EVALUATING THE DYNAMIC AND SPATIAL ECONOMIC IMPACTS OF AN EARTHQUAKE: A CGE APPLICATION TO JAPAN

Hiroyuki SHIBUSAWA*
Department of Architecture and Civil Engineering, Toyohashi University of Technology, Japan
hiro-shibu@tut.jp
Yuzuru MIYATA
Department of Architecture and Civil Engineering, Toyohashi University of Technology, Japan
miyata@ace.tut.ac.jp

Abstract
We have developed a dynamic spatial computable general equilibrium model to investigate the regional economic impacts of an earthquake. In our spatial model, Japan is subdivided into 47 regions. All the regions are connected by transportation networks. Our model is of a decentralized economy with utility-maximizing consumers and value-maximizing firms in a dynamic context. The model embodies both the spatial commodity flows among regions and the dynamics of regional investments. The model is calibrated for the regional economy using a multi-regional input-output table for Japan. We estimate the impacts of a hypothetical earthquake, which is expected to occur in the near future, on the regional economy in a case study of the Tokai region of Japan. The results show the indirect and distributional economic impacts before and after an earthquake. This study suggests that any disaster analysis should evaluate the economic impacts of a disaster based on both ex-ante and ex-post criteria.

Keywords: Disaster Protection, Indirect Economic Impacts, Tokai Earthquake, Dynamic Spatial CGE Modeling

1. Introduction

In this paper, we develop a dynamic spatial computable general equilibrium (DSCGE) model to evaluate the economic impacts of an earthquake on the Tokai region of Japan. Our model is of a decentralized economy with utility-maximizing consumers and value-maximizing firms in a dynamic context. The model embodies both the spatial interactions among regions and the dynamics of regional investments.

A numerical simulation model is developed of an inter-regional inter-sectoral economy in which Japan is subdivided into 47 regions. All the regions are connected by transportation networks. The model is calibrated for the regional economy in Japan. As a case study, the dynamic impacts of an earthquake in the Tokai region are analyzed by numerical simulation. In our hypothetical scenario, the primary physical damage caused by an earthquake is simply given by the reduction in the industrial capital stock. The dynamic optimizing production sector would make an investment before and after an earthquake to protect against economic losses or repair crucial damage. Regional economic growth would be more sensitive to a disaster.

The Tokai region is located at the center of Japan and faces the northern end of the Philippine Sea plate. The Tokai region is a potential location for a great earthquake. An earthquake is expected to occur in the Tokai Region (Mogi 1970, Sato 1970, Ando 1975). In this region, earthquakes with a magnitude of 8 recur with an interval of about 100-150 years. The most recent earthquake occurred in the Tonankai region in 1944. The occurrence of great earthquakes is approximately periodic (Mogi 1985).

Computable general equilibrium (CGE) analysis is a major tool in economics, regional science, and engineering. It is also widely recognized as a policy evaluation method (see, e.g., Shoven and Whalley 1992, Kehoe et al. 2005, Borglin 2004). There is a vast literature reporting

* Corresponding author

applications of static CGE models, but few studies have employed dynamic and spatial frameworks (see, e.g., Oosterhaven and Knaap 2003, Donaghy 2009). Recent trials of dynamic spatial or multi-regional CGE modeling have been undertaken by Ciesecke (2002,2003), McGregor, Swales and Yin (1995), and McKibbin and Wilcoxen (1992). Those previous studies mostly rely on a quasi-dynamic framework, which is characterized by an evolutionary approach and a sequential procedure.

The economic impacts of disasters have been analyzed by computational modeling approaches, such as the input-output model, mathematical programming, CGE, and econometric models (see, e.g., Ellson et al. 1984, Rose et al. 1997, Shon, Kim, Hewings 2003, Lee and Jang 2003, Okuyama and Chang 2004, Rose et al. 2005). Those studies mostly focused on assessing the economic impacts of damage to the public infrastructure such as transportation links, electric utility lifelines, water facilities, and telecommunications networks.

The CGE model gives us an excellent framework for analyzing disaster impacts and policy responses both across and between industries, households, and government. To assess the distribution impacts of a disaster in multi-regional settings, the spatial CGE model approach, which disaggregates the world or a country into a number of regions or counties, has also been developed. The models were characterized by the optimizing behavior of individual consumers and firms, subject to market balances and resource constraints in a static framework. The spatial interactions between regions are internalized by the transportation networks and trade costs. The spatial CGE (or CGE) model is a powerful tool but has some disadvantages as regards disaster analysis. The major reason for these disadvantages is that the economy is always established in equilibrium.

In Japan, several disasters have been assessed including the Tokai, Tonankai, and Niigata-Chuetsu earthquakes. Empirical studies have adequately estimated direct and some indirect economic losses based on actual data and input-output models (see e.g. Toyoda and Kochi 1997, Taniguchi 2007). On the other hand, the spatial CGE models have been used to capture spatial and distribution impacts (see, e.g., Koike and Ueda 2005, Tsuchiya, Tatano and Okada 2003, Tatano and Tsuchiya 2008). In such practical studies, to incorporate a disequilibrium phenomenon after a disaster in the SCGE models, short-run and long-run equilibriums were defined in a non-perfect competitive regional market condition, and the model was solved in a static environment. Those solutions were compared based on a hypothetical scenario. The distributional impacts across economic institutions and between regions, and caused by the direct economic loss in specific regions after an earthquake, were adequately estimated.

