Evaluating Impacts of a Disaster in Tokai Region of Japan: A Dynamic Spatial CGE Model

Hiroyuki SHIBUSAWA*, Makoto YAMAGUCHI* and Yuzuru MIYATA*

1. Introduction

In this paper, we develop a dynamic spatial CGE model to evaluate the economic impacts of an earthquake on Tokai region in Japan. Our model is characterized as a decentralized economy with utility-maximizing consumers and value-maximizing firms in the dynamic context. Both the spatial interactions among regions and the dynamics of regional investments are specified in this model.

A numerical simulation model is constructed under the inter-regional inter-sectoral economy where Japan is subdivided into 47 regions. All the regions are connected by the transportation networks. The model is calibrated for the regional economy in Japan. By numerical simulation, we will evaluate the economic impacts of an earthquake on Tokai region.

2. The Model

The world is subdivided by region. There are general industry (tradable goods and non-tradable goods), transportation industry and households. The economy is endowed with primary factors, 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. Commodity trade between regions in the country generates demand for transportation services and unit transportation costs are endogenous. Commodities are imperfect substitutes, i.e., they are differentiated according to region of production. The interaction of commodities among regions is performed by transportation networks. The model is solved for rational expectation equilibrium under perfect competition and foresight.

The model is finitely set up in discrete time. \( I_p = \{1, 2, \ldots, T\} \) denotes a planning period index and \( T \) is the final planning period. The world is divided into a home country and foreign country. These are subdivided by region. \( R \) denotes a

* Toyohashi University of Technology, 1-1 Tempaku Toyohashi, Aichi 441-8580, Japan
regional index at the home country. There are four kinds of industries, i.e. tradable goods, non-tradable goods, transportation and distribution industries. The tradable goods industry involves domestic and foreign trades among regions. \( I_t \) denotes a sector index for the tradable goods industry and \( I_o \) denotes a sector index for the non-tradable goods industry. \( I_r \) is a sector index of the transportation industry and \( I_D \) is a sector index of the composite production industry. We also tractably set two indices, \( I_{Io} = I_I \cup I_o \) and \( I_{IOT} = I_I \cup I_o \cup I_r \). All regions interact with each other by transportation networks. The 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 Decentralized Economy

The model is based on dynamic macroeconomic theory with a multi-region and multi-sector specification. In each region, there are production and household sectors. Commodity trade flows are linked by the Armington system. We characterize the maximization problem of production and household sectors in this economy.

3.1 Production Sectors

Each sector of the tradable, non-tradable, transportation industries maximizes the present value of its cash flow at each period \( NC'_u \) and the asset value of industrial capital at final period \( \Phi'_I(\Omega) \). The sector operates with constant returns to scale technology. The sector chooses the optimal investment and labor employment strategies. The behavior of the production sector \( i \in I_{IOT} \) in region \( r \in R \) is given as

\[
\max_{(K'_i,L'_u,X'_i,Z'_i)} \sum_{i \in I_T} \rho_i NC'_u + \rho_{T+1} \Phi'_i(K'_{i,T+1}),
\]

subject to \( K'_{i,T+1} = (1-\delta)K'_{i,u} + \Delta K'_{i,u}(Z'_{i,u}), \)

where \( NC'_{u} = p_{i}^{Dr} Y'_{i}(K'_{i,u},L'_{u},X'_{i}) - w'_i L'_u - \sum_{j \in I_{Io}} p^{Dr}_{j} X'_{ji} - \sum_{j \in I_{Io}} p^{Dr}_{j} G_{j}(Z'_{ji}). \)

