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General Equilibrium Analysis of Regional Redistributive Effects of Investment for Reconstruction from the Great East Japan Earthquake[1]

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Abstract

After the Great East Japan Earthquake of 2011, government investment in the disaster stricken areas (DSA) is for reconstruction of capital stock damaged, and dynamic analysis is needed to reveal the long-term effects of investment. On the other hand, Government investment for reconstruction increases in aggregate demand, gross income and gross production in the disaster areas, and has spill-over effects on the other prefectures except the disaster areas, even if amount of damaged capital stock is given. The purpose of this study is to measure the economic impacts and regional spillover effects of investment for reconstruction, by developing and using a spatial computable general equilibrium model that consists of 47 prefectures and 20 production sectors. The two findings in this study are shown below. Firstly, it has been shown that reconstruction investment distributed uniformly over the DSA aimed at immediate reconstruction and restoration in the DSA was quite effective in both the DSA and all prefectures except the DSA, even so 1 percent of all tax revenues was collected as the funds for reconstruction. Secondly, it has been seen that, in all prefectures except the DSA, reconstruction investment distributed uniformly over the DSA contributed to more significant welfare improvement than reconstruction investment distributed uniformly throughout the nation.

Keywords: Spatial computable general equilibrium model, the Great East Japan Earthquake, Investment for reconstruction, Redistributive effect

JEL classification: C68, D58, D61, H54

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1. Introduction

The Cabinet Office, Government of Japan (2011a), (2011b) estimated approximately 16 trillion yen of capital stock damage, as shown in **Table.1**, due to the Great East Japan Earthquake. It has been considered that such capital stock damages had serious impacts on both supply-side and demand-side. As for a supply-side, supply constraints on intermediate input goods and final input goods caused great damages to some areas except the disaster stricken areas (DSA). In particular, since the supply constraint on intermediate input goods reduces production outputs in areas except the DSA, it has significantly regional spill-over effects. In particular, since the supply constraint on intermediate input goods reduces production outputs in areas except the DSA, it has significantly regional spill-over effects. Moreover, through decreases in employment opportunities and income in the DSA, the various supply constraints have impacts on the demand-side. The decrease in income in the DSA brings about decrease in consumption demand, and it feeds through to the supply-side.

In order to accelerate reconstruction in the DSA from the earthquake, the government determined to expand the financial framework for reconstruction to approximately 25 trillion yen in January 2013. Various kinds of reconstruction measures by the government recover capital stocks damage by the earthquake, a dynamic analysis is needed to reveal the long-term effects of these reconstructions. On the other hand, government investment for reconstruction increases in an aggregated demand, a gross income and a gross production in the DSA and has spill-over effects on the other areas except the DSA, even if amount of damaged capital stock is given. Then, a static analysis is conducted to reveal the short-term effects without considering the impact of capital stock.

By focusing on the impacts of government investment in the disaster areas on the demand-side effects, the purpose of this study is to measure the statically economic impacts and regional spill-over effects of reconstruction investment on the economy in the disaster stricken areas after the Great East Japan Earthquake. Also, this study develops a spatial computable general equilibrium (SCGE) model to evaluate 47 prefectural and sectral impacts quantitatively. Then, in our simulation analyses, after economic costs due to capital stock damages in the DSA are measured, economic impacts of reconstruction investment are done.

The structure of this study is the following. Chapter.2 formulates our SCGE model. Chapter.3 explains scenarios on a supply constraint by private capital stock damaged and reconstruction investment. Chapter.4 performs numerical analyses using our SCGE model and some scenarios, and examine these simulation results. Finally, Chapter.5 shows some concluding remarks and topics for future study.

2. Structure of Spatial Computable General Equilibrium Model

This study develops a spatial computable general equilibrium model that consists of 47 prefectures and 20 industrial sectors in Japan, by using the 2000 Inter-regional Input-Output table that has been developed by Miyagi *et al.* (2003) and Ishikawa and Miyagi (2004) as the reference data set. As

shown by **Table.2** and **Table.3**, we integrate 45 production sectors into 20 production sectors, and cover 47 prefectures in Japan. And, as for population data in each prefecture, we use the 2000 population census of Japan by the Ministry of Internal Affairs and Communication (2001).

The structure and its simultaneous equation system of our SCGE model in this study are shown in order of (1) domestic production sector, (2) household consumption sector, (3) government consumption sector, (4) investment sector (private and government investment), (5) export/domestic transformation and import/domestic substitution, and (6) market clearance conditions. Our SCGE model is based on the model developed by Hayashiyama *et al*. (2011), and approach proposed by Hosoe *et al*. (2010) is applied to calibrate parameters and derive equations. On the other hand, formulations of regional economic activities are based on the model by Ban (2007) that was the dynamic multi-regional CGE model in Japan following MONASH-MRF model by Peter et al. (1996) and the model by Paltsev (2004). In the following, we assume that $S(s \in S)$ is the set of region (47 prefectures) that goods are consumed, $R(r \in R)$ is the set of region (47 prefectures) that goods are produced, $I(i \in I)$ is the set of goods, and $J(j \in J)$ is the set of 20 production sectors. And, we use the Armington assumption, proposed by Armington (1969), that means that goods domestically produced or consumed and those imported or exported are imperfectly substitutable with each other (Hosoe *et al*. (2010)).

2.1. Domestic Production Sector

The domestic production sectors have a nested structure shown in **Figure.1**. Firstly, in the j-th sector $j(j \in J)$ in the s-th region $s(s \in S)$, labor L_j^s and capital stock K_j^s are aggregated into the composite production factor Y_j^s using a Cobb-Douglas production function, under profit maximization. Similarly, the composite inputs X_{ij}^s are made up of intermediate inputs XX_{ij}^{rs} from all regions using a constant elasticity of substitution (CES) production function. Secondly, in order to produce the gross domestic output Z_j^s for the j-th production sector in the s-th region, the composite production factor Y_j^s is combined with the composite inputs X_{ij}^s using a Leontief production function that describes the perfect substitution between the composite production factor and the composite inputs.

[Figure.1]

All economic activities in a domestic production sector in our SCGE model are described as optimization problems (P.1) to (P.3) as follows.

$$\begin{cases} \max\limits_{K_j^s, L_j^s} . \; p_{Y_j^s} Y_j^s - \left(p_{K_j^s} K_j^s + p_{L_j^s} L_j^s \right) \\ \text{s.t.} \;\; Y_j^s = \alpha_{LK_j^s} \left[\beta_{L_j^s} \left(K_j^s \right)^{\frac{\sigma_{LK}-1}{\sigma_{LK}}} + \beta_{K_j^s} \left(L_j^s \right)^{\frac{\sigma_{LK}-1}{\sigma_{LK}}} \right]^{\frac{\sigma_{LK}}{\sigma_{LK}-1}} \end{cases} \tag{P.1}$$

$$\begin{cases} \max\limits_{XX_{ij}^{rs}} . p_{X_{ij}^s} X_{ij}^s - \sum\limits_{r\in R} p_{Q_i^r} XX_{ij}^{rs} \\ \text{s.t.} \;\; X_{ij}^s = \alpha_{XX_{ij}^s} \left[\sum\limits_{r\in R} \beta_{XX_{ij}^{rs}} \left(XX_{ij}^{rs} \right)^{\frac{\sigma_X - 1}{\sigma_X}} \right]^{\frac{\sigma_X}{\sigma_X - 1}} \end{cases} \tag{P.2}$$

$$\begin{cases} \max\limits_{Y_j^s, X_{ij}^s} . p_{Z_j^s} Z_j^s - \left(p_{Y_j^s} Y_j^s + \sum\limits_{i\in I} p_{X_{ij}^s} X_{ij}^s \right) \\ \text{s.t.} \;\; Z_j^s = \min \left[\dfrac{Y_j^s}{\alpha_{Y_j^s}}, \dfrac{X_{1,j}^s}{\alpha_{X_{1,j}^s}}, \cdots, \dfrac{X_{20,j}^s}{\alpha_{X_{20,j}^s}} \right] \end{cases} \tag{P.3}$$

A system of simultaneous equations for the domestic production sector consists of Eq.(1) to Eq.(8) as follows.

$$Y_j^s = \alpha_{LK_j^s} \left[\beta_{K_j^s} \left(K_j^s \right)^{\frac{\sigma_{LK} - 1}{\sigma_{LK}}} + \beta_{L_j^s} \left(L_j^s \right)^{\frac{\sigma_{LK} - 1}{\sigma_{LK}}} \right]^{\frac{\sigma_{LK}}{\sigma_{LK} - 1}} \tag{1}$$

$$K_j^s = \left[\frac{\alpha_{LK_j^s} \beta_{K_j^s} p_{Y_j^s}}{p_{K_j^s}} \right]^{\sigma_{LK}} \frac{Y_j^s}{\alpha_{LK_j^s}} \tag{2}$$

$$L_j^s = \left[\frac{\alpha_{LK_j^s} \beta_{L_j^s} p_{Y_j^s}}{p_{L_j^s}} \right]^{\sigma_{LK}} \frac{Y_j^s}{\alpha_{LK_j^s}} \tag{3}$$

$$X_{ij}^s = \alpha_{XX_{ij}^s} \left[\sum_{r\in R} \beta_{XX_{ij}^{rs}} \left(XX_{ij}^{rs} \right)^{\frac{\sigma_X - 1}{\sigma_X}} \right]^{\frac{\sigma_X}{\sigma_X - 1}} \tag{4}$$

$$XX_{ij}^{rs} = \left[\frac{\alpha_{XX_{ij}^s} \beta_{XX_{ij}^{rs}} p_{X_{ij}^s}}{p_{Q_i^r}} \right]^{\sigma_X} \frac{X_{ij}^s}{\alpha_{XX_{ij}^s}} \tag{5}$$

$$Y_j^s = \alpha_{Y_j^s} Z_j^s \tag{6}$$

$$X_{ij}^s = \alpha_{X_{ij}^s} Z_j^s \tag{7}$$

$$p_{Z_j^s} = p_{Y_j^s} \alpha_{Y_j^s} + \sum_{i\in I} p_{X_{ij}^s} \alpha_{X_{ij}^s} \tag{8}$$

where:

$p_{Y_j^s}$: price of composite factor of the j-th sector in the s-th region,

$p_{L_j^s}$: wage of the j-th sector in the s-th region,

$p_{K_j^s}$: capital price of the j-th sector in the s-th region,

$p_{Q_i^r}$: price of the Armington composite goods produced in the r-th region,

$p_{X_{ij}^s}$: price of the composite inputs of the j-th sector in the s-th region,

$p_{Z_j^s}$: price of the gross domestic output of the j-th sector in the s-th region,

$\sigma_{LK}(=1), \sigma_X(=2)$: elasticity of substitution,

$\alpha_{LK_j^s}$: scaling coefficient in the composite factor production function,

$\alpha_{XX_{ij}^s}$: scaling coefficient in the composite input production function,

$\beta_{L_j^s}, \beta_{K_j^s}$: share coefficient in the composite factor production function ($\beta_{L_j^s} + \beta_{K_j^s} = 1$),

$\beta_{XX_{ij}^{rs}}$: share coefficient in the composite input production function ($\sum_{r \in R} \beta_{XX_{ij}^{rs}} = 1$),

$\alpha_{Y_j^s}, \alpha_{X_{ij}^s}$: input requirement coefficient of the j-th composite good for a unit output of the j-th good

2.2. Household Consumption Sector

The structure of household behavior is shown as **Figure.2**. We assume that there is one representative household in each region. In order to yield utility UH^s under a budget constraint, a household in the s-th region demands household consumption goods XH_i^{rs} in the r-th region, using a CES function that has the parameter of elasticity of substitution $\sigma_H(=0.5)$. All household behaviors in our SCGE model are described as optimization problems (P.4) as follows.