In disaster analysis, another important issue has largely been neglected in the SCGE literature, namely, the indirect effects of disaster protection before an earthquake. Tsuchiya, Tatano and Okada (2003) presented one of the few attempts to implement an SCGE model for an ex-ante disaster analysis. They focused on the impacts of information provision in a potential disaster and the transported-related economic losses induced by an earthquake warning were estimated under a short-term equilibrium using an SCGE model. However, a natural disaster inevitably involves both indirect and distributional effects before and after its occurrence. Natural disasters have been recorded throughout history, and the periodic characteristics of disasters have been investigated and widely recognized. Economic assessments before and after a possible disaster are expected to be resolved simultaneously in an analytical framework.

In this study, a dynamic spatial CGE model is developed based on dynamic macroeconomic theory with a multi-regional and multi-sectoral specification (ref. Abel Blanchard, 1983). Regional investment is endogenously determined by the behavior of value-maximizing firms, which involve capital adjustment functions. The dynamic impact of an earthquake is evaluated by using our dynamic spatial CGE model. Here, we extend our earlier work (Shibusawa, Yamaguchi and Miyata 2009). Specifically, our model is calibrated using the multi-regional input-output table in Japan. A steady state solution is derived as a base case. By numerical simulation, we assess the economic impacts of an earthquake in the Tokai region using our hypothetical scenarios. Two cases, i.e. unpredicted and predicted occurrences, are assumed and the two solutions, which are characterized as non-steady state, are compared with the base case.

Our contributions are as follows. Firstly, since industrial investment is determined by a firm's dynamic optimizing behavior, we can assess dynamic changes in investment before and after an earthquake. We derive the optimal investment before an earthquake from our model. Although we do not fully resolve the disequilibrium phenomena related to a disaster, we derive industrial investment responses before and after an earthquake as a non-steady state solution. A dynamic analytical framework highlights the estimation of indirect and distributional economic impacts before and after an earthquake. Secondly, since our model involves the transportation networks, we can also evaluate dynamic distributional impacts through the intra- and inter-regional trade before and after an earthquake. Lastly, we describe the methodological advantage of DSCGE modeling for application to periodically predicted disasters. It may contribute to an understanding of artificial and non-natural disasters caused by human activity, such as global warming and other environmental issues.

The paper is organized as follows. We first describe basic assumptions in Section 2. In section 3, we outline the dynamic spatial CGE model, and describe the optimization behaviors of firms and households. To obtain the market prices, we also define the equilibrium conditions. Section 4 provides simulation results. Two cases are compared to a base case, which is a steady state solution for a 21-year period. Section 5 summarizes the paper and offers some concluding remarks.

2. Basic Assumptions

The world is subdivided into regions. Throughout the world there are general industries, transportation industries and households. The economy is endowed with the primary factors of labor and capital. Labor is mobile across industries but not regions and capital is immobile across industries and regions. Goods and factor prices are determined in perfectly competitive regional markets. The commodity trade between regions in a country generates demand for transportation services, and unit transportation costs are endogenous. Commodities are perfect substitutes, i.e., trade between regions is calculated by trade coefficients. The movement of commodities among regions is enabled by road, rail, sea and air transportation networks. The modal share is also given. The model is solved for rational expectation equilibrium under the assumptions of perfect competition and foresight. However, we assume that firms place priority on the investment-savings balance. Then the level of investment is determined by the firm's optimizing behavior.

The model is finitely set up in discrete time. $T \equiv \{1, 2, \cdots, t_F\}$ denotes a planning period index and t_F is the final planning period. The world is divided into a home country and a foreign country. These are subdivided by region. R denotes a regional index in the home country. There are three kinds of industries, i.e. general, transportation and distribution industries. The general industry involves domestic and foreign trade between regions. I denotes a sector index for the general industry. M is a sector index for the transportation industry. All the regions interact with each other via the transportation networks. A transportation network is defined by nodes and links. A transport path connecting two regions is fixed and the transport link distance is exogenously given.

3. The Model

The model is based on dynamic macroeconomic theory with a multi-region and multi-sector specification. Each region has production and household sectors. Commodity trade flows are determined by the trade and modal share coefficients. We characterize the problems related to the maximization of the production and household sectors in this economy.

3.1 Production Sectors

Each sector of the general and transportation industries maximizes its present cash flow value in each period NC_{jt}^r and the asset value of their industrial capital in the final period $\Phi_j^r(\cdot)$. The sectors operate with constant returns to scale technology. The sectors choose the optimal investment and labor employment strategies. The behavior of the production sector $j \in I \cup M$ in region $r \in R$ is given as

$$\max_{\{K_{jt}^r, L_{jt}^r, \mathbf{X}_{jt}^r, \mathbf{Z}_{jt}^r\}} \sum_{t \in T} \rho_{jt} NC_{jt}^r + \rho_{t_F+1} \Phi_j^r (K_{j,t_F+1}^r),$$

subject to $K_{j,t+1}^r = (1-\delta_j) K_{jt}^r + \Delta K_{jt}^r (\mathbf{Z}_{jt}^r)$,

where $NC_{jt}^r \equiv p_{jt}^{Or} Y_j^r (K_{jt}^r, L_{jt}^r, \mathbf{X}_{jt}^r) - w_t^r L_{jt}^r - \sum_{i \in I \cup M} p_{it}^{Dr} X_{ijt}^r - \sum_{i \in I \cup M} p_{it}^{Dr} G_i^r (Z_{ijt}^r)$.

