the capital depreciation rate. The flood scenario due to climate change is assumed to increase in the capital depreciation rate of private capital stock by the flood damage rate calculated by a climate model. For calculations of the flood damage rate due to the future climate change, we use a total of 4 scenarios that consist of 4 calculation results made by CSIRO, GFDL, MIROC and MRI. The annual flood damage rate (% per year) calculated by these climate models is described as proportion of differences between flood damage costs in 1981 and in 2081 to the private capital stock in 2000.

2.4. Definition of damage cost

Damage cost equivalent to negative benefit is the utility differences, converted to monetary term, between scenarios with and without flood. As shown in (19), our damage cost is an instantaneous equivalent variation (EV) and this equivalent variation based on price in the reference equilibrium is defined as the difference between household consumption with and without flood.

$$EV(t) = C^{w}(t) - C^{wo}(t) \tag{19}$$

On the other hand, dynamic multiplier of damage cost is defined in (20), where EV^{static} is a static damage cost or a direct damage cost due to flood. This index means that the ratio of a dynamic damage cost to a static damage cost represents direct damage due to flood. While a static damage cost is constant over time without consideration of an economic growth, a dynamic damage cost diminishes over time with consideration of an economic reconstruction from flood. That is because each household increases investment and decreases consumption to maximize its lifetime utility over an entire period, and an accumulation of capital stock simulates recovery of production ability in the economy. This study applies 4% as a social discount rate used in Japan.

$$\varphi = \sum_{t} \left[\frac{EV(t)}{(1+r)^{t}} \right] \Big/ EV^{static} \tag{20}$$

3. Simulation results

Now, we are calculating flood damages by using new scenarios based on four climate model (MIROC5, MRI-CGCM3.0, GFDL CM3, and HadGEM2-ES) and two representative concentration pathway scenarios (RCP2.6 and RCP8.5). However, as we have not finished yet, we show results of change in flood damage cost over time by the old scenarios based on four climate model as mentioned above. In the congress, we would like to present some results of the new scenarios.

Figure.5 shows the changes in damage cost of flood, **Figure.6** shows average flood damages from 2031 to 2050 in each region and **Table.3** shows the values of direct damage, calculated by four flood damage scenarios.

First, **Figure.5** means dynamic damage costs in transitional dynamics. While flood damage costs in 2000 were estimated to be from about 0.22 billion US dollars per year to about 1.69 billion US dollars per year, those in 2050 were estimated to be from about 0.26 billion US dollars per year to about 2.05 billion US dollars per year. In 2050, the minimum value of flood damage was calculated by using the CSIRO scenario and the maximum value was calculated by the MRI scenario.

Secondly, by calculating the dynamic multipliers of damage cost from dynamic damage costs in transitional dynamics, we estimated the values of 1.211 in CSIRO scenario, 1.248 in GFDL scenario, 1.235 in MIROC scenario and 1.212 in MRI, respectively. On the other hand, Morisugi *et al*. (2012) estimated the value of 1.357. We can confirm that our results are close to the result of Morisugi *et al*. (2012) and our dynamic multipliers are over 1. Also, our results can be explained that when the increase in flood damages due to climate change is expected to reduce the rate of return on investment, the decreases in investment and savings by the long-term expectation results in the decrease in consumption.

Thirdly, **Table.3** shows that direct damage costs were estimated to be from about 0.25 billion US dollars per year to about 1.87 billion US dollars per year. These are flood damages in constant capital stock and are equivalent to those of the comparative statics in the short-term. In comparison of direct damage costs to dynamic damage costs, it can be seen that each dynamic damage cost in all scenarios gets larger than direct damage costs over time. Since direct damage costs add incremental costs of asset damage with climate change and possible spillover effects of flood damage over time are not considered, direct damage costs are underestimated. Thus, we can see that our results in this simulation analysis are consistent with those in this theoretical analysis indicated in Morisugi *et al*. (2012).