[Figure.2]

$$\begin{cases} \max_{XH_i^{rs}} . UH^s = \left[\sum_{r \in R} \sum_{i \in I} \left(\beta_{XH_i^{rs}} \right)^{\frac{1}{\sigma_H}} \left(XH_i^{rs} \right)^{\frac{\sigma_H - 1}{\sigma_H}} \right]^{\frac{\sigma_H}{\sigma_H - 1}} \\ \text{s.t.} \ \sum_{r \in R} \sum_{i \in I} p_{Q_i^r} XH_i^{rs} = p_{K^s} \bar{K}^s + p_{L^s} \bar{L}^s - TD^s - SH^s \end{cases} \quad \text{(P.4)}$$

A system of simultaneous equations for the household consumption sector consists of Eq.(9) to Eq.(11) as follows.

$$XH_i^{rs} = \frac{\beta_{XH_i^{rs}} \left({}_{K^s} \bar{K}^s + p_{L^s} \bar{L}^s - TD^s - SH^s \right)}{\left(p_{Q_i^r} \right)^{\sigma_H} \left[\sum_{i \in I} \beta_{XH_i^{rs}} \left(p_{Q_i^r} \right)^{(1-\sigma_H)} \right]} \quad (9)$$

$$TD^s = \tau_D \left(p_{K^s} \bar{K}^s + p_{L^s} \bar{L}^s \right) \tag{10}$$

$$SH^s = \mu_{SH}^s \left(p_{K^s} \bar{K}^s + p_{L^s} \bar{L}^s \right) \tag{11}$$

where:

$\beta_{XH_i^{rs}}$: share coefficient in the utility function ($\sum_{r \in R} \sum_{i \in I} \beta_{XH_i^{rs}} = 1$),

$\bar{L}^s$, $\bar{K}^s$: initial endowments of labor and capital stock for a household,

$\tau_D \left(= 0.09 \right)$: direct tax rate (exogenously uniform throughout the region),

μ_{SH}^s : saving rate in the s-th region.

The social welfare measure in this study is defined as an equivalent variation (EV) of welfare economics, in Eq.(12) and Eq.(13) as follows.

$$E_t^s \left[\mathbf{p}_0^s, \overline{UH_t^s \left(\mathbf{XH}_t^s \right)} \right] \equiv \min_{\mathbf{XH}_t^s} . \left[\mathbf{p}_0^s, \mathbf{XH}_t^s \left| UH_t^s \left(\mathbf{XH}_t^s \right) \right. \right] \tag{12}$$

$$EV^s \equiv E_1^s \left[\mathbf{p}_0^s, UH_1^s \left(\mathbf{XH}_1^s \right) \right] - E_0^s \left[\mathbf{p}_0^s, UH_0^s \left(\mathbf{XH}_0^s \right) \right] \tag{13}$$

where:

$\underline{E_t^s \left[\mathbf{p}_0^s, \overline{UH_t^s \left(\mathbf{XH}_t^s \right)} \right]}$: expenditure function in the s-th region,

$\overline{UH_t^s \left(\mathbf{XH}_t^s \right)}$: exogenous utility level in the s-th region with or without an earthquake,

$\mathbf{XH}_t^s$: household consumption vector in the s-th region with or without an earthquake,

$\mathbf{p}_t^s$: price vector of household consumption goods in the s-th region with or without an earthquake,

$t = 0,1$: If $t = 0$, it denotes “without earthquake”. On the other hand, If $t = 1$, it does “with it”.

2.3. Government Consumption Sector

The structure of government consumption sector is described in the same way as that of household consumption sector, as shown in **Figure.3**. According to the assumption of Ban (2007), we assume that there does not exist in the central government and government in each region decides government consumption goods XG_i^{rs} to maximize government utility. We also assume that government savings are determined by constant average propensity for savings μ_{SG}^s, and each regional government earns revenues from production tax $\sum_{i \in I} TZ_i^s$ and indirect tax TD^s and spends these revenues on government consumption and investment. All government behaviors in our SCGE model are described as optimization problems (P.5) as follows.

[Figure.3]

$$\begin{cases} \max\limits_{XG_i^{rs}} .UG^s = \left[\sum\limits_{r\in R}\sum\limits_{i\in I} \left(\beta_{XG_i^{rs}} \right)^{\frac{1}{\sigma_G}} \left(XG_i^{rs} \right)^{\frac{\sigma_G-1}{\sigma_G}} \right]^{\frac{\sigma_G}{\sigma_G-1}} \\ \text{s.t.} \ \sum\limits_{r\in R}\sum\limits_{i\in I} p_{Q_i^r} XG_i^{rs} = \sum\limits_{j\in J} TZ_j^s + TD^s - SG^s \end{cases} \tag{P.5}$$

A system of simultaneous equations for the government consumption sector consists of Eq.(14) to Eq.(16) as follows.

$$XG_i^{rs} = \frac{\beta_{XG_i^{rs}} \left(\sum\limits_{j\in J} TZ_j^s + TD^s - SG^s \right)}{\left(p_{Q_i^r} \right)^{\sigma_G} \left[\sum\limits_{i\in I} \beta_{XG_i^{rs}} \left(p_{Q_i^r} \right)^{(1-\sigma_G)} \right]} \tag{14}$$

$$TZ_j^s = \tau_{Z_j^s} p_{Z_j^s} Z_j^s \tag{15}$$

$$SG^s = \mu_{SG}^s \left(\sum_{j\in J} TZ_j^s + TD^s \right) \tag{16}$$

where:

$\sigma_G (= 0.1)$: parameter of elasticity of substitution,

$\beta_{XG_i^{rs}}$: share coefficient in the government utility function ($\sum_{r\in R}\sum_{i\in I}\beta_{XG_i^{rs}} = 1$),

$\tau_{Z_j^s}$: production tax rate,

SG^s : government savings in the s-th region.

2.4. Investment Sector: Private Investment and Government Investment

As shown in **Figure.4**, the structure of private investment sector and government investment sector is assumed in the same way as that of household consumption sector. We also assume that there is one virtual private and government investment agent, respectively, in each region. Total savings for total investments consist of the sum of household savings SH^s, government savings SG^s, foreign savings SF^s and transfer TR^s in each region, and all government savings are expenditure for government investment goods. While private investment sector demands investment goods XI_i^{rs} over region, government investment sector does one XGI_i^{rs} in its own region. All private and government investment behaviors in our SCGE model are described as optimization problems (P.6) and (P.7) as follows.

[Figure.4]

$$\begin{cases} \max\limits_{XI_i^{rs}} .UI^s = \left[\sum\limits_{r\in R}\sum\limits_{i\in I} \left(\beta_{XI_i^{rs}} \right)^{\frac{1}{\sigma_I}} \left(XI_i^{rs} \right)^{\frac{\sigma_I - 1}{\sigma_I}} \right]^{\frac{\sigma_I}{\sigma_I - 1}} \\ \text{s.t.} \ \sum\limits_{r\in R}\sum\limits_{i\in I} p_{Q_i^r} XI_i^{rs} = SH^s - SG^s + \varepsilon SF^s + TR^s \end{cases} \tag{P.6}$$

$$\begin{cases} \max\limits_{XGI_i^{rs}} .UGI^s = \left[\sum\limits_{r\in R}\sum\limits_{i\in I} \left(\beta_{XGI_i^{rs}} \right)^{\frac{1}{\sigma_{GI}}} \left(XGI_i^{rs} \right)^{\frac{\sigma_{GI} - 1}{\sigma_{GI}}} \right]^{\frac{\sigma_{GI}}{\sigma_{GI} - 1}} \\ \text{s.t.} \ \sum\limits_{r\in R}\sum\limits_{i\in I} p_{Q_i^r} XGI_i^{rs} = SG^s \end{cases} \tag{P.7}$$

A system of simultaneous equations for the private and government investment sector consists of Eq.(17) to Eq.(20) as follows.

$$XI_i^{rs} = \frac{\beta_{XI_i^{rs}} \left(SH^s - SG^s + \varepsilon SF^s + TR^s \right)}{\left(p_{Q_i^r} \right)^{\sigma_I} \left[\sum\limits_{i\in I} \beta_{XI_i^{rs}} \left(p_{Q_i^r} \right)^{(1-\sigma_I)} \right]} \tag{17}$$

$$XGI_i^{rs} = \frac{\beta_{XGI_i^{rs}} SG^s}{\left(p_{Q_i^r} \right)^{\sigma_{GI}} \left[\sum\limits_{i\in I} \beta_{XGI_i^{rs}} \left(p_{Q_i^r} \right)^{(1-\sigma_{GI})} \right]} \tag{18}$$

$$SF^s = \sum_{j\in J} \left(p_{IM_j}^W IM_j^s - p_{EX_j}^W EX_j^s \right) \tag{19}$$

$$TR^s = \sum_{r\in R}\sum_{i\in I} p_{Q_i^r} XI_i^{rs} - SH^s + SG^s - \varepsilon SF^s \tag{20}$$

where:

$\sigma_I (= 0.5), \sigma_{GI} (= 0.1)$: parameters of elasticity of substitution,

$\beta_{XI_i^{rs}}$: share coefficient in the s-th private investment sector ($\sum_{r\in R}\sum_{i\in I} \beta_{XI_i^{rs}} = 1$),

$\beta_{XGI_i^{rs}}$: share coefficient in the s-th government investment sector ($\sum_{r\in R}\sum_{i\in I} \beta_{XI_i^{rs}} = 1$),

ε : foreign exchange rate (domestic currency/foreign currency),

$p_{EX_j}^W$: exogenous export price in terms of foreign currency,

$p_{IM_j}^W$: exogenous import price in terms of foreign currency.

In order to introduce dynamic factors like investment into a static model consistently, we are forced

to have a strong assumption for relationships between investment and savings. According to Hosoe *et al*. (2010), however, we employ formulations of investments and savings based on the assumption used by Hosoe *et al*. (2010).

2.5. Export/Domestic Transformation and Import/Domestic Substitution

In accordance with Hosoe *et al*. (2010), the structure of the substitution between imports and domestic goods and that of the transformation between exports and domestic goods is shown in **Figure.5**. By the Armington's assumption, the i-th Armington-composite-goods-producing sector in the r-th region aggregates domestic goods D_i^r and imports IM_i^r into composite goods (Armington goods) Q_i^r using a CES function. On the other hand, gross domestic output Z_i^r is transformed into domestic goods D_i^r and exports EX_i^r using a CET (constant elasticity of transformation) function. While parameters of elasticity of transformation σ_{DEX} in this study are assumed as 2.0 exogenously, parameters of elasticity of substitution σ_{DIM} are set as the values estimated by GTAP7.1 and are shown in **Table.5**. The optimization problems about the substitution between imports and domestic goods and the transformation between exports and domestic goods are described as (P.8) and (P.9) as follows.