$\rho_{jt} \equiv 1/(1+\rho_j)^{t-1}$ represents the discount factor and ρ_j is the positive discount rate. $Y_j^r(\cdot)$ is a production function of capital K_{jt}^r, labor L_{jt}^r, and a vector of intermediate input $\mathbf{X}_{jt}^r = \{X_{1jt}^r, \cdots, X_{Ijt}^r\}$. The value added production function for labor and capital has a Cobb-Douglas form, while the intensities of intermediate goods are fixed. The asset value for the final period $\Phi_j^r(\cdot)$ is a linear function of the capital stock for the final period. The capital stock K_{jt}^r is accumulated by an investment function $\Delta K_{jt}^r(\cdot)$ with constant returns to scale. It is a function of a vector of intermediate inputs for the investment $\mathbf{Z}_{jt}^r = \{Z_{1jt}^r, \cdots, Z_{Ijt}^r\}$, and a Leontief type technology is assumed. δ_j is the depreciation rate. It is assumed that the cost function of intermediate goods for investment $G_i^r(\cdot)$ has increasing returns to scale. It can be interpreted that the function reflects both the costs of intermediate goods and the costs of adjusting their capital inputs.

In these sectors, there are two kinds of prices in each region, namely, the producer's price p_{jt}^{Or} and the purchaser's price p_{jt}^{Dr} in region r. If a commodity j is tradable between regions o and d, then the producer's price in region o is represented by p_{jt}^{Oo} and the purchaser's price is represented by p_j^{Dd} $(j \in I)$. In the transportation sector, p_{jt}^{Or} $(j \in M)$ means the unit price of the transportation services in region r. w_t^r is the wage rate.

After paying wages to households, the sector has to decide how to distribute profit and finance investment. In this model, the net investment is financed by new bonds. Let B_{jt}^r be the number of bonds in period t and r_{jt}^r be the interest rate. The bonds are traded in each region. The initial number of bonds is normalized by $B_{j1}^r = K_{j1}^r$. In this case, the profit dividend is calculated as

$$\pi_{jt}^r = p_{jt}^{Or} Y_j^r (K_{jt}^r, L_{jt}^r, \mathbf{X}_{jt}^r) - r_{jt}^r B_{jt}^r - w_t^r L_{jt}^r - \sum_{i \in I \cup M} p_i^{Dz} X_{ij}^z - p_{Bjt}^r \delta_j K_{jt}^r.$$

If net investment is financed by issuing new bonds, it holds that

$$p_{Bjt}^r \Delta B_{jt}^r = \sum_{i \in I \cup M} p_{it}^{Dr} G_i^r (Z_{ijt}^r) - p_{Bjt}^r \delta_j K_{jt}^r,$$

where ΔB_{jt}^r is the number of new bonds issued by sector j in region r for period t. p_{Bjt}^r is the price of the new bond. Therefore the outstanding bond is given by $B_{j,t+1}^r = B_{jt}^r + \Delta B_{jt}^r$ with

$B^r_{j1} = \bar{B}^r_{j1}$. It is assumed that the price of the new bond is given by $p^r_{Bjt} = q^r_{jt}$ where q^r_{jt} is the costate variable of the current-value Hamiltonian function

$$H^r_{jt} = NC^r_{jt} + q^r_{jt}[\Delta K^r_{jt}(\mathbf{Z}^r_{jt}) - \delta_j K^r_{jt}].$$

In this model, we assume that tradable goods are perfect substitutes. The profit of the distribution sector is given by $(j \in M)$

$$\pi^r_{Djt} = p^{Dr}_{jt} \sum_{o\in R}\sum_{m\in M} \mu^{or}_{jmt} F^{or}_{jt} - \sum_{o\in R}\sum_{m\in M} (p^{Oo}_{jt} + p^{Tor}_{jmt})\mu^{or}_{jmt} F^{or}_{jt} \quad \text{where } p^{Tor}_{jmt} \equiv \kappa_{jmt} p^{Or}_{mt} D^{or}_{mt}.$$

μ^{or}_{jmt} is the given modal share. The commodity flow F^{or}_{jt} is calculated as

$$F^{or}_{jt} = \tau^{or}_{jt}\left(\sum_{i\in I\cup M} X^r_{jit} + C^r_{jt}N^r_t + \sum_{i\in I\cup M} G_{ji}(Z^r_{jit})\right)$$

where τ^{or}_{jt} is the given trade coefficient. p^{Tor}_{jmt} is the transportation cost of mode m from region o to region r. D^{or}_{mt} is the distance between origin and destination along with a given path. κ_{jmt} is a given unit transportation service of mode m for goods j. From the zero profit condition, the purchaser's price is given by

$$p^{Dr}_{jt} = \sum_{o\in R}\sum_{m\in M} (p^{Oo}_{jt} + p^{Tor}_{jmt})\mu^{or}_{jmt}\tau^{or}_{jt}.$$

3.2 Household Sector

A representative household maximizes the utility level subject to income constraints. The full income consists of wages and interest on bond holdings. The behavior of a household in region $r \in R$ is given as

$$\max_{\{\mathbf{C}^r\}} \quad \sum_{t\in T} \rho_t U^r(\mathbf{C}^r_t),$$

subject to $$w^r_t + \sum_{i\in I\cup M} r^r_{it} A^r_{it} + d^r_t + FA^r_t - \sum_{i\in I\cup M} p^{Dr}_{it} C^r_{it} - \sum_{i\in I\cup M} p^r_{Bit}\Delta A^r_{it} \geq 0.$$

$U^r(\cdot)$ is a Cobb-Douglas utility function for period t, and it is a function of consumption $\mathbf{C}^r_t = \{C^r_{1t}, \cdots, C^r_{It}\}$. A^r_{it} is the number of bond holdings per household. ΔA^r_{it} represents new bonds issued for industrial investments. The household can receive the interest income but must pay to obtain a new bond. FA^r_t is the income transfer that provides a balance against a surplus or deficit in foreign and regional trade. d^r_t is the profit dividend that is given as $d^r_t \equiv \sum_{i\in I\cup M} \pi^r_{it} / N^r_t$ since the utility function is not identical among regions.