\( \rho \equiv 1/(1+\rho)^{t-1} \) represents the discount factor and \( \rho \) is the positive discount rate. \( Y'_{i}(\Omega) \) is a production function of capital \( K'_{i,u} \), labor \( L'_{u} \), and a vector of intermediate input \( X'_{i,u} = \{X'_{iu},\cdots,X'_{iu}\} \). The value added production function for labor and capital is of Cobb-Douglas form, while the intensities of intermediate goods are fixed. The asset value at final period \( \Phi'_I(\Omega) \) is a linear function of capital stock at the final period. The capital stock \( K'_{i,u} \) is accumulated by an investment function \( \Delta K'_{i,u}(\Omega) \) with constant-returns-to-scale. It is a function of a vector of intermediate inputs for the
investment \( Z'_i = \{Z'_{ix}, \ldots, Z'_{ixq} \} \) and a Leontief type technology is assumed. \( \delta_i \) is the depreciation rate. The investment involves adjustment costs. \( G_j(\cdot) \) represents an adjustment function and it has an increasing returns to scale. In those sectors, there are two kinds of prices in each region. One is the producer’s price \( p_{iy}' \) and another is the purchase’s price \( p_{iy}^{odr} \) in region \( r \). If a commodity \( i \) is tradable between region \( o \) and region \( d \), then the producer’s price in region \( o \) is represented by \( p_{io}' \) and the purchaser’s price is represented by \( p_{id}'(i \in I_o) \). If it is non-tradable one, then two prices have the same values and are denoted by \( p_{id}' = p_{io}'(i \in I_o) \). In the transportation sector, \( p_{iy}'(i \in I_o) \) means the unit price of the transportation services in region \( r \). \( w_i' \) is the wage rate.

After having paid wages to households, the sector has to decide to how to distribute profit and finance the investment. In this model, we follow an assumption that a replacement investment is financed out of retained earnings and net investment is financed by new bonds (ref. Abel and Blanchard (1983)). Let \( B_{it}' \) be the number of bonds at period \( t \) and \( r_i' \) be the interest rate. The bonds are traded in the regional market in each region. The initial number of bonds is normalized by \( B_{it}' = K_{it}' \). In this case, the profit dividend is calculated as

\[
\pi_{it}' = p_{iy}' Y_i'(K_{it}', L_{it}', X_{it}') - r_i'B_{it}' - w_i'L_{it}' - \sum_{j=1}^{N} p_{ij}' X_{ij}' - p_{iy}' \delta K_{it}' .
\]

If the production function is of the constant returns to scale, then the dividend to households can be calculated as \( p_{iy}' \delta K_{it}' \). If the net investment is financed by issuing new bonds, it holds that

\[
p_{iy}' \Delta B_{it}' = \sum_{j=1}^{N} p_{ij}' G_j(Z_{ij}') - p_{iy}' \delta K_{it}' ,
\]

where \( \Delta B_{it}' \) is the number of new bonds issued by sector \( i \) in region \( r \) at period \( t \). \( p_{iy}' \) is the price of the new bond. Therefore the outstanding bond is given by \( B_{it+1}' = B_{it}' + \Delta B_{it}' \) with \( \sum_{i=1}^{N} B_{it}' = \bar{B}' \).

In this model, we rely on the theory of demand distinguished by place of production. We assume that tradable goods are imperfect substitutes (Armington 1969)\(^1\). The behavior of the sector for regional composite goods is given by \((i \in I_D)\)

\[
\max_{\{F_{it}' \}} \pi_{it}' = p_{iy}' Y_i'(F_{it}') - \sum_{o \in R \backslash I_D} (p_{io}' + p_{it}' D_{it}^{or}) F_{it}^{or} \quad \text{where} \quad p_{it}' \equiv \kappa_{it} \sum_{j=1}^{N} p_{ij}' D_{ij}^{or} .
\]

\(^1\) The Armington approach internalizes the trade coefficients, making them sensitive to the relative prices of goods from different origins.
\(Y'_{it}(\cdot)\) is a function of a vector of commodity trade flows \(F_{it}^o = \{F_{it}^o, \ldots, F_{it}^{Re}, \ldots, F_{it}^{R_{11}}\}\) and it is of a nested CES production function with constant returns to scale. \(p_{it}^{\text{for}}\) is the transportation cost of mode \(l\) from region \(o\) to region \(r\). \(D_{it}^{qr}\) is the link distance in region \(r\) and the total distance between origin and destination is calculated by the sum of \(D_{it}^{qr}\) along with a path. The path is exogenously given by the shortest path rule. \(\kappa_{it}\) is a given unit transportation services of mode \(l\) for goods \(i\).