Finally, **Figure.6** that describes regional average damage from 2031 to 2050 shows that flood damages in Kanto and Chubu region are relatively larger in all scenarios. On the other hand, damages in Hokkaido and Kyushu region in GFDL scenario and damage in Kinki region in MRI scenario are relatively larger, respectively. As regions including the urban area of Kanto, Chubu and Kinki region account for 88% of flood damage, it can be seen that flood damages in regions including the urban area are severe.

4. Conclusions

In order to examine regional economic impacts of the long-term flood damage due to climate change over time in Japan, we develop a dynamic multi-regional computable general equilibrium

(CGE) model and measure flood damage costs and adaptation benefits by some numerical experiments. The findings of this study are as follows.

(1) By our numerical simulation analyses, the total amount of flood damage cost in Japan was estimated to be from about 0.26 billion US dollars per year to about 2.05 billion US dollars per year in the 50th period.
(2) The decrease in the rate of investment return by the long-term increase in flood damage causes decreases in savings and consumption, so that the dynamic multiplier of damage cost was estimated to be from 1.211 times to 1.248 times.

There are several works remaining for future. First, in order to evaluate regional and sectoral impacts of flood damage more precisely, we need to expand our CGE model; 8 regions to 47 regions (all prefectures in Japan) and 20 sectors to more sectors. Second, we need to apply our framework to economic evaluation of some adaptation strategies to climate change.

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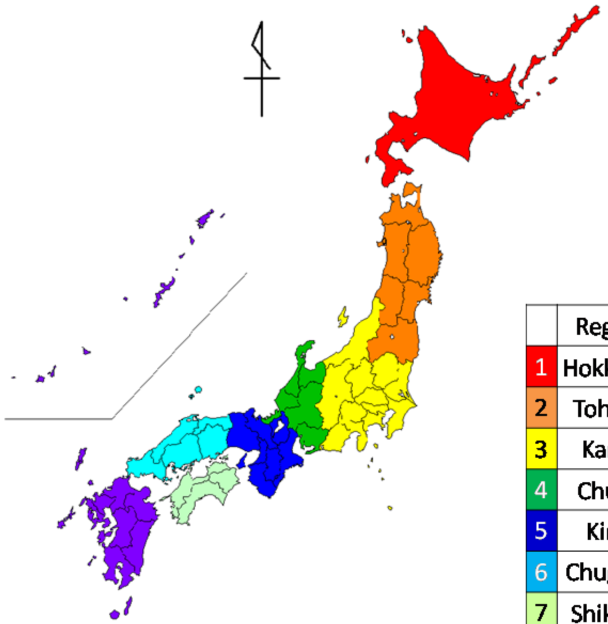
Figures and Tables



	Region	Code
1	Hokkaido	HKD
2	Tohoku	THK
3	Kanto	KNT
4	Chubu	CHB
5	Kinki	KIK
6	Chugoku	CGK
7	Shikoku	SKK
8	Kyushu	KYS