In this model, we assume that the level of investment is determined by a firm's optimization behavior. Firms place priority on the investment-savings balance. Therefore, the level of household savings is adjusted to coincide with the level of investment. In this case, the new bonds and the bond holdings per household are calculated as

$$\Delta A^r_{it} = \Delta B^r_{it} / N^r_{it} \ (i \in I \cup M) \text{ and } A^r_{i,t+1} = (\Delta A^r_{it} + A^r_{it}) N^r_t / N^r_{t+1} \ (i \in I \cup M).$$

3.3 Equilibrium Conditions

To obtain an equilibrium solution, the following market clearing conditions should be satisfied in each region $(r \in R)$.

(1) Goods and Services Markets

General Goods

$$Y^r_j(K^r_{jt}, L^r_{jt}, \mathbf{X}^r_{jt}) = \sum_{i\in I\cup M} X^r_{jit} + C^r_{jt}N^r_t + \sum_{i\in I\cup M} G_{ji}(Z^r_{jit}) + \sum_{d\in R} F^{rd}_{jt} - \sum_{o\in R} F^{or}_{jt} + E^r_{jt} - M^r_{jt} \ (j \in I)$$

where E^r_{jt} is a given export from region r and M^r_{jt} is a given import to region r.

Transportation Services

$$Y_m^r(K_{mt}^r, L_{mt}^r, \mathbf{X}_{mt}^r) = \sum_{i\in I}\sum_{o\in R}\kappa_{imt}^r \mu_{imt}^{or} D_{mt}^{or} F_{imt}^{or} \quad (m \in M)$$

(2) Labor

$$N_t^r = \sum_{i\in I\cup M} L_{it}^r$$

N_t^r is the total labor force (population) in each region and it is exogenously given.

(3) Capital

$$\Delta A_{it}^r N_t^r = \Delta B_{it}^r \quad (i \in I \cup M)$$

$$A_{it}^r N_t^r = B_{it}^r = K_{it}^r \text{ with } \bar{A}_{i1}^r N_1^r = \bar{B}_{i1}^r = \bar{K}_{i1}^r \quad (i \in I \cup M)$$

$\bar{A}_{1i}^r$ is the initial number of bond holdings of a household.

4. Numerical Application

(1) Scenarios

In the simulation model, the world is subdivided into 47 regions, which cover all Japan's prefectures. The economy is divided into seven sectors. General industry is divided into three sectors ($I = \{1,2,3\}$), i.e. agriculture, manufacturing, and services. There are four kinds of transportation networks: road, railway, sea, and air. Then the transportation industry is also divided into four sectors ($M = \{4,5,6\}$). The network structure, which is defined by the distance between an origin and a destination, is given for each period. The simulation period is set at *tF*=21. Population growth and technological progress are also fixed over time. Utility, production, and investment functions are specified for the simulation analysis as shown in the Appendix. Our simulation model is calibrated using the multi-regional input-output table in Japan (ref. Hitomi and Bunditsakulchai 2008).

Three cases are examined to evaluate the dynamic impacts of an earthquake in the Tokai region. The primary physical damage is simply assumed in terms of the reduction in the industrial capital stock in the Tokai region. In this simulation, the Tokai region covers ten prefectures, Chiba, Tokyo, Kanagawa, Yamanashi, Nagano, Gifu, Shizuoka, Aichi, Mie, and Wakayama as our target area.

(a) Base Case

The base case is the business as usual case where there is no earthquake. In this case, a steady state solution is derived where it holds that $K_{j,t+1}^r = K_{jt}^r$ and $q_{j,t+1}^r = q_{jt}^r$. The population growth rate and the technical progress growth are also both given as 0%.

(b) Case 1

We assume that an unpredicted earthquake occurs suddenly and hits the target area. In this simulation, the earthquake occurs in the 11th period. The level of physical damage is also assumed to comprise a reduction in capital stocks. The estimated rate of the damage is shown in Table 1 (ref. Central Disaster Prevention Council 2003, Taniguchi 2007). In this situation, no industry can make a new investment to protect itself from the disaster before the earthquake.

No. Prefecture	Rate of Damage Loss
12 Chiba	0.016%
13 Tokyo	0.001%
14 Kanagawa	0.058%
19 Yamanashi	0.247%
20 Nagano	0.147%
21 Gifu	0.011%
22 Shizuoka	10.000%
23 Aichi	1.421%
24 Mie	0.237%
30 Wakayama	0.016%

Table 1. Rate of Damage Loss in Capital Stock in Tokai Region

(c) Case 2

In this case, it is assumed that an earthquake is accurately predicted. Here, the earthquake occurs in the 11th period. Then the capital stocks are reduced in the 11th period as shown in Table 1. The amount of the reduction is the same as in Case 1. In Case 2, each industry can make an additional investment to protect itself before the earthquake.