[Figure.5]

$$\begin{cases} \max_{D_i^r, EX_i^r} p_{D_i^r} D_i^r + p_{EX_i^r} EX_i^r - \left(1+\tau_{Z_i^r}\right) p_{Z_i^r} Z_i^r \\ \text{s.t. } Z_i^r = \alpha_{DEX_i^r} \left[\beta_{D_i^r} \left(D_i^r \right)^{\frac{\sigma_{DEX}+1}{\sigma_{DEX}}} + \beta_{EX_i^r} \left(EX_i^r \right)^{\frac{\sigma_{DEX}+1}{\sigma_{DEX}}} \right]^{\frac{\sigma_{DEX}}{\sigma_{DEX}+1}} \end{cases} \tag{P.8}$$

$$\begin{cases} \max_{D_i^r, IM_i^r} p_{Q_i^r} Q_i^r - \left(p_{D_i^r} D_i^r + p_{IM_i^r} IM_i^r \right) \\ \text{s.t. } Q_i^r = \alpha_{DIM_i^r} \left[\beta_{DD_i^r} \left(D_i^r \right)^{\frac{\sigma_{DIM}-1}{\sigma_{DIM}}} + \beta_{IM_i^r} \left(IM_i^r \right)^{\frac{\sigma_{DUN}-1}{\sigma_{DIM}}} \right]^{\frac{\sigma_{DIM}}{\sigma_{DIM}-1}} \end{cases} \tag{P.9}$$

A system of simultaneous equations for the substitution between imports and domestic goods and the transformation between exports and domestic goods consists of Eq.(21) to Eq.(28) as follows.

$$EX_i^r = \left[\frac{\alpha_{DEX_i^r} \beta_{EX_i^r} \left(1+\tau_{Z_i^r}\right) p_{Z_i^r}}{p_{EX_i^r}} \right]^{-\sigma_{DEX}} \frac{Z_i^r}{\alpha_{DEX_i^r}} \tag{21}$$

$$D_i^r = \left[\frac{\alpha_{DEX_i^r} \beta_{D_i^r} \left(1 + \tau_{Z_i^r}\right) p_{Z_i^r}}{p_{D_i^r}} \right]^{-\sigma_{DE}} \frac{Z_i^r}{\alpha_{DEX_i^r}} \tag{22}$$

$$Z_i^r = \alpha_{DEX_i^r} \left[\beta_{D_i^r} \left(D_i^r \right)^{\frac{\sigma_{DEX}+1}{\sigma_{DEX}}} + \beta_{EX_i^r} \left(EX_i^r \right)^{\frac{\sigma_{DEX}+1}{\sigma_{DEX}}} \right]^{\frac{\sigma_{DEX}}{\sigma_{DEX}+1}} \tag{23}$$

$$Q_i^r = \alpha_{DIM_i^r} \left[\beta_{DD_i^r} \left(D_i^r \right)^{\frac{\sigma_{DIM}-1}{\sigma_{DIM}}} + \beta_{IM_i^r} \left(IM_i^r \right)^{\frac{\sigma_{DUN}-1}{\sigma_{DIM}}} \right]^{\frac{\sigma_{DIM}}{\sigma_{DIM}-1}} \tag{24}$$

$$D_i^r = \left[\frac{\alpha_{DIM_i^r} \beta_{DD_i^r} p_{Q_i^r}}{p_{D_i^r}} \right]^{\sigma_{DIM}} \frac{Q_i^r}{\alpha_{DIM_i^r}} \tag{25}$$

$$IM_i^r = \left[\frac{\alpha_{DIM_i^r} \beta_{IM_i^r} p_{Q_i^r}}{p_{IM_i^r}} \right]^{\sigma_{DIM}} \frac{Q_i^r}{\alpha_{DIM_i^r}} \tag{26}$$

$$p_{EX_i^r} = \varepsilon p_{EX_i}^W \tag{27}$$

$$p_{IM_i^r} = \varepsilon p_{IM_i}^W \tag{28}$$

where:

$\beta_{D_i^r}$: share coefficient for the i-th goods transformation,

$\beta_{EX_i^r}$: share coefficient for the i-th goods transformation ($\beta_{D_i^r} + \beta_{EX_i^r} = 1$),

$\beta_{DD_i^r}$: input share coefficients in the Armington composite goods production function,

$\beta_{IM_i^r}$: input share coefficients in the Armington production function ($\beta_{DD_i^r} + \beta_{IM_i^r} = 1$),

$\alpha_{DEX_i^r}$: scaling coefficient of the i-th transformation,

$\alpha_{DIM_i^r}$: scaling coefficient in the Armington production function,

$p_{EX_i^r}$: price of the i-th exported goods in terms of domestic currency,

$p_{IM_i^r}$: price of the i-th import price in terms of domestic currency,

$p_{D_i^r}$: price of the i-th domestic goods,

$\sigma_{DEX} (= 2)$,: parameters of elasticity of transformation,

σ_{DIM} ,: parameters of elasticity of substitution,

According to Hosoe et al. (2010), we employ a small-country assumption that our economy does not have a significant impact on the rest of the world. Therefore, relationships between import and export prices in terms of domestic currency and these prices in terms of foreign currency are defined in Eq.(27) and Eq.(28), respectrively.

[Table.5]

2.6. Market Clearance Conditions

In order to meet demand and supply in all markets, the market equilibrium conditions are imposed in Eq.(29) to Eq.(32) as follows.

$$Q_i^r = \sum_{s\in S}\sum_{j\in J} XX_{ij}^{rs} + \sum_{s\in S} XH_i^{rs} + \sum_{s\in S} XG_i^{rs} + \sum_{s\in S} XI_i^{rs} + \sum_{s\in S} XGI_i^{rs} \tag{29}$$

$$\bar{L}^s = \sum_{j\in J} L_j^s \tag{30}$$

$$\bar{K}^s = \sum_{j\in J} K_j^s \tag{31}$$

$$\sum_{s\in S} TR^s = 0 \tag{32}$$

Eq.(29) shows the market equilibrium conditions for the Armington goods, which means that its supply meets the sum of demands for intermediate input goods, household consumption goods, government consumption goods, private investment goods and government investment goods. Eq.(30) is the equilibrium condition for the labor market and Eq.(31) for the capital market, respectively. Then, Eq.(32) means that the sum of transfer in all regions is zero.

As mentioned above, we have shown a system of simultaneous equations for our SCGE model. In our system, exogenous values, such as scaling parameters, share parameters, input coefficients, saving rates, tax rates and so on, are estimated by a calibration method. On the other hand, as it is difficult to estimate parameters of elasticity of substitute and transformation by the calibration, we employ the model parameters used in Hosoe *et al*. (2010), Ban (2007) and GTAP7.1.

3. Setting of Scenarios for Impact of the Earthquake and Reconstruction Strategy

Four prefectures, which are Iwate, Miyagi, Fukushima and Ibaraki, are covered as the disaster stricken area (DSA) due to the Great East Japan Earthquake in this study. We assume that direct impacts of the earthquake on the DSA spills over our economic activities that include 20 production sectors in 47 prefectures.

In order to measure economic impacts of capital stock damaged by the earthquake and regional spill-over effects of investment in the DSA for reconstruction, we assume two simulation scenarios as follows.

(1) Supply constraint by collapsed private capital stocks in the DSA,

(2) Regional redistribution by reconstruction investment in the DSA.

3.1. Assumption of Capital Stock Damage due to the Great East Japan Earthquake

After the Great East Japan Earthquake in 2011, the Cabinet Office, Government of Japan (2011a), (2011b), and Development Bank of Japan (2011a), (2011b) have estimated the direct damages of capital stock. As for 7 prefectures, which are Hokkaido, Aomori, Iwate, Miyagi, Fukushima, Ibaraki and Chiba, the Cabinet Office, Government of Japan (2011a), (2011b) have estimated these damages from about 16 trillion yen to about 25 trillion yen. Similarly, Development Bank of Japan (2011a), (2011b) have estimated damage of about 16 trillion yen. From these estimations, it is likely that capital stock damage due to the earthquake is about 16 trillion yen. In addition, notice that various kinds of damage caused by the Fukushima Daiichi nuclear disaster are not included in these estimation.

Next, capital stock damage applied in our SCGE model is assumed. The capital stock damage discussed above is the stock concept. On the other hand, since capital stock data used in a SCGE model is the flow concept, capital stock damage due to the earthquake is transformed into that of the flow concept. According to Hayashiyama *et al*. (2012), we calculate the damage rate of capital stock δ^s in the s-region by dividing total amount of estimated capital stock damage by total amount of capital stock estimated. These estimated values are shown in the rightmost column of **Table.6**. Then, by using estimated damage rates of capital stock δ^s and an initial private capital endowment before the earthquake $\bar{K}^s\big|_{t=0}$, an initial private capital endowment in the s-th region after the earthquake $\bar{K}^s\big|_{t=1}$ is defined in Eq.(33) as follows. In addition, calculation process of the capital stock damage discussed above means that we apply the results estimated by Development Bank of Japan (2011a), (2011b), and employ direct capital stock damages of 16.4 trillion yen (3.15% of GDP) due to the Great East Japan Earthquake.

$$\bar{K}^s\Big|_{t=1} = \left(1-\delta^s\right)\bar{K}^s\Big|_{t=0} \tag{33}$$

[Table.6]

3.2. Assumption of Reconstruction Investment After the Great East Japan Earthquake

For the reconstruction investment in our SCGE model, a virtual reconstruction agency is supposed that tax for reconstruction is collected from tax revenue in each prefecture at a certain rate ϕ^s and is distributed into government savings in each prefecture as funds for reconstruction investment.

Therefore, funds for reconstruction SRE, which are collected from each prefecture, are defined in Eq.(34).

$$SRE = \sum_{s \in S} \phi^s \left(\sum_{j \in J} T_{Z_j^s} + TD^s \right) \tag{34}$$

When θ^s is the distribution rate of the funds for reconstruction, the funds for reconstruction distributed to the s-th region RI^s are defined in Eq.(35). In addition, when the funds are uniformly distributed to the DSA such as Iwate, Miyagi, Fukushima and Ibaraki, the distribution rate of the funds is θ^s =1/4.

$$RI^s = \theta^s \cdot SRE \tag{35}$$

Since the distributed funds for reconstruction are added to government savings, the budget constraints of government consumption sector and government investment sector are rewritten in Eq.(36) as government consumption demand and Eq.(37) as government investment demand, respectively. Therefore, demand for government investment including the funds for reconstruction, which is expressed in Eq.(37), is employed as the reconstruction investment in this study.

$$XG_i^{rs} = \frac{\beta_{XG_i^{rs}} \left[\sum_{j \in J} TZ_j^s + TD^s - \left(SG^s + \upsilon \cdot RI^s \right) \right]}{\left(p_{Q_i^r} \right)^{\sigma_G} \left[\sum_{i \in I} \beta_{XG_i^{rs}} \left(p_{Q_i^r} \right)^{(1-\sigma_G)} \right]}, \tag{36}$$

$$\upsilon = \begin{cases} 0, & \text{without funds for reconstruction} \\ 1, & \text{with funds for reconstruction} \end{cases}$$

$$XGI_i^{rs} = \frac{\beta_{XGI_i^{rs}} \left(SG^s + \upsilon \cdot RI^s \right)}{\left(p_{Q_i^r} \right)^{\sigma_{GI}} \left[\sum_{i \in I} \beta_{XGI_i^{rs}} \left(p_{Q_i^r} \right)^{(1-\sigma_{GI})} \right]} \tag{37}$$

$$\upsilon = \begin{cases} 0, & \text{without funds for reconstruction} \\ 1, & \text{with funds for reconstruction} \end{cases}$$

3.3. Assumption of Impact of the Great East Japan Earthquake

Since the damage of the Great East Japan Earthquake is characterized by not only large amount of damage but various impacts on area except the DSA through different channels, damage items covered by the earlier studies and this study are shown in **Table.7**. The shaded items in this table are

focused in this study.

Firstly, as our SCGE model is a static model, the long-term impacts of the earthquake based on the structural changes of the economy cannot be analyzed. In order to consider these macroeconomic changes, since a SCGE model with a dynamic structure and dynamic handling of some parameters in a SCGE model are needed, developing a dynamic model would be a future work.

Secondly, since supply constraints by collapsed supply-chain shown by Hayashiyama *et al*. (2012) and by electric power shown by Yamazaki and Ochiai (2011) have been resolved in several months after the earthquake, impacts of these constraints are not discussed in this study. In particular, the impact of supply constraint of electric power cannot be ignored. As the electric power sector is aggregated in our SCGE model, however, this impact by fewer electric power is not discussed in this study.

As mentioned above, in order to measure economic damages due to the Great East Japan Earthquake and macroeconomic impacts of reconstruction investment in the DSA, the supply constraint by collapsed private capital stocks in the DSA and the regional redistribution effects by reconstruction investment in **Table.7** are focused on in this study.

[Table.7]

3.4. Scenario for Simulation Analysis

3.4.1. Supply Constraint by Collapsed Private Capital Stock in the DSA

In order to measure impacts of a supply constraint by collapsed private capital stocks in the DSA on the economy, by using shaded values in **Table.6** as the damage rate of capital stock δ^s in Eq.(33), the initial capital endowment after the earthquake can be calculated.