Figure.1: Regional classification in Japan

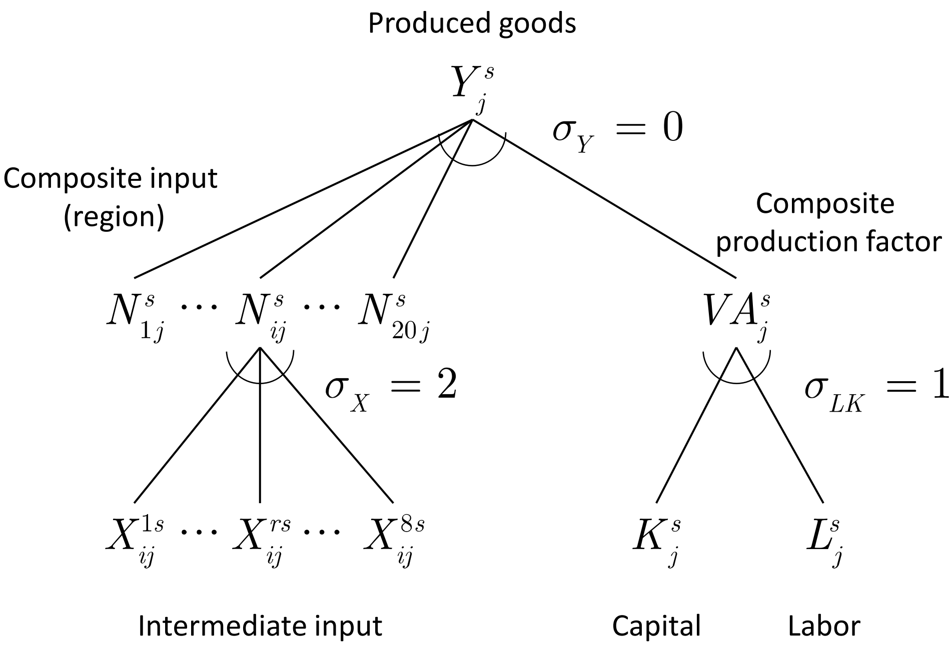


Figure.2: Structure of production sector

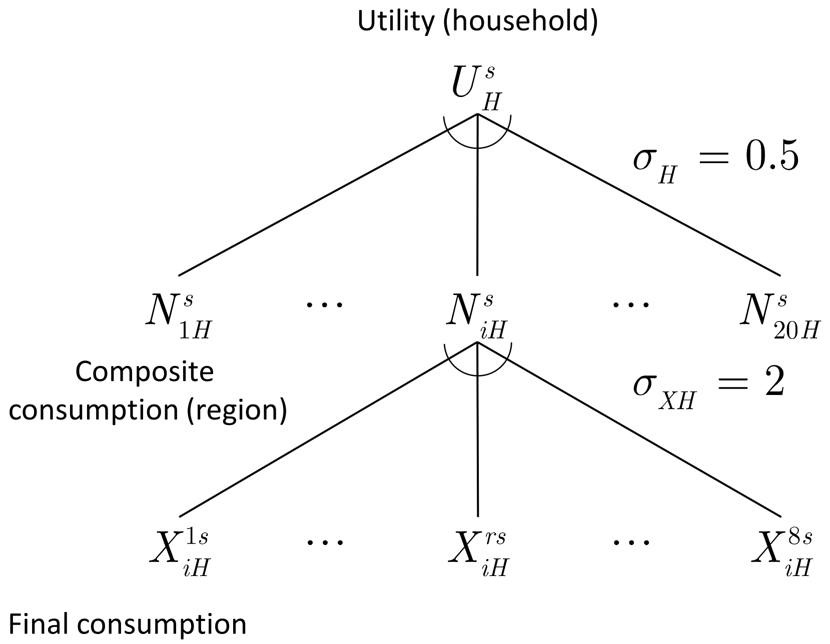


Figure.3: Structure of household sector