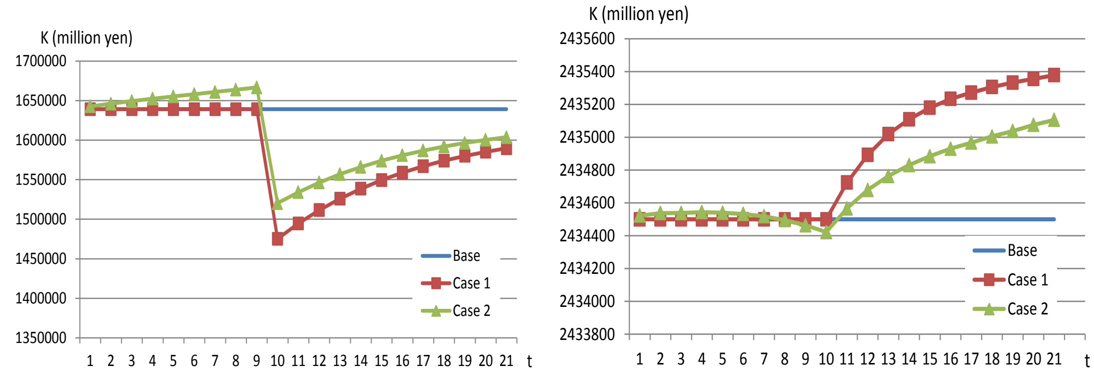
(2) Simulation Results

(a) Impacts on Capital Stock

The dynamic solutions for the capital stocks and the value of the capital stocks (i.e., the costate variable) of the manufacturing sector are examined. We focus on two prefectures, Shizuoka and Osaka, as the more influenced regions. Shizuoka is directly affected by the earthquake and suffers great losses. Osaka is not adjacent to the Tokai region and in our scenario but it is indirectly influenced by the earthquake through the transportation network. Figures 1 and 2 show the dynamic impacts of the earthquake on the capital stock and its value. In our dynamic simulation, the capital stock is accumulated by forward calculation, while the costate variable is solved by backward calculation.

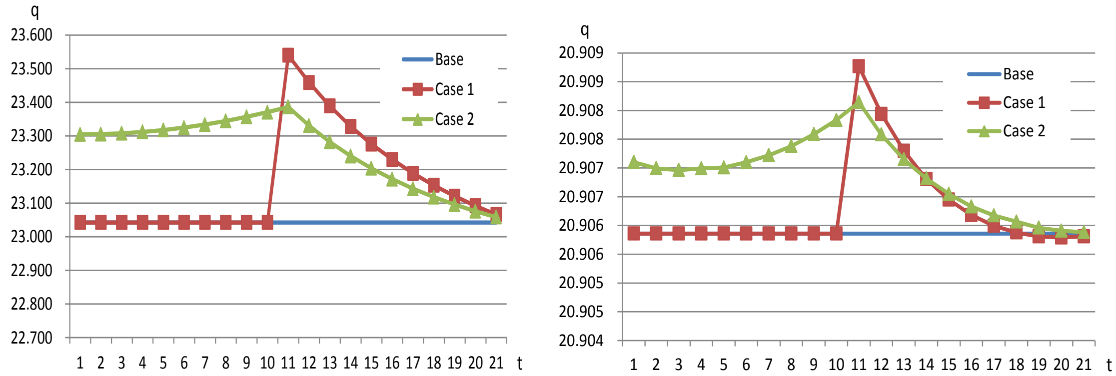
In Shizuoka prefecture, the capital stock suddenly decreases during the 11th period and is gradually restored after the earthquake in Case 1. The capital stock value is unchanged before the earthquake, and it increases unexpectedly during the 11th period due to the capital stock damage in Case 1. In Case 2, the capital damage seems to be more rapidly repaired after the earthquake by an increase in investment to protect against the earthquake. In Case 2, the capital stock value would increase more before the earthquake than in the Base case and Case 1. This implies that industrial sector would exactly estimate the value of the capital stock before the earthquake since it can accurately predict the occurrence of an earthquake.

Osaka prefecture is severely influenced by the earthquake and is indirectly affected by the Tokai region through the inter-trade between prefectures. In Case 1, Osaka prefecture experiences an increase in investment since the output in the Tokai region decreases after the earthquake. By contrast, in Case 2, due to an increase in investment and output in the Tokai region before the earthquake, the capital stock and output in Osaka prefecture partly decreases more than in the Base case.