3.4.2. Regional Redistribution Effects by Reconstruction Investment

In order to measure impacts of reconstruction investment, a certain tax rate ϕ^s determined by a virtual reconstruction agency in Eq.(34) and a distributed rate θ^s of the funds for reconstruction in Eq.(35) can be set. We assume that 1% uniform tax throughout the nation, as the funds for reconstruction, is collected from tax revenue in each prefecture, that is $\phi^s = 0.01$. Since our SCGE model has total tax revenues of about 82 trillion yen, the funds for reconstruction in our model are assumed to be about 80 billion yen. As mentioned above, considering that the funds of about 25 trillion yen would be implemented in the Concentrated Reconstruction Period, the funds for reconstruction supposed in this study are very small. Since the purpose of this study, however, is to measure the inter-regional redistribution effects of reconstruction investment, the funds of 1 percent of tax revenues collected from all prefectures are seen as a benchmark. Also, two scenarios are assumed in this study. One is the scenario that the reconstruction funds are uniformly distributed over the DSA such as Iwate, Miyagi, Fukushima and Ibaraki, and the distribution rate of the funds is $\theta^s = 1/4$. The other is the scenario that the funds are uniformly throughout the nation, and it is $\theta^s = 1/47$.

4. Results and Discussion

4.1. Impacts of Supply Constraint by Collapsed Private Capital Stock in the DSA

Figure.6 to **Figure.9** show simulation results of macroeconomic impacts of a supply constraint by collapsed private capital stocks in the DSA on the economy.

Firstly, as shown in **Figure.6**, since the changes in real GDP due to the supply constraint by capital stocks damaged by the earthquake were estimated to cause 1.24 trillion yen per year in damage in Japan and 1.20 trillion yen per year in damage in the DSA, marked decreases in real GDP in the DSA are found. On the other hand, there were slight increases in real GDP in western Japan, and it was considered that inter-regional substitution in the production function in this study affected these results. Compared with results of other earlier study, since Hayashiyama (2012) estimated to cause 1.12 trillion yen per year in total and 1.37 trillion yen per year in the DSA, results in this study were much the same as those.

Secondly, as shown in **Figure.7**, decreases in welfare were estimated to be 1.09 trillion yen per year in total and 0.86 trillion yen per year in the DSA. Hayashiyama (2012) estimated welfare decreases of 6.71 billion yen per year in total and of 6.56 billion yen per year in the DSA, and Muto (2012) estimated those of 2.50 trillion yen per year in total and of 2.27 trillion yen per year in the DSA. Thus, it was found that the changes in welfare by damages in private capital stock varied widely and our estimations were among these estimations. In addition, marked decreases in welfare per capita in **Figure.8** were estimated to be 145.5 thousand yen per year in Miyagi prefecture and 152.0 thousand yen per year in Iwate prefecture.

Thirdly, as shown in **Figure.9**, decreases in prefectural production outputs were estimated to be 2.13 trillion yen per year in total and 2.04 trillion yen per year in the DSA. These changes mean decreases in output of 0.23% in total and of 3.24 in the DSA. Muto (2012) estimated decreases in output of 0.445 in total and of 7.443% in the DSA. Also, from the changes in prefectural and sectoral production output shown in **Table.8**, there were significant decreases in the foods, the electronic equipment, the construction and the commerce, and those of 0.518 in the foods, 0.365 in the electronic equipment, 0.182 in the construction and 0.168 in the commerce.

[Figure.6]

[Figure.7]

[Figure.8]

[Figure.9]

[Table.8]

4.2. Impacts of Regional Redistribution Effects by Reconstruction Investment

4.2.1. Uniform Distribution over the DSA of the Funds

Figure.10 to **Figure.13** show results of inter-regional redistribution effect by reconstruction investment that the funds are uniformly distributed over the DSA, which means that the distribution rate is $\theta^s = 1/4$ in Eq.(35) and the reconstruction funds of approximately 20.66 billion yen per year are used as government investment in each disaster stricken area. In addition, in our simulation analysis of reconstruction investment, by comparing to scenario with private capital stock damaged and scenario with reconstruction investment, the differences between two scenarios are considered as the effects of reconstruction investment. In the results below, notice that if the change in an economic index is positive, then an economic condition could be improved by reconstruction investment. On the other hand, if the change is negative, then it could be worsened.

Firstly, as shown in **Figure.10**, since the increase in real GDP by reconstruction investment after the earthquake were estimated to be 16.0 billion yen per year in total and 567.0 billion yen per year in the DSA, it was found that reconstruction investment contributed significantly to the improvements in real GDP in these areas. Especially, real GDP of 29.40 billion yen per year were improved in Miyagi prefecture. On the other hand, though improvements of real GDP in most prefectures were achieved, decrease in real GDP in Tokyo was estimated to be 25.61 billion yen per year. It is considered that worsening real GDP in Tokyo stems from significant decrease in government expenditures, since a great amount of fund for reconstruction is collected from tax revenue in Tokyo.

Secondly, as shown in **Figure.11**, welfare improvements by reconstruction investment were estimated to be 3.60 trillion yen per year in total and 1.21 trillion yen per year in the DSA. Especially, welfare of 512.0 billion yen per year was improved in Miyagi. On the other hand, though welfare improvements in some prefectures except the DSA were shown, welfare in Tokyo was significantly worsened. In addition, as shown in **Figure.12**, it was found that considerable improvements in welfare per capita in the DSA were achieved. In particular, welfare improvement per capita in Miyagi was estimated to be 216.5 thousand yen per year.

Thirdly, as shown in **Figure.13**, improvements in prefectural production outputs were estimated to be 730.0 billion yen per year in total and 177.0 billion yen per year in the DSA. These changes mean increases in output of 0.01% in total and of 0.28% in the DSA. Then, from the changes in prefectural and sectoral production output shown in **Table.9**, there were increases in output of 70.00 billion yen per year in the construction and of 22.90 billion yen per year in the electronic equipment, respectively. On the other hand, there was decrease in output of 28.40 billion yen per year in the medical services.

[Figure.10]

[Figure.11]

[Figure.12]

[Figure.13]

[Table.9]

4.2.2. Uniform Distribution throughout the Nation of the Funds

Figure.14 to **Figure.17** show results of regional spill-over effects of reconstruction investment that the funds are uniformly distributed throughout the nation, which means that the distribution rate is $\theta^s = 1/47$ in Eq.(35), and the reconstruction funds of approximately 17.60 billion yen per year are used as government investment in each prefecture. This scenario of reconstruction investment distributed uniformly throughout the nation is used as a benchmark to compare with the scenario of reconstruction investment distributed uniformly over the DSA.

Firstly, as shown in **Figure.14**, since the decrease in real GDP in total was estimated to be 12.00 billion yen per year, whereas the sum of increases in it real GDP in the DSA to be 1197.0 billion yen per year, it was found that this reconstruction investment contributed significantly to the improvements in real GDP in the disaster areas. On the other hand, as discussed above, reconstruction investment distributed uniformly over the DSA was shown to improve the both real GDP in total and in DSA.

Secondly, as shown in **Figure.15**, welfare improvements were estimated to be 3.57 trillion yen per year in total and 1.56 trillion yen per year in the DSA, by reconstruction investment distributed uniformly throughout the nation. On the other hand, reconstruction investment distributed uniformly over the DSA improved welfare of 3.60 trillion yen per year in total. These two results mean that the latter reconstruction investment is at least as important as the former. In addition, welfare per capita in the DSA was considerably improved, and welfare improvement per capita in Miyagi was estimated to be 247.1 thousand yen per year in **Figure.16**.

Thirdly, as shown in **Figure.17**, reconstruction investment distributed uniformly throughout the nation increased in prefectural production outputs of 91.00 billion yen per year in total, which means improvement in that of 0.01%, whereas it decreased in outputs of 10.00 billion yen per year in the DSA, which means worsening that of 0.02%.

[Figure.14]
[Figure.15]
[Figure.16]
[Figure.17]

4.3. Discussion

To begin with, the results of our simulation analysis, as indicated in 4.2.1, have shown two findings below. Firstly, it was shown that reconstruction investment improved the real GDP, welfare and production output in the DSA. Secondly, it was shown that though reconstruction investment worsened the economic conditions in Tokyo, it improved these there economic indices in total. Therefore, it can be seen that reconstruction investment distributed uniformly over the DSA aimed at immediate reconstruction and restoration in the DSA was quite effective in both the DSA and all prefectures except the DSA, even so 1 percent of all tax revenues was collected as the funds for reconstruction.

Next, our results indicated in 4.2.2 have shown two findings. Firstly, in the DSA, reconstruction investment distributed uniformly over the DSA improved welfare of 1.21 trillion yen per year, whereas reconstruction investment distributed uniformly throughout the nation did that of 1.56 trillion yen per year. Secondly, in all prefectures except the DSA, the former investment improved welfare of 2.39 (= 3.57 – 1.21) trillion yen per year, whereas the latter investment did that of 2.01 (= 3.57 – 1.56) trillion yen per year. Therefore, it can be seen that, in all prefectures except the DSA, reconstruction investment distributed uniformly over the DSA contributed to more significant welfare improvement than reconstruction investment distributed uniformly throughout the nation.

5. Concluding Remarks

By using the spatial computable general equilibrium model that consists of 47 prefectures and 20 production sectors in Japan, this study has measured the statically economic impacts and the regional spill-over effects of reconstruction investment on the disaster stricken areas after the Great East Japan Earthquake. The findings in this study are shown below.

(1) Firstly, The changes in real GDP due to the supply constraint of collapsed private capital stocks by the Great East Japan Earthquake were estimated to cause 1.24 trillion yen per year in damage in total and 1.20 trillion yen per year in the DSA. Secondly, decreases in welfare were estimated to be 1.09 trillion yen per year in total and .086 trillion yen per year in the DSA, marked decreases in welfare per capital in the DSA, such as Miyagi and Iwate, were indicated. Thirdly, decreases in prefectural production outputs were estimated to be 2.13 trillion yen per year (0.23%) in total and 2.04 trillion yen per year (3.24%) in the DSA, and there were significant decreases in the foods, the electronic equipment, the construction and the commerce sector.

(2) It has been shown that reconstruction investment contributed significantly to economic recoveries in the DSA. Firstly, in the scenario with reconstruction investment distributed uniformly over the DSA, the increases in real GDP by reconstruction were estimated to be 16 billion yen per year in total and 567.0 billion yen per year in the DSA. Secondly, welfare improvements were estimated to be 3.60 trillion yen per year in total and 1.21 trillion yen per year in the DSA. Thirdly, increases in prefectural production outputs were estimated to be 73.0 billion yen per year (0.01%) in total and 177.0 billion yen per year (0.28%) in the DSA. Also, outputs produced by the construction sector and the electronic equipment sector were improved, whereas outputs by the medical services was worsened.

(3) By our results of simulation analyses in this study, it has been shown that reconstruction investment distributed uniformly over the DSA aimed at immediate reconstruction and restoration in the DSA was quite effective in both the DSA and all prefectures except the DSA, even so 1 percent of all tax revenues was collected as the funds for reconstruction. Also, it has

been seen that, in all prefectures except the DSA, reconstruction investment distributed uniformly over the DSA contributed to more significant welfare improvement than reconstruction investment distributed uniformly throughout the nation.

There are several remaining for future. Firstly, in order to analyze the long-term impacts of the Great East Japan Earthquake and reconstruction processes after the earthquake, we need to extend our static SCGE model to a forward-looking dynamic model such as that of Paltsev (2004) and Ban (2007). Secondly, because of using the unrealistic scenario for reconstruction investment, we need to apply more realistic scenarios.