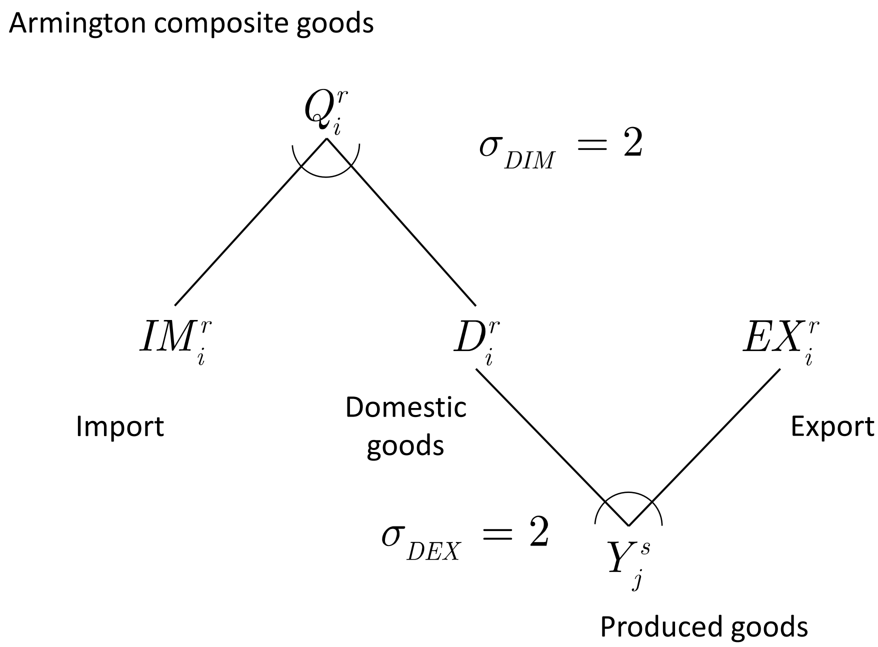


Figure.4: Structure of export and import

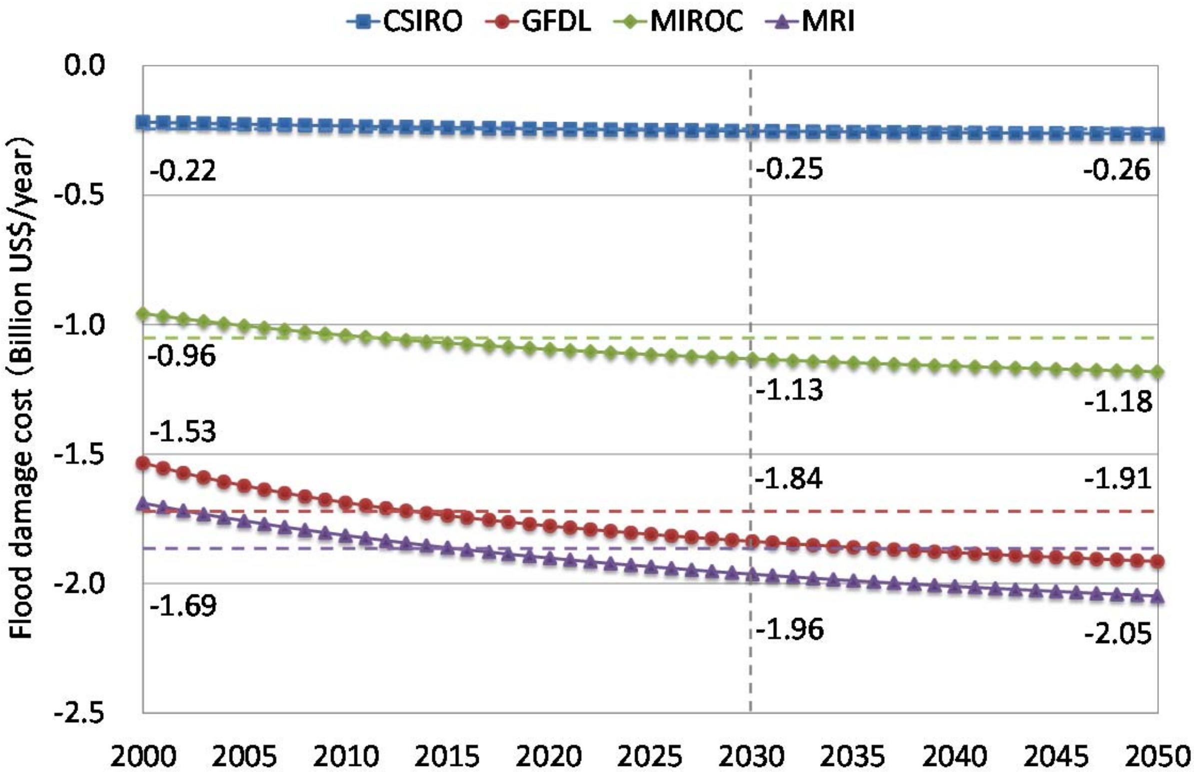


Figure.5: Changes in flood damage cost (Billion US$/year)