### 3.2 Household Sector

A representative household maximizes the utility level subject to the income constraint. The full income consists of wage and interest on bond holdings. The behavior of the household in region \(r \in R\) is given as

\[
\max_{\{C, \lambda, \Delta A\}} \sum_{i \in I_r} \rho_i \frac{1}{\sigma} U'(T_H - L^r_{it}, C_i')^{\sigma} + \rho_{T_{it}} \Phi'_{it}(A'_{t+1}),
\]

subject to

\[
w_i' L_{it} + \sum_{i \in I_{it}} r_i' A_i' + d_i' + FA_i' - \sum_{i \in I_{it}} p_{it}^{\text{Dr}} C_i' - \sum_{i \in I_{it}} p_{Bi} \Delta A_i' \geq 0,
\]

\[A_{i,t+1} = \Delta A_i' + A_i' (i \in I_{Ht}), \quad d_i' = \sum_{i \in I_{it}} \pi_i' / N_i'.\]

\(U'(\cdot)\) is a Cobb-Douglas utility function at period \(t\) and it is a function of leisure \(T_H - L^r_{it}\) and a vector of consumptions \(C_i' = \{C_{it}', \ldots, C_{it}^{\text{for}}\}\). \(\sigma\) is the parameter which is related to the elasticity of intertemporal substitution. \(T_H\) is the given available time and \(L^r_{it}\) is labor time. \(A_i'\) is the number of bond holdings per household. \(\Delta A_i'\) is new bonds issued for industrial investments. The household can get the interest income but pay to get a new bond. \(FA_i'\) is the income transfer which balances against a surplus or deficit in the foreign trade. \(\Phi'_{it}(\cdot)\) is the assets value at final period and it is a linear function of a vector of bonds \(A'_{t+1} = \{A_{i,t+1}', \ldots, A_{i,t+1}^{\text{for}}\}\).

### 3.3 Equilibrium Conditions

(1) Goods and Services Markets

(a) Tradable Goods

\[Y'_i(K'_i, L'_i, X'_i) = \sum_{d \in R} \sum_{i \in I_d} F_{id} + \overline{EX}_{it}' (r \in R, i \in I)\]

\(\overline{EX}_{it}'\) is given export goods from region \(r\) to another country.

(b) Non-tradable Goods

\[Y'_i(K'_i, L'_i, X'_i) = \sum_{j \in I_{it}} X'_j + C_{it}' N_i' + \sum_{j \in I_{it}} G_j(Z_{ij}') (r \in R, i \in I)\]

(c) Transportation Services
\[ Y'_i(K'_r, L'_r, X'_r) = \sum_{j=1}^{n} \sum_{a=b}^{c} k_{ja} D_{ja}^{ord} F_{ja}^{ord} \quad (r \in R, i \in I_T) \]

(d) Regional Composite Goods

\[ Y'_d(F'_u) = \sum_{j=1}^{n} X'_{ji} + C'_{u} N'_i + \sum_{j=1}^{n} G'_j(Z'_{ij}) - \overline{IM}'_u \quad (r \in R, i \in I_D) \]

\( \overline{IM}'_u \) is a given total import from abroad to region \( r \).

(2) Labor

\[ L'_i = \sum_{i=1}^{n} L'_u \quad (r \in R) \]

\( N'_i \) is total labor (population) in each region.

(3) Capital

\[ \Delta A'_i = \Delta B'_i \quad (r \in R, i \in I_{TOT}) \]

\[ A'_i = B'_i = K'_i \quad \text{with} \quad \overline{A}'_i = \overline{B}'_i = \overline{K}'_i \quad (r \in R, i \in I_{TOT}) \]

\( \overline{A}'_i \) is an initial number of bond holdings of a household.

4. Numerical Application

In the simulation model, the world is subdivided into 47 regions of which cover all prefectures of Japan. The economy is classified into 7 sectors. General industry is simply divided to 3 sectors, i.e. agriculture, manufacturing industry, and services. There are four kinds of transportation networks: road, railway, sea, and air. Then the transportation industry is classified into 4 sectors. Each network structure, node and link, is given at each period. To fix a path between an origin and a destination, the shortest path rule is adopted. The planning period is given as \( T=10 \). Population growth and the technological progress are also fixed during planning periods.

Several scenarios are set to evaluate dynamic impacts of an earthquake on Tokai region (including Shizuoka, Aichi, and Mie prefectures). Numerical results will be shown in the meeting.
References