Shizuoka Osaka

Figure 1 Capital Stock



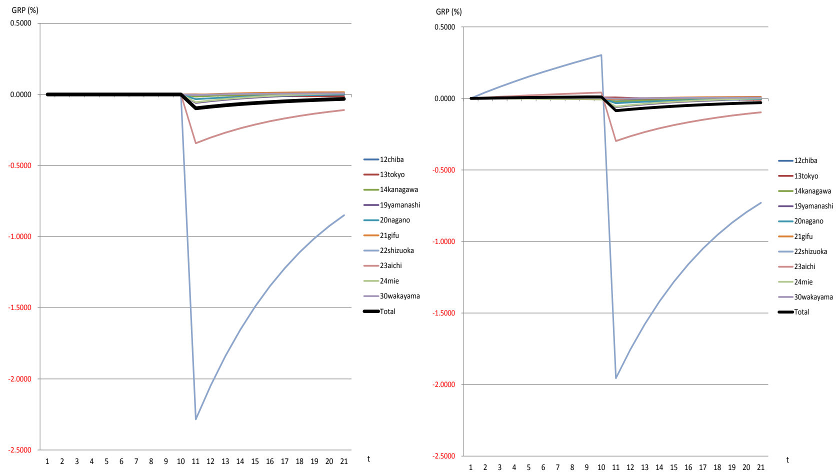
Shizuoka Osaka

Figure 2 Value of Capital Stock

(b) Impacts on GRPs

Figure 3 shows the results of the impacts of the earthquake on the GRP (Gross Regional Products) in the Tokai region. The change in the GRP is defined as $\Delta x = (x_{Case} - x_{Base}) / x_{Base} \times 100\%$. In both cases, the earthquake occurs in the Tokai region during the 11th period. This figure shows the dynamic impacts of the earthquake in the Tokai region, i.e. Chiba, Tokyo, Kanagawa, Yamanashi, Nagano, Gifu, Shizuoka, Aichi, Mie, and Wakayama prefectures as our target area. In addition, the bold line depicts the change in the total GRP of Japan and it implies the average impact of the earthquake. It may be useful to compare a regional impact and a national impact. The industrial capital stocks in those prefectures are directly reduced by the earthquake. In both cases, the Tokai region suffers damage from the earthquake and the percentage of damage in Shizuoka and Aichi prefectures appears to be greater than that of the whole of Japan. In particular, Shizuoka prefecture sustains crucial damage.

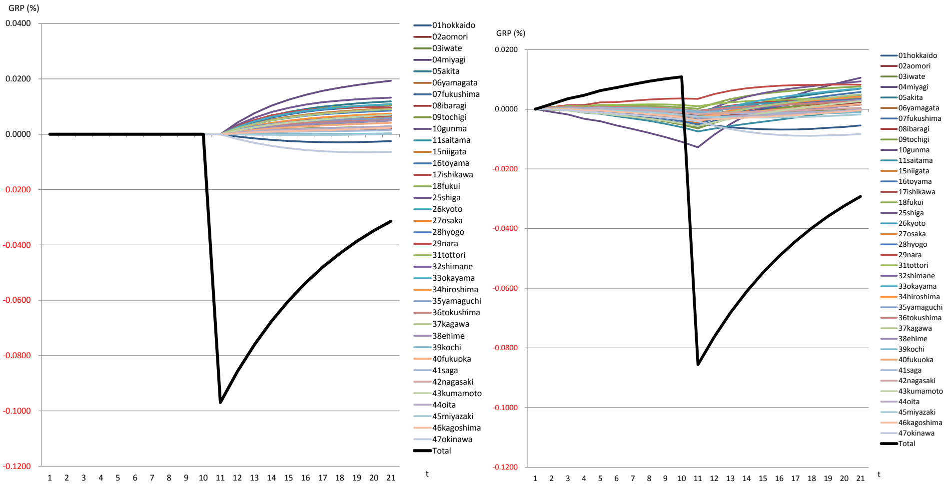
In Case 2, the production sectors can make an additional investment before the earthquake. It is assumed that the disaster hits in the 11th period, and the earthquake is accurately predicted. Before the earthquake, the Tokai region experiences a positive impact owing to the increase in investment designed to protect the region from earthquake damage. In particular, the GRP in Shizuoka prefecture is largely influenced by the additional investment before the disaster and the change in the GRP would be greater than that of Japan. After the disaster, the Tokai region in Case 2 is more rapidly restored by the investment from other prefecture than Case 1.



(a) Case 1 vs. Base (b) Case 2 vs. Base

Figure 3 GRPs in Tokai Region

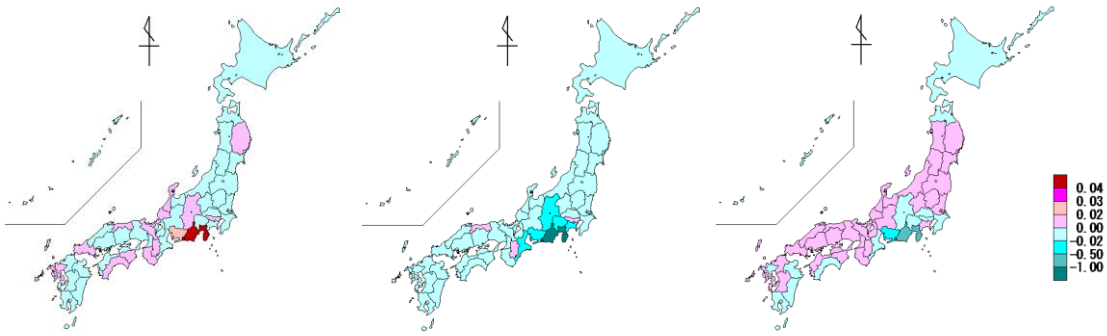
Figure 4 shows the results of the changes in the GRPs in every region except for the Tokai region. In Case 1, most prefectures far from the Tokai region experience positive changes in their GRPs after the earthquake, although the change in the total impact in Japan has a negative value, which is depicted by the bold line. In Case 2, most prefectures except for the Tokai region are affected by a negative impact before the earthquake owing to increases in investment designed to protect the Tokai region from earthquake damage, although the change in the total GRP in Japan has a positive value. On the other hand, after the earthquake, most prefectures experience a positive impact owing to the increase in investment to repair the damage.