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A.1. Figures and Tables

Table.1: Summaries of estimations of economic costs affected by the Great East Japan Earthquake by earlier studies

Study	Approach	Analysis		Estimation
		Direct*	Indirect**	
Cabinet Office (2011a), (2011b)	• Production function approach • Capital stock damage: social overhead capital stock, private capital stock • Supply constraints by collapsed private capital stock, disconnected supply chain and electricity. • Increase in output by capital stock recovery	○	○	• Approximately 16 to25 trillion yen of capital stock damage in all disaster stricken areas • Decreasing approximately 1.25 to 2.25 trillion yen per year in GDP due to supply constraint by collapsed private capital stock • Decreasing approximately 0.25 trillion yen in the 1st half of the 2011 fiscal year due to disconnected supply chain • Estimation disable of uncertain supply constraint in electricity • Increasing approximately 5 to 7 trillion yen in 2011 and approximately 6 to 9 trillion yen in 2012 in 2012 in GDP by capital stock recovery
Yamazaki and Ochiai(2011)	• Multi-regional CGE model: 8 regions and 17 sectors • Supply constraints by disconnected supply chain and electricity	○	○	• Decreasing 8.0% in real GDP in the Kanto region, including Tokyo, by damages due to the earthquake and 10% electricity shortage • Decreasing approximately 4.2 trillion yen per year in Tohoku region, including the DSA, and approximately 4.3 billion yen per year in welfare by damages as mentioned above
Osanai (2011)	• GDP gap by production function approach • Assumption of capital stock breakdowns: 5% breakdown, 2.5% and 1% • Assumption of declining in the capacity utilization rate: 20% down, 10% and 5%	Δ	Δ	• Limited impact of capital stock breakdowns on GDP gap • Large impact of the lower capacity utilization rate
Ishimaru (2011)	• Analysis of supply-side • Production function approach • Capital stock damage • Supply constraints by disconnected supply chain and electricity	○	○	• Approximately 20 trillion yen of capital stock damage (approximately 8 trillion yen of private production equipment) in disaster stricken 11 prefectures
Ishimaru and Takayama (2011)	• Analysis of demand-side	×	○	• Delayed recovery risk by heightened uncertainty over the future • Recovery of investment by reconstruction demand • Sluggish exports by decreasing in productivity
Development Bank of Japan (2011a), (2011b)	• Estimation from existing disaster statistics and data of the Great Hanshin-Awaji Earthquake	○	×	• Approximately 16.4 trillion yen of capital stock damage in Tohoku region including the DSA

Hayashiyama *et al.* (2012)	• Multi-regional CGE model: 47 prefectures and 15 sectors • Supply constraints by collapsed private capital stock and disconnected supply chain	○	○	• Decreasing 1.51 to 2.83 trillion yen per year in total in GDP • By collapsed private production equipment , decreasing 1.12 trillion yen per year in total in real GDP, 67.1 billion yen per year in total in welfare, and 1.63 trillion yen per year in total in production output • By disconnected supply chain, decreasing 0.39 to 1.71 trillion yen per year in total in real GDP, 1.04 trillion yen per year in total in welfare, and 3.49 trillion yen per year in total in production output
Muto *et al*. (2012)	• SCGE model: 9 regions and 23 sectors • Collapsed private capital stock	○	○	• Decreasing 2.50 trillion yen per year in total in welfare and 2.27 trillion yen per year in Tohoku region in welfare by collapsed private capital stock • Decreasing 0.445% in total in production output and 0.667% in total in tax revenue

* Direct impact: collapsed capital stock, collapsed production equipment,

** Indirect impact: the changes in GDP, welfare and production level

Source: 出所: Our modifications by reference to Hayashiyama *et al.* (2012)

Table.2: Production sector classification in SCGE model

No.	20 sectors in SCGE	Code	45 production sectors in 47 prefectural IO table
1	Agriculture	AGR	Agriculture
2	Forestry	FRS	Forestry
3	Fishery	FSH	Fishery
4	Mining	MIN	Mining
5	Foods	FOD	Foods
6	Other manufacturing	OMF	Textile products, Timber & wooden products, Furniture & fixtures, Pulp, paper, paperboard & building paper, Publishing & Printing, Leather, fur skins & miscellaneous leather products, Ceramic, stone & clay products, Publishing & printing, Leather, fur skins & miscellaneous leather products, Ceramic, stone & clay products, Miscellaneous manufacturing products
7	Chemical products	CPR	Chemical products, Plastic products, Rubber products
8	Petroleum and coal products	P_C	Petroleum & coal products
9	Iron and steel	I_S	Iron & steel
10	Metal products	MTL	Non-ferrous metals, Metal products
11	Machinery	MCH	General industrial machinery, Machinery for office & service industry, Motor Vehicles, Other transportation equipment
12	Electronic equipment	ELM	Household electronic & electric appliances, Electronic & communication equipment, Other electrical equipment, Precision instruments
13	Construction	CNS	Building construction & repair of construction, Public construction & other civil engineering
14	Electricity	ELY	Electricity
15	Gas and heat supply	GDT	Gas & heat supply
16	Water supply	WTR	Water supply & waste management services
17	Commerce	COM	Wholesale & retail trade, Finance & insurance, Real estate
18	Transport	TRS	Transport
19	Medical services	MED	Medical service, health and social security & nursing care
20	Other services	ANC	Communication & broadcasting, Education & research, Public administration, Other public services, Business services, Personal services, Activities not elsewhere classified

Table.3: Regional classification in SCGE model

No.	Pref.	Code	No.	Pref.	Code	No.	Pref.	Code
1	Hokkaido	HKD	17	Ishikawa	ISK	33	Okayama	OKY
2	Aomori	AMR	18	Fukui	FKI	34	Hiroshima	HRS
3	Iwate	IWT	19	Yamanashi	YMN	35	Yamaguchi	YGC
4	Miyagi	MYG	20	Nagano	NGN	36	Tokushima	TKS
5	Akita	AKT	21	Gifu	GIF	37	Kagawa	KGW
6	Yamagata	YGT	22	Shizuoka	SZK	38	Ehime	EHM
7	Fukushima	FKS	23	Aichi	ACH	39	Kochi	KOC
8	Ibaraki	IBR	24	Mie	MIE	40	Fukuoka	FKO
9	Tochigi	TCG	25	Shiga	SIG	41	Saga	SAG
10	Gunma	GMM	26	Kyoto	KYT	42	Nagasaki	NGS
11	Saitama	STM	27	Osaka	OSK	43	Kumamoto	KMT
12	Chiba	CHB	28	Hyogo	HYG	44	Oita	OIT
13	Tokyo	TKY	29	Nara	NAR	45	Miyazaki	MYZ
14	Kanagawa	KNG	30	Wakayama	WKY	46	Kagoshima	KGS
15	Niigata	NGT	31	Tottori	TTR	47	Okinawa	OKW
16	Toyama	TYM	32	Shimane	SMN			

Table.4: Proportion of private and public capital formation in 47 prefectures

	Private	Public		Private	Public		Private	Public
Hokkaido	0.517	0.483	Ishikawa	0.653	0.347	Okayama	0.673	0.327
Aomori	0.644	0.356	Fukui	0.623	0.377	Hiroshima	0.722	0.278
Iwate	0.570	0.430	Yamanashi	0.669	0.331	Yamaguchi	0.669	0.331
Miyagi	0.715	0.285	Nagano	0.673	0.327	Tokushima	0.625	0.375
Akita	0.564	0.436	Gifu	0.642	0.358	Kagawa	0.745	0.255
Yamagata	0.655	0.345	Shizuoka	0.791	0.209	Ehime	0.668	0.332
Fukushima	0.719	0.281	Aichi	0.823	0.177	Kochi	0.507	0.493
Ibaraki	0.718	0.282	Mie	0.758	0.242	Fukuoka	0.715	0.285
Tochigi	0.765	0.235	Shiga	0.736	0.264	Saga	0.622	0.378
Gunma	0.749	0.251	Kyoto	0.694	0.306	Nagasaki	0.611	0.389
Saitama	0.788	0.212	Osaka	0.816	0.184	Kumamoto	0.677	0.323
Chiba	0.749	0.251	Hyogo	0.721	0.279	Oita	0.693	0.307
Tokyo	0.837	0.163	Nara	0.622	0.378	Miyazaki	0.587	0.413
Kanagawa	0.802	0.198	Wakayama	0.567	0.433	Kagoshima	0.577	0.423
Niigata	0.645	0.355	Tottori	0.579	0.421	Okinawa	0.567	0.433
Toyama	0.683	0.317	Shimane	0.462	0.538			

Table.5: Setting values of elasticity of substitution σ_{DIM}

Production Sector	Value	Production Sector	Value
Agriculture	2.5	Machinery	3.6
Forestry	2.5	Electronic equipment	4.4
Fishery	1.3	Construction	1.9
Mining	5.6	Electricity	2.8
Foods	2.5	Gas and heat supply	2.8
Other manufacturing	3.4	Water supply	2.8
Chemical products	3.3	Commerce	1.9
Petroleum and coal products	2.1	Transport	1.9
Iron and steel	3.0	Medical services	1.9
Metal products	3.9	Other sevices	1.9

Table.6: Estimation of capita stock damages by the Development Bank of Japan (2011a)

DSA		Estimated Capital Stock (1 bn. Yen)	Estimated Capital Stock Damage (1 billion Yen)					Damage Rate (%)
			Infra-structure	House	Manu-facturing	Others	Total	
Iwate	Inland	26,369	457	22	64	211	754	2.9
	Coast	7,449	1,943	607	191	781	3,522	47.3
	Total	33,818	2,400	629	255	992	4,276	12.6
Miyagi	Inland	31,443	856	40	148	551	1,595	5.1
	Coast	23,182	2,031	1,446	290	1,130	4,897	21.1
	Total	54,625	2,887	1,486	438	1,681	6,492	11.9
Fukushima	Inland	34,314	630	7	263	370	1,270	3.7
	Coast	15,941	1,244	145	151	319	1,859	11.7
	Total	50,254	1,874	152	414	689	3,129	6.2
Ibaraki	Inland	47,827	460	40	175	318	993	2.1
	Coast	21,727	766	87	355	275	1,483	6.8
	Total	69,553	1,226	126	530	593	2,476	3.6
Total	Inland	139,952	2,403	109	650	1,451	4,612	3.3
	Coast	68,299	5,985	2,285	987	2,504	11,781	17.2
	Total	208,251	8,387	2,394	1,637	3,955	16,373	7.9

Table.7: Categories of impacts related to the Great East Japan Earthquake

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Macroeconomic structure</td></tr>
<tr><td>without change (the short-term)</td><td>with change (the long-term)</td></tr>
<tr><td rowspan="4">Impacts of the Great East Japan Earthquake</td><td rowspan="3">(the Stock)
Direct impact</td><td>• Capital stock damages
(= about 16.4 trillion yen)</td><td rowspan="4">• Long-term impacts of the earthquake
• Sustainable reconstruction strategy</td></tr>
<tr><td rowspan="3">(the Flow)
Indirect impact</td><td>• Supply constraint by collapsed private capital stocks in the DSA
– Hayashiyama et al. (2011)
– Muto et al. (2011)</td></tr>
<tr><td>• Supply constraint by collapsed supply-chain
– Hayashiyama et al. (2011)
– Yamazaki and Ochiai (2011)</td></tr>
<tr><td>• Supply constraint of electric power
– Yamazaki and Ochiai (2011)</td></tr>
<tr><td>RE</td><td>• Regional redistribution effects by reconstruction investment</td></tr>
</table>

Table.8: The changes in prefectural and sectoral production outputs by collapsed private capital stock (billion yen per year)