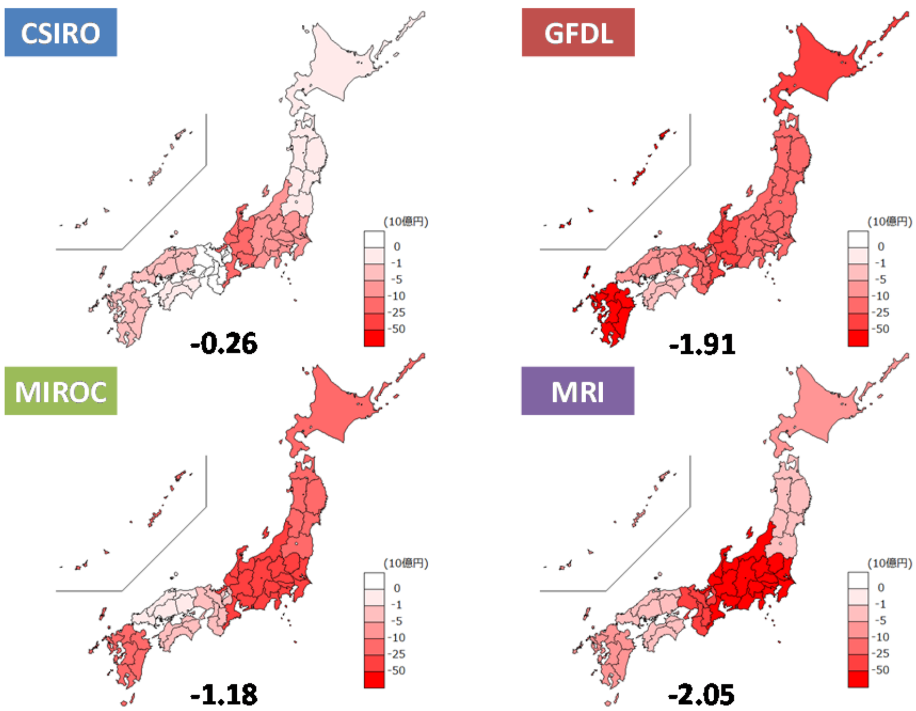


Figure.6: Regional flood damage costs in 2031-2050 (Billion US$/year)

Table.1: Regional classification

	Region	Code	Prefecture
1	Hokkaido	HKD	Hokkaido
2	Tohoku	THK	Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima
3	Kanto	KNT	Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Niigata, Yamanashi, Nagano, Shizuoka
4	Chubu	CHB	Toyama, Ishikawa, Aichi, Gifu, Mie
5	Kinki	KIK	Fukui, Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama
6	Chugoku	CGK	Tottori, Shimane, Okayama, Hiroshima, Yamaguchi
7	Shikoku	SKK	Tokushima, Kagawa, Ehime, Kochi
8	Kyushu	KYS	Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, Kagoshima, Okinawa

Table.2: Sectoral classification

	Sector	Code	47 Prefectural Input-Output Table
1	Agriculture	AGR	Agriculture
2	Forestry	FRS	Forestry
3	Fishery	FSH	Fishery
4	Mining	MIN	Mining
5	Foods	FOD	Foods
6	Other manufacturing products	OMF	Textile products, Timber and wooden products, Furniture and fixtures, Pulp, paper, paperboard, building paper, Publishing, printing, Leather, fur skins and miscellaneous leather products, Ceramic, stone and clay products, Miscellaneous manufacturing products
7	Chemical products	CPR	Chemical products, Plastic products, Rubber products
8	Petroleum and coal products	P_C	Petroleum and coal products
9	Iron and steel	I_S	Iron and steel
10	Metal products	MTL	Non-ferrous metals, Metal products
11	Industrial machinery	MCH	General industrial machinery, Machinery for office and service industry, Motor Vehicles, Other transportation equipment,
12	Electrical equipment	ELM	Household electronic and electric appliances, Electronic and communication equipment, Other electrical equipment, Precision instruments

13	Construction	CNS	Building construction and repair of construction, Public construction and Other civil engineering
14	Electricity	ELY	Electricity
15	Gas	GDT	Gas and heat supply
16	Water supply	WTR	Water supply and waste management services
17	Commerce	COM	Wholesale and retail trade, Finance and insurance, Real estate
18	Transport	TRS	Transport
19	Medical service	MED	Medical service, health and social security and nursing care
20	Services	ANC	Communication and broadcasting, Education and research, Public administration, Other public services, Business services, Personal services, Activities not elsewhere classified

Table.3: Direct damage costs due to flood

Scenario	**Direct Damage Cost (Billion US dollars)**
CSIRO	-0.25
GFDL	-1.72
MIROC	-1.05
MRI	-1.87