(a) Case1 vs. Base (b) Case 2 vs. Base

Figure 4 GRPs in Non-Tokai Region

The geographical and dynamic impacts of the earthquake in Case 2 are shown in Figure 5. In the figure, blue and red, respectively, indicate negative and positive impacts on GRP compared with the Base case. The Tokai region experiences positive changes in its GRP before the earthquake, and sustains great damage after the earthquake. On the other hand, in other regions, most prefectures experience negative impacts on their GRPs before the disaster. After the earthquake, the situation becomes positive.

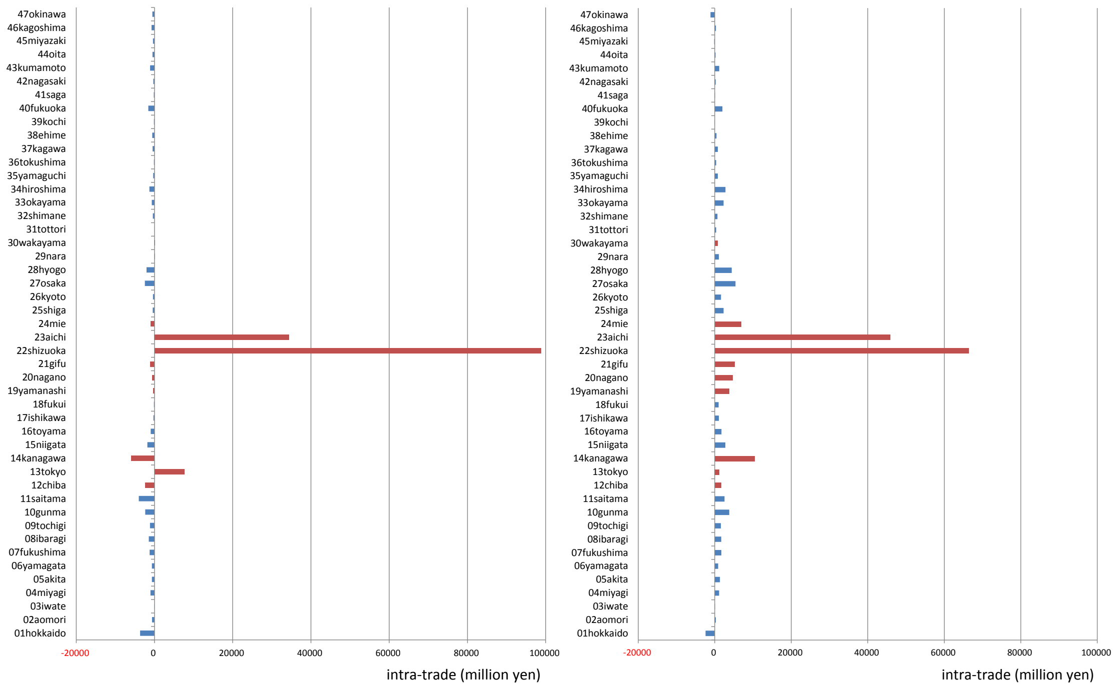


t=5 t=11 t=21

Figure 5 Distributional Effects (%)

(c) Impacts on Commodity Flows

Here, we examine the dynamic impacts of the earthquake on the commodity flows between regions. The changes in investment before and after the earthquake inevitably involve changes in the intra- and inter-trade commodity flows through the transportation networks. The intraand inter-trade of manufactured goods during the 9th and 11th periods are shown in those figures. Figure 6 shows the changes in the intra-trade commodity flows of manufactured goods for all the transport modes before and after the earthquake in Case 2. The change is defined as $\Delta x = (x_{\text{Case}} - x_{\text{Base}})$. The intra-trade commodity flows in Chiba, Tokyo, Kanagawa, Yamanshi, Nagano, Gifu, Shizuoka, Aichi, Mie, and Wakayama prefectures, which are shown as red lines, increase both before and after the earthquake, and the change in Shizuoka before the earthquake is particularly noticeable. In other prefectures, the intra-trade commodity flows increase in most prefectures after the earthquake, while they decrease in some prefectures before the earthquake. In Case 1, after the earthquake, similar changes can be seen, i.e. there is an increase in intra-trade commodity flows in the Tokai region and other prefectures.



(a) Before (t=9) (b) After (t=11)

Figure 6 Changes in Intra-trade Commodity Flows

The landscape of the commodity flows between prefectures is shown in Figure 7. The figure presents the changes in the inter-trade commodity flows of manufactured goods for all the transport modes between prefectures. We observe that the changes in the commodity flows before the earthquake are smaller than those after the earthquake in Case 2. Three kinds of major change can be seen in the figures. The first is a noticeable increase in commodity inflows to the Tokai region from other prefectures. The second is a noticeable increase in the inter-trade commodity flows between prefectures in the Chubu region, which is adjacent to the Tokai region. The last major change is an increase in the inter-trade commodity flows between prefectures in the Kanto region where the Tokyo metropolitan area is located and economic activity is concentrated. It shows that the commodity flows in the Chubu and the Kanto regions seem to be influenced by an increase in the investment in the Tokai region.