	Agriculture	Forestry	Fishery	Mining	Foods	Other manufacturing	Chemical products	Petroleum and coal products	Iron and steel	Metal products	Machinery	Electronic equipment	Construction	Electricity	Gas and heat supply	Water supply	Commerce	Transport	Medical services	Other services	**Total**
Hokkaido	0	0	0	0	-1	0	0	-1	0	0	0	0	-1	0	0	0	-2	0	0	1	**-2**
Aomori	1	0	0	0	-4	1	0	0	0	0	-1	0	-3	0	0	0	1	1	-1	0	**-4**
Iwate	-33	-7	-3	-2	-35	-22	-6	-1	-3	-4	-13	-43	-43	-12	-1	-7	-127	-17	-13	-80	**-470**
Miyagi	-26	-3	-4	-2	-54	-50	-10	-10	-10	-20	-9	-49	-61	-29	-2	-8	-239	-32	-19	-168	**-807**
Akita	0	0	0	0	-1	0	0	0	0	-1	0	1	-2	0	0	0	0	0	0	0	**-2**
Yamagata	1	0	0	0	-1	1	1	0	0	0	0	-3	-3	0	0	0	0	1	-1	0	**-2**
Fukushima	-14	-2	0	-2	-25	-17	-16	0	-1	-7	-5	-32	-29	-84	0	-3	-72	-9	-11	-66	**-396**
Ibaraki	-14	0	0	-1	-21	-17	-41	-6	-19	-18	-12	-18	-25	-17	0	-4	-71	-18	-8	-56	**-365**
Tochigi	0	0	0	0	-2	0	-1	0	0	1	0	-1	-2	0	0	0	0	0	-1	0	**-4**
Gunma	0	0	0	0	-2	0	-1	0	0	0	-1	0	0	0	0	0	0	0	0	0	**-3**
Saitama	0	0	0	0	-2	0	-1	0	0	1	-2	0	-2	0	0	0	0	1	-1	1	**-5**
Chiba	0	0	0	0	-3	0	-1	-4	-1	0	0	0	-2	1	0	0	-2	1	-1	0	**-9**
Tokyo	0	0	0	0	-3	-2	-1	0	-1	0	0	-1	-2	0	0	0	-1	1	-2	0	**-10**
Kanagawa	0	0	0	0	-4	0	-1	-3	0	-1	-1	2	-2	0	0	0	-1	0	-1	2	**-10**
Niigata	0	0	0	0	-1	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	1	**-2**
Toyama	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-1**
Ishikawa	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	**-1**
Fukui	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-1**
Yamanashi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-1**
Nagano	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-2**
Gifu	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-1**
Shizuoka	0	0	0	0	-2	0	0	0	0	0	1	-4	-1	0	0	0	1	0	0	1	**-4**
Aichi	0	0	0	0	-1	-1	-1	0	0	0	4	-2	-1	0	0	0	-2	0	0	-1	**-6**
Mie	0	0	0	0	0	0	-2	-1	0	0	1	0	0	0	0	0	0	0	0	0	**-2**
Shiga	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	**-1**
Kyoto	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-1**
Osaka	0	0	0	0	-1	-1	-1	0	0	-1	-1	-1	0	0	0	0	0	0	0	1	**-4**
Hyogo	0	0	0	0	-1	0	0	0	-1	0	-2	1	0	0	0	0	0	0	0	0	**-3**
Nara	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Wakayama	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Tottori	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Shimane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Okayama	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	**-2**
Hiroshima	0	0	0	0	0	0	1	0	-3	0	0	0	0	0	0	0	-1	0	0	1	**-3**
Yamaguchi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-1**
Tokushima	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Kagawa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-1**
Ehime	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	**-1**
Kochi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Fukuoka	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-1**
Saga	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Nagasaki	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Kumamoto	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Oita	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-1**
Miyazaki	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Kagoshima	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Okinawa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**-84**	**-11**	**-8**	**-4**	**-168**	**-113**	**-80**	**-27**	**-40**	**-50**	**-41**	**-151**	**-182**	**-138**	**-4**	**-18**	**-518**	**-71**	**-58**	**-365**	**-2,130**

Table.9: The changes in prefectural and sectoral production outputs by reconstruction investment (billion yen per year)

	Agriculture	Forestry	Fishery	Mining	Foods	Other manufacturing	Chemical products	Petroleum and coal products	Iron and steel	Metal products	Machinery	Electronic equipment	Construction	Electricity	Gas and heat supply	Water supply	Commerce	Transport	Medical services	Other services	**Total**
Hokkaido	-1	0	1	0	0	-5	0	9	-1	-1	-2	-1	4	1	0	0	8	-5	2	-6	**6**
Aomori	0	0	0	0	3	-2	-1	0	1	2	1	0	2	0	0	0	1	-2	0	-1	**4**
Iwate	5	3	1	1	15	10	0	0	1	3	5	10	69	2	0	-12	64	11	-69	-82	**35**
Miyagi	0	-1	-2	-1	13	-11	-6	9	-3	-1	-1	-11	138	-1	0	-2	103	10	-65	-128	**40**
Akita	-1	0	0	0	0	-3	0	0	0	2	0	-2	0	1	0	0	3	0	0	-1	**-1**
Yamagata	-1	0	0	0	-2	-1	-1	0	0	1	1	-1	0	0	0	0	2	0	0	1	**-1**
Fukushima	5	1	0	1	14	13	-3	0	1	7	5	18	94	14	0	-2	54	12	-80	-114	**42**
Ibaraki	-3	0	0	1	6	8	3	7	11	19	15	29	109	0	0	-5	57	12	-68	-140	**60**
Tochigi	-1	0	0	-1	-5	-5	-12	0	0	-3	-2	2	13	-1	0	0	9	-2	2	1	**-6**
Gunma	-2	0	0	0	-8	-4	-7	0	-1	-6	-16	-8	17	-1	0	0	13	-2	5	3	**-18**
Saitama	-2	0	0	0	-19	-19	6	-1	2	3	19	14	9	0	0	-2	-1	-14	5	-6	**-6**
Chiba	-1	0	0	0	-8	-5	-6	-2	1	0	1	3	14	-4	0	-1	6	-10	4	-7	**-14**
Tokyo	2	0	1	4	-4	153	87	0	16	43	92	271	-6	1	-15	-12	-615	-57	-101	130	**-9**
Kanagawa	0	0	0	0	-10	-5	-6	-7	2	1	10	11	17	-4	1	-2	13	-9	7	-33	**-13**
Niigata	1	0	0	-1	0	-5	-4	0	-2	-7	-1	-4	9	1	0	0	10	-2	3	-2	**-2**
Toyama	1	0	0	0	1	-2	-5	0	-1	-3	-1	-1	5	0	0	0	6	-1	1	1	**1**
Ishikawa	1	0	0	0	5	-1	-1	0	0	-1	1	-2	0	1	0	0	2	-1	1	-2	**4**
Fukui	0	0	0	0	1	-3	-4	0	0	-1	-1	-3	4	2	0	0	5	0	1	1	**1**
Yamanashi	0	0	0	0	0	-4	0	0	0	0	1	2	3	0	0	0	0	0	1	-2	**-1**
Nagano	0	0	0	0	-1	-3	-1	0	0	-2	1	-5	8	1	0	0	6	-2	2	-4	**-1**
Gifu	1	0	0	0	1	-5	-4	0	-1	-2	-6	-3	5	1	0	0	7	-1	1	1	**-4**
Shizuoka	1	0	0	0	1	-22	-17	0	-1	-7	-19	-1	24	0	0	0	-6	22	5	4	**-16**
Aichi	2	0	0	0	8	-9	-17	7	-14	-10	-120	-9	35	4	1	2	62	1	9	18	**-31**
Mie	1	0	-1	0	4	-1	-9	11	-1	-4	-7	-6	9	1	0	0	7	-1	2	5	**10**
Shiga	1	0	0	0	2	-2	-9	0	-1	-3	-3	-4	7	0	0	0	10	1	2	3	**5**
Kyoto	1	0	0	0	7	-7	-3	0	0	-2	-6	-7	5	1	0	0	12	0	2	2	**5**
Osaka	0	0	0	-1	-1	-30	-40	4	-23	-23	-19	-24	37	1	3	2	86	-10	17	3	**-18**
Hyogo	1	0	0	-1	11	-5	-13	3	-18	-4	-9	-11	11	3	1	0	25	-3	4	4	**0**
Nara	1	0	0	0	1	-1	-1	0	0	0	0	-1	-1	1	0	0	2	0	0	-1	**0**
Wakayama	1	0	0	0	2	-2	-3	8	-7	-1	-1	-1	2	1	0	0	3	0	1	1	**4**
Tottori	1	0	0	0	2	-1	0	0	0	0	0	-2	1	0	0	0	1	0	0	0	**1**
Shimane	0	0	0	0	0	-1	0	0	-1	0	0	1	1	1	0	0	2	0	0	-1	**0**
Okayama	0	0	0	-1	1	-3	-12	5	-15	-3	-6	-5	10	0	0	0	15	-3	3	5	**-9**
Hiroshima	1	0	0	-1	6	-3	-7	0	-22	-5	-12	-4	12	0	0	0	24	-3	4	3	**-7**
Yamaguchi	1	0	0	-1	2	-2	-11	8	-5	-2	-5	-1	7	0	0	0	8	-1	2	3	**2**
Tokushima	1	0	0	0	3	-1	-2	0	0	0	0	-1	1	0	0	0	2	0	1	0	**2**
Kagawa	0	0	0	0	0	-3	-2	2	0	-2	-2	-1	5	0	0	0	6	-1	1	2	**3**
Ehime	1	0	1	0	3	-8	-2	3	0	-1	0	-3	3	1	0	0	4	-2	1	2	**3**
Kochi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	**0**
Fukuoka	1	0	0	-1	7	-5	-6	1	-11	-3	-12	-6	10	0	0	0	22	-4	5	-2	**-4**
Saga	1	0	0	0	1	-1	-1	0	0	-1	-1	-1	2	1	0	0	2	0	1	0	**1**
Nagasaki	1	0	0	0	-2	0	0	0	0	0	0	0	-1	2	0	0	0	0	0	0	**1**
Kumamoto	2	0	0	0	1	-1	-1	0	0	0	-2	0	0	0	0	0	2	0	0	-1	**1**
Oita	-5	0	0	-1	2	0	-2	2	-4	0	-1	2	3	0	0	0	3	-1	1	0	**0**
Miyazaki	1	0	0	0	2	-1	-1	0	0	0	0	-1	1	0	0	0	2	0	1	-1	**2**
Kagoshima	1	0	0	0	2	-1	0	0	0	0	0	0	1	1	0	0	2	-1	0	-2	**1**
Okinawa	0	0	0	1	-1	0	0	3	0	0	0	0	-2	0	0	0	1	1	0	-2	**1**
Total	**17**	**3**	**2**	**-1**	**68**	**-9**	**-124**	**73**	**-99**	**-18**	**-106**	**229**	**700**	**33**	**-5**	**-38**	**52**	**-71**	**-284**	**-348**	**73**

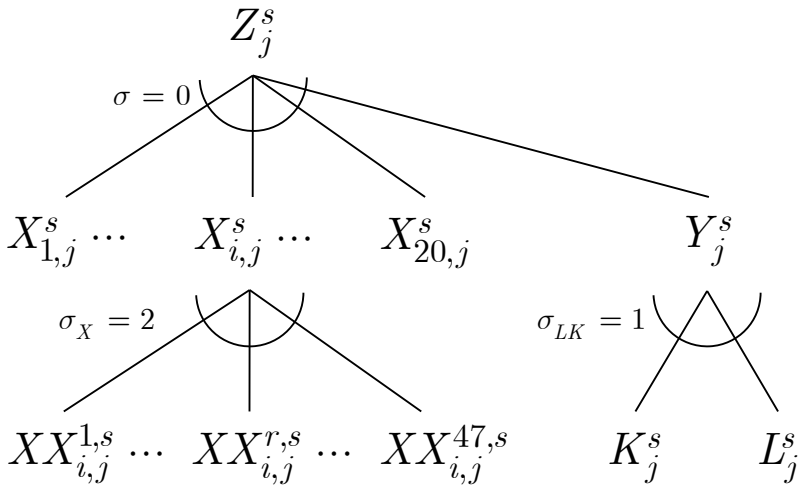


Figure.1: Structure of domestic production sector

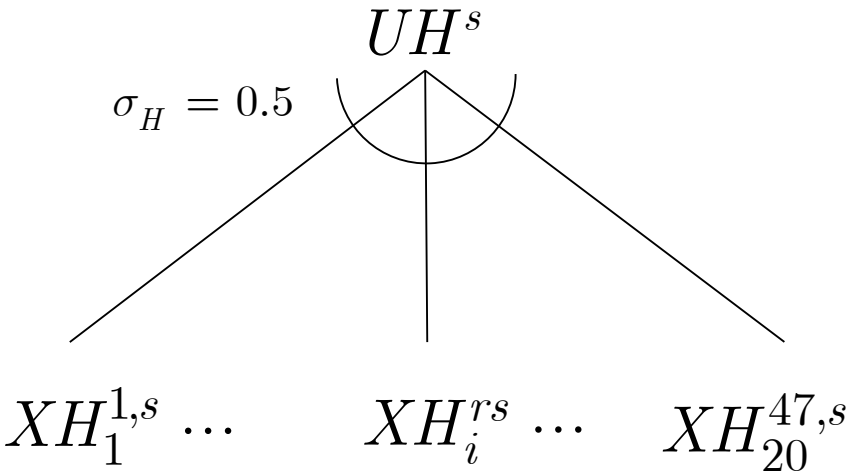


Figure.2: Structure of household consumption sector

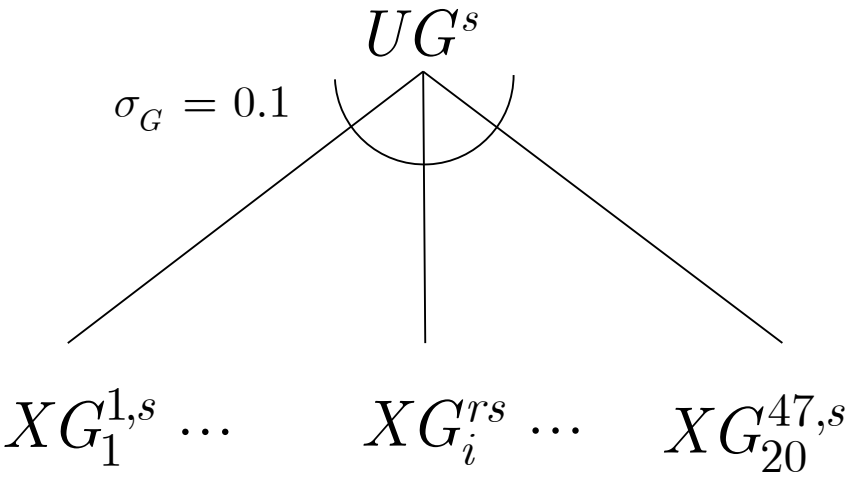
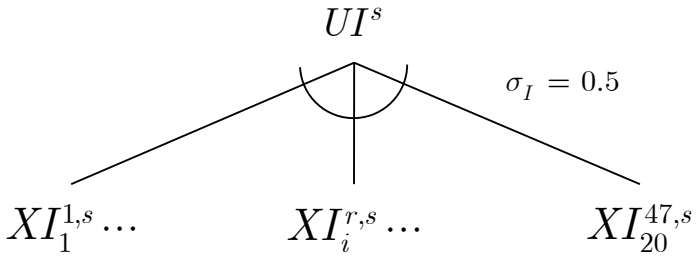


Figure.3: Structure of government consumption sector

Private investment



Government investment

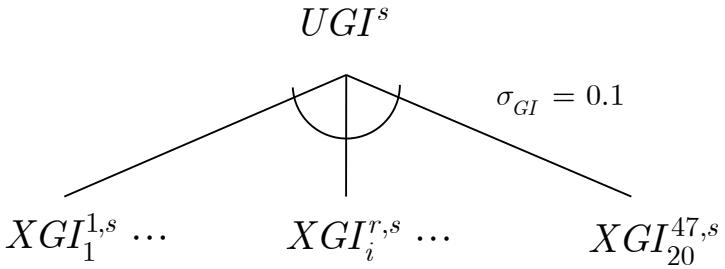


Figure.4: Structure of private and government investment sector

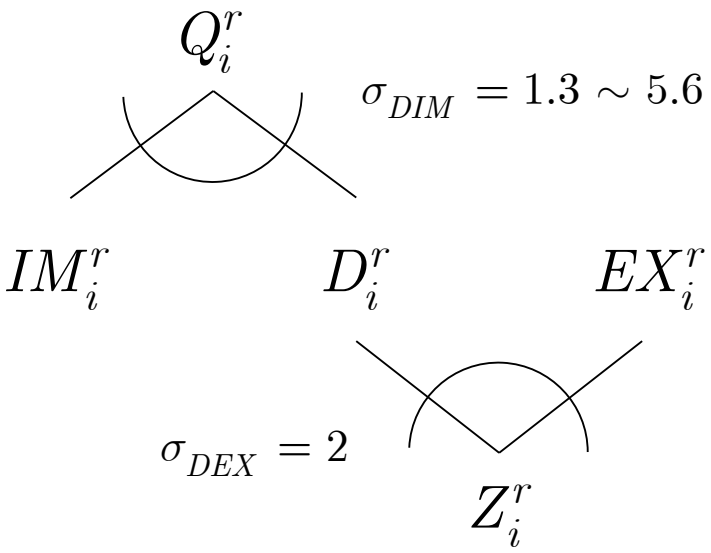


Figure.5: Structure of the substitution between imports and domestic goods and the transformation between exports and domestic goods

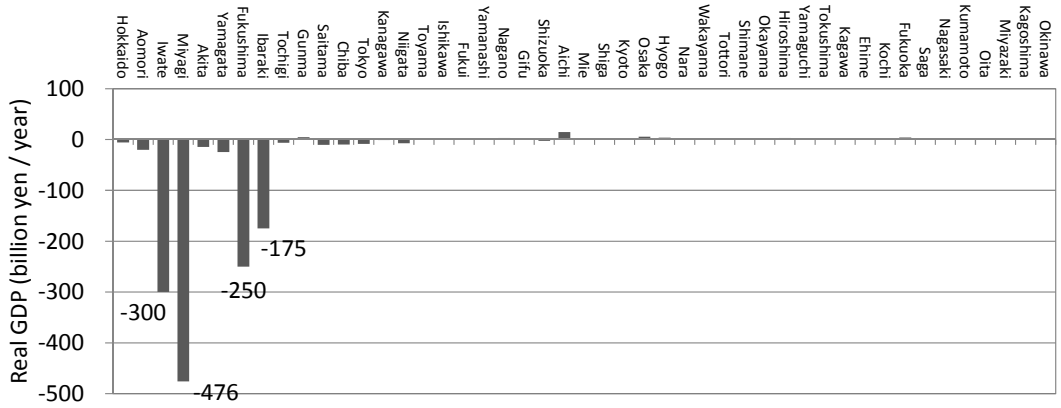


Figure.6: The changes in prefectural real GDP by collapsed private capital stock (billion yen per year)

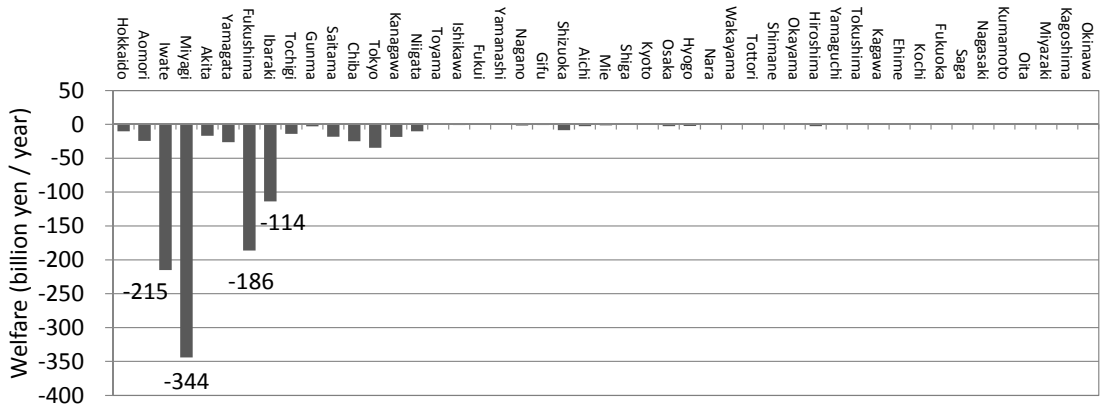


Figure.7: Prefectural welfare changes by collapsed private capital stock (billion yen per year)

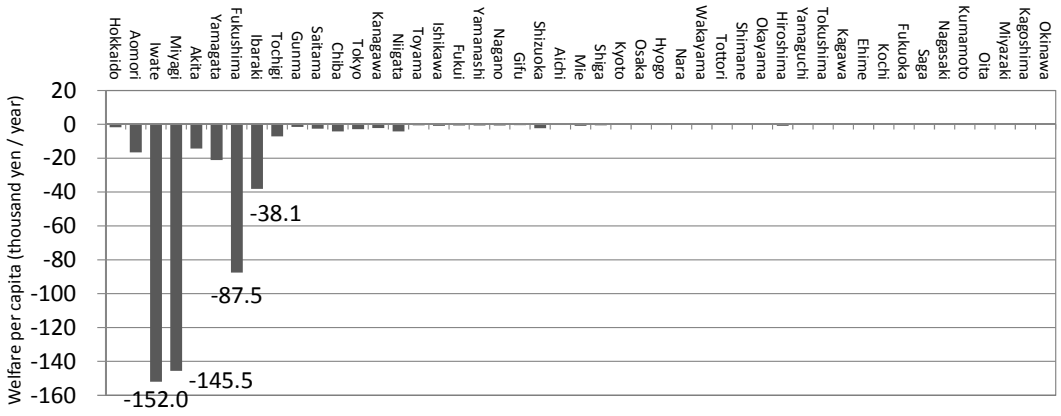


Figure.8: The changes in prefectural welfare per capita by collapsed private capital stock (thousand yen per year)

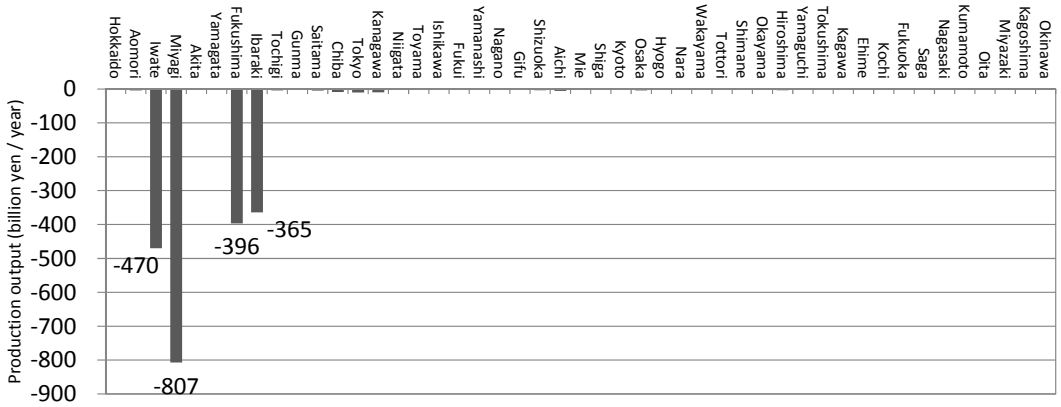


Figure.9: The changes in prefectural production output by collapsed private capital stock (billion yen per year)