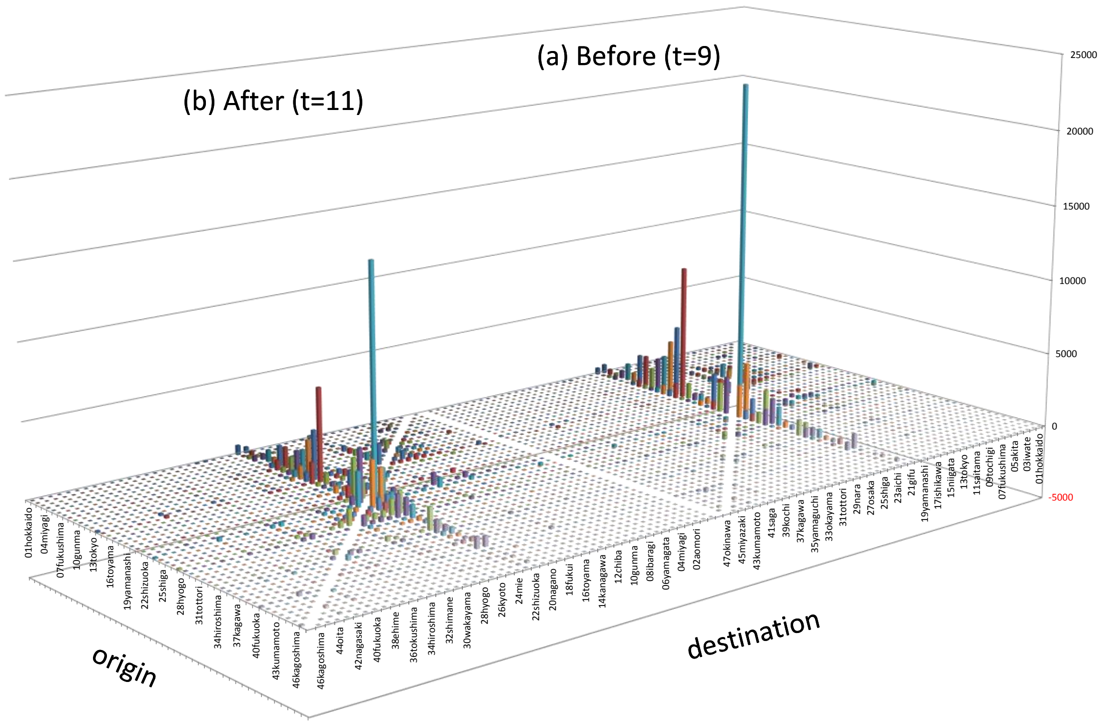


Figure 7 Changes in Inter-trade Commodity Flows

5. Concluding Remarks

In this paper, we described a dynamic spatial general equilibrium model. A decentralized economic system, which linked with the transportation networks, was constructed in a dynamic framework. The main purpose of the paper is to assess the impacts of a disaster in the Tokai region on the regional economy in Japan. We presented the results of three simulations: no earthquake, unpredicted earthquake and predicted earthquake in terms of the occurrence of an earthquake. We estimated dynamic and spatial impacts, i.e. industrial investments and commodity flows between regions before and after the earthquake. The indirect effects before and after a disaster were simultaneously solved. Two cases were compared with a base case. The results showed the importance of investment in terms of protecting the regional economy in the event of a disaster, i.e., an ex-ante evaluation. Our results suggest that any disaster analysis should evaluate the economic impacts of a disaster based on both ex-ante and ex-post criteria.

Many aspects of this study require further investigation. We could introduce the logit model or the Armington assumption to determine the traffic assignments and trade patterns between prefectures endogenously. We could also consider the impacts of the damage to transportation links. As another ex-ante criterion, an insurance system should be employed to relieve the effects of the damage. The investment-savings balance should be endogenously determined by both the firm's and consumer's optimizing behaviors. This approach may provide fruitful results for comparison with deterministic and stochastic models. The basic assumptions in the decentralized model should be relaxed to internalize regional policies such as the tax-subsidy system and regulation.

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Appendix

$$Y_j^r(K_{jt}^r, L_{jt}^r, \mathbf{X}_{jt}^r) = \min\left\{\frac{Y_{Vjt}^r}{A_{Vjt}^r}, \frac{X_{1jt}^r}{a_{1jt}^r}, \frac{X_{2jt}^r}{a_{2jt}^r}, \cdots\right\} \text{ with } Y_{Vjt}^r = A_j^z (K_{jt}^r)^{\alpha_j^r} (L_{jt}^r)^{\beta_j^r} \quad (j \in I \cup M)$$

$$\Delta K_{jt}^r(\mathbf{Z}_{jt}^r) = \min\left\{\frac{Z_{1jt}^r}{\phi_{1jt}^r}, \frac{Z_{2jt}^r}{\phi_{2jt}^r}, \cdots\right\} \quad (j \in I \cup M)$$

$$U^r(\mathbf{C}_t^r) = A_U \prod_{i \in I} (C_{it}^r)^{\omega_{Ci}} \quad \left(\sum_{i \in I} \omega_{Ci} = 1\right)$$

$$G_{ij}^r(Z_{ijt}^r) = G_{ij}^r(\phi_{ij}^r \Delta K_{jt}^r) = \phi_{ij}^r \cdot c_{Kj} (\Delta K_{jt}^r)^{\varpi_{Kj}} \quad (j \in I \cup M, i \in I) \quad (\varpi_{Kj} > 1)$$

$$\Phi_j^r(K_{j,T+1}^r) = \eta_j^r K_{j,T+1}^r \quad (j \in I \cup M)$$