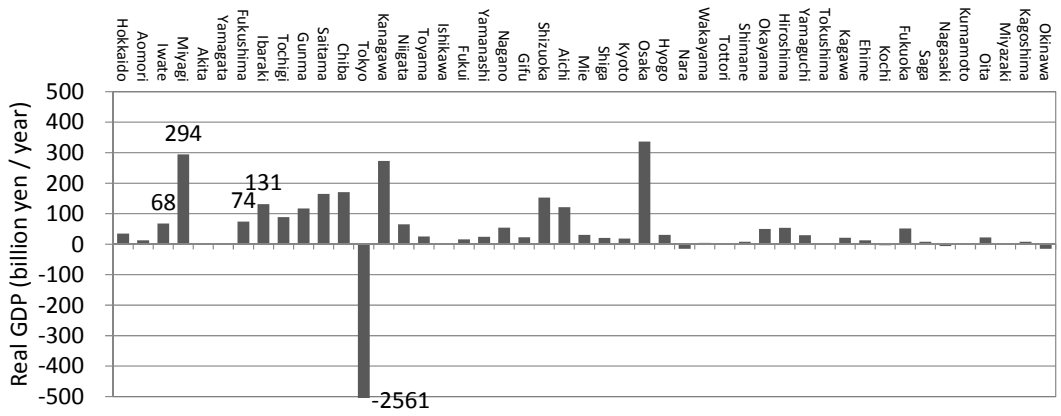


Figure.10: The changes in prefectural real GDP by reconstruction investment (billion yen per year)

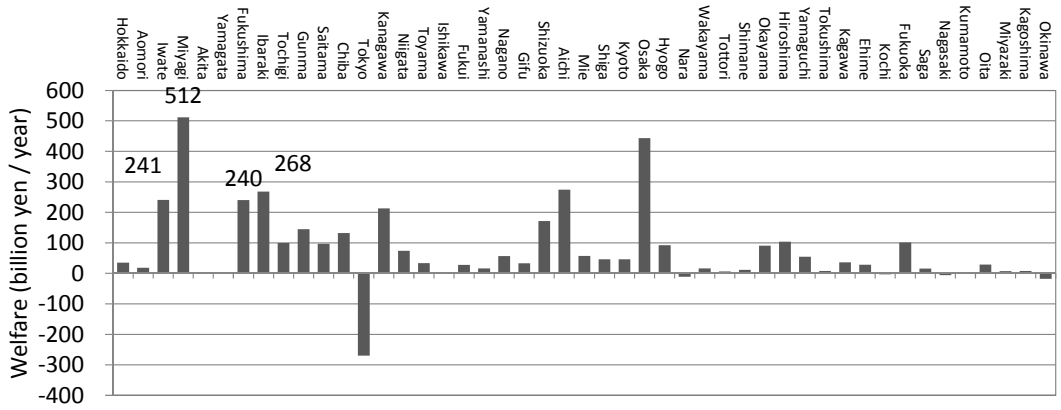


Figure.11: Prefectural welfare changes by reconstruction investment (billion yen per year)

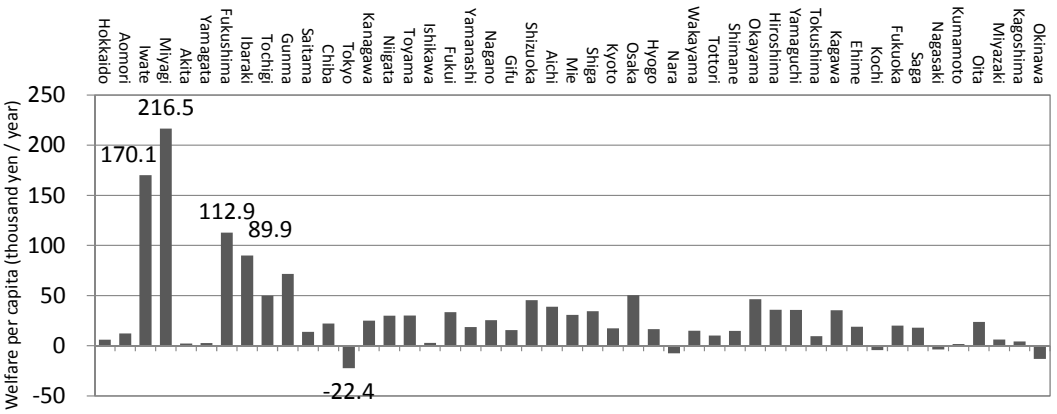


Figure.12: The changes in prefectural welfare per capita by reconstruction investment (thousand yen per year)

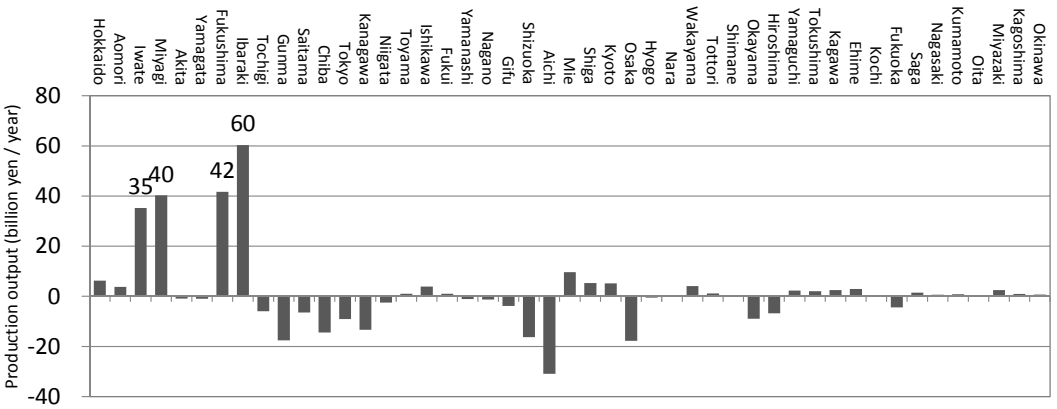


Figure.13: The changes in prefectural production output by reconstruction investment (billion yen per year)

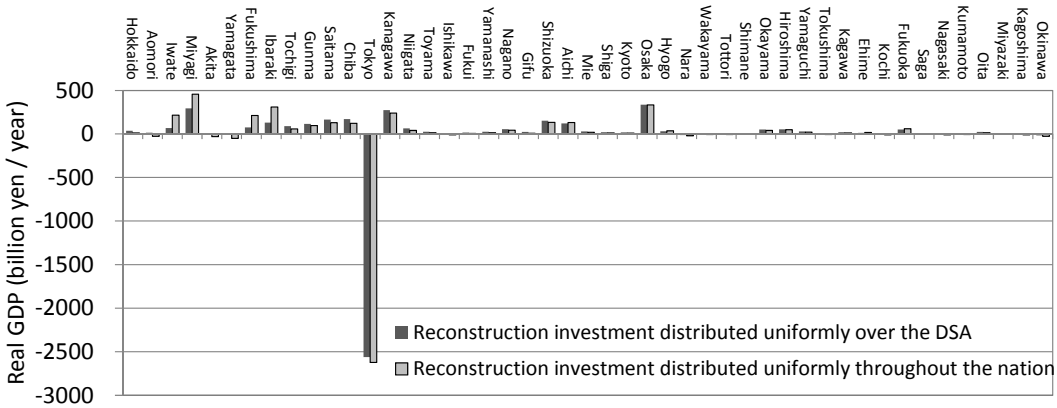


Figure.14: Comparison with the changes in real GDP by reconstruction investments distributed uniformly over the DSA and throughout the nation (billion yen per year)

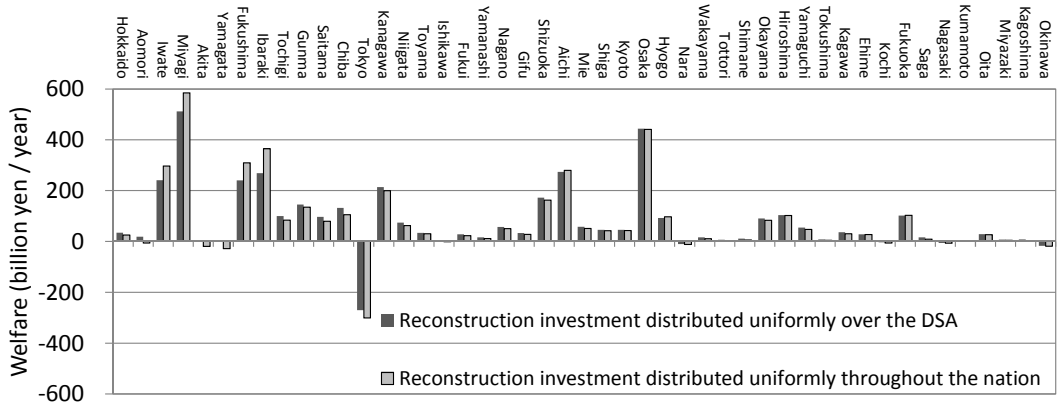


Figure.15: Comparison with welfare changes by reconstruction investments distributed uniformly over the DSA and throughout the nation (billion yen per year)

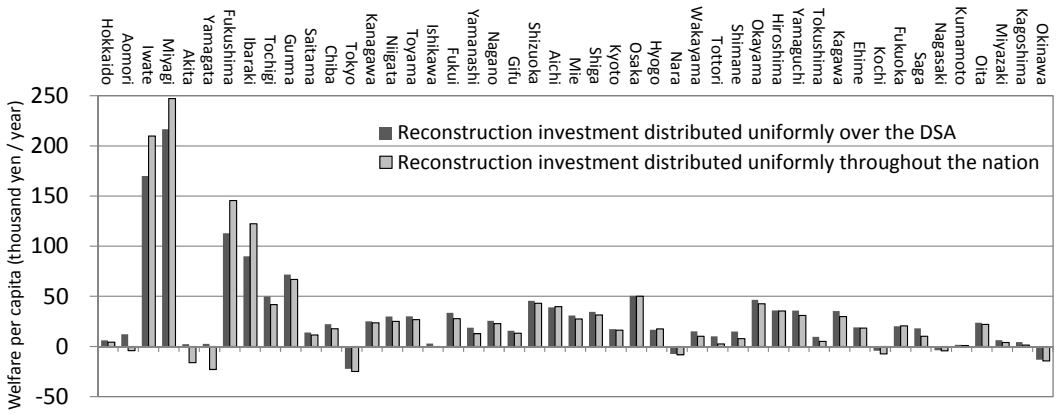


Figure.16: Comparison with the changes in welfare per capita by reconstruction investments distributed uniformly over the DSA and throughout the nation (thousand yen per year)

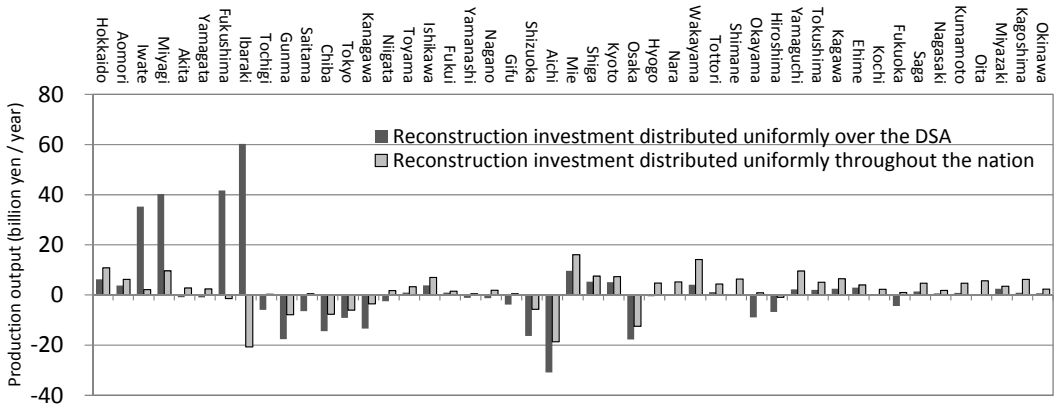


Figure.17: Comparison with the changes in production output by reconstruction investments distributed uniformly over the DSA and throughout the nation (billion yen per year)