Recovery Process of Regional Economy from Disaster in Developing Countries

Muneta YOKOMATSU[1], Kotaro INOUE[2]

[1]Member of JSCE, Assoc. Professor, Disaster Prevention Research Institute, Kyoto University
(Gokasho, Uji, 611-0011, Japan)
E-mail: yoko@drs.dpri.kyoto-u.ac.jp
[2]Non-member of JSCE, Taikisha, Ltd.
(8-17-1, Nishi-Shinjuku Shinjuku-ku, Tokyo 160-6129, Japan)

We formulate a regional economy model to analyze the recovery process of an affected region of natural disasters in developing countries. With a focus on a role of migrant workers and intensive demand for residential houses and households assets, the two-region-two-sector model is set up, which is composed of an affected rural region and an unaffected urban region, and the composite goods sector and the physical assets sector. Moreover, we incorporate a structure of social network model into the model, which represents the strength of the social ties among households in community, on which we formulate community work in the affected region and the function of informal mutual insurance.

Key Words: *disaster, regional economy, migrant worker, community work*

1. INTRODUCTION

Despite the importance of macroscale evaluation of economic impact of disaster, we sometimes fail to grasp seriousness of local damage by applying macroeconomic model of the national level due to several problems such as movement of factors of production from an affected region to unaffected regions whose increase in production partially cancels out decrease in production in the affected region that actually suffers from disaster for a long time. Moreover, we tend to guess that disasters in affected regions could accelerate rural-urban migration that undergoes even at normal times, and make the region more depopulated and regional economy further declined.

However, contrary to the intuition, it has been reported in previous studies that the economic process that affected regions actually follow varies a great deal; it even includes a case of increase in population. For example, in Indonesia, after the Sumatra offing earthquake in 2004, there were some cases where repeated natural disasters in Indonesia prompted inhabitants to remain in their original region and suppressed the transference action of households to outside regions[2)]. Tse (2011) points out the following three reasons: 1) a rise in marginal labor productivity as well as increased demand of labor for reconstruction of destroyed infrastructure and houses in the affected area, 2) a decrease in financial resources to support emigration, and 3) the existence of mutual insurance and social ties that are further strengthened by disaster[3)].

To the knowledge of the authors, few studies have analyzed the disaster recovery process at the regional level using an equilibrium model. This study formulates a two-region-two-sector model with social network structure to investigate an equilibrium with migration, and intends to provide a potential framework for future quantitative analysis with data.

2. MODEL

(1) Two regions and two sectors

The modeled economy consists of two regions and two sectors where Region 1 has just been affected by a natural disaster while Region 2 represents an urban region that is large and unaffected by the disaster. There are N households in Region 1, and each household, indexed by $i(=1,...,N)$, is endowed with labor L_i and asset a_i.

Two sectors are composed of Sector A and Sector B; Sector A produces composite goods that include foods, non-durable goods and services while Sector B produces physical assets and capital goods such as

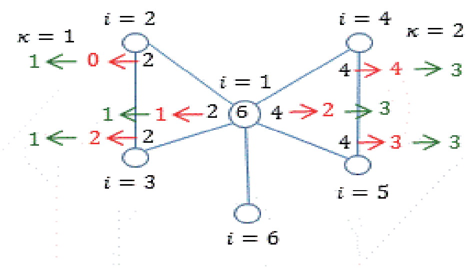

Fig.1 Mutual insurance

houses, household assets, and facilities for production. Goods that are produced by Sector A will be termed by "A-goods" or "composite goods" for convenience hereafter, and goods that are produced by Sector B, "B-goods" or "physical assets". A market of A-goods is open without any transportation cost between the two regions, and since Region 2 is assumed to be large, its price is one in any case. Moreover, we assume that Sector A in Region 1 is associated with risk of labor productivity related with epidemics, weather, sudden changes in technologies and global standards, and so forth. On the other hand, a market of B-goods is closed in Region 1, and its price, p, is endogenously determined. We assume for analytical convenience that Sector B is not faced with any risk.

(2) Mutual insurance and community work

Mutual help in communities of Region 1 after disaster[5] is formulated in the model by an informal mutual insurance system on social network as follows; the insurance provides mutual assistance, such as the distribution and sharing of water, foods, and essential goods[6], which takes an effect only once after a disaster. The community network in Region 1 is denoted by the adjacency matrix g whose components are represented by g_{ij} $(i, j = 1, \cdots, N)$. By definition, household i and j are directly connected if and only if $g_{ij} = 1$; otherwise, $g_{ij} = 0$[7]. The matrix is symmetric meaning that $g_{ij} = 1(0)$ goes with $g_{ji} = 1(0)$. By convention, $g_{ii} = 0$. Now, we introduce a variable η_i that is a stock of goods that can be shared with other households in a community. **Fig.1** illustrates the mutual insurance system in a community. Suppose that there are six households, $i = 1, \cdots, 6$, and two clusters; Cluster 1 ($\kappa = 1$) is composed of $\{1, 2, 3\}$, and Cluster 2 ($\kappa = 2$), $\{1, 4, 5\}$. In Cluster 1, Household 1,2,3 determine that each household provides two units of a stock of composite goods to their insurance pool to share six units among the three households. On the other hand, Cluster 2 takes the same system with four units of provision by each household. Suppose further that disaster destroys their stocks and the red-colored numbers of units are left; Household 1 who had six units in total lost three units and keeps three units for example. Cluster 1 now has three units in total; Household 1,2,3 own 1,0,2 respectively. Then they reallocate those three units among themselves equally to consume one unit for each household as is indicated in green color. Likewise, in Cluster 2, the goods left after disaster is 2+4+3=9 in total (indicated in red color), which are reallocated among Household 1,4,5 so that each of them has three units (indicated in green color). In this way, Household 1, who decreased its stock to three units once, is compensated by the mutual insurance system to eventually have four units.

Moreover, a community is able to produce the two kinds of goods by itself. Households have an option to allocate their labor to community work whose productivity depends on strength of their social ties in a community.

3. EQUILIBRIUM CONDITIONS

(1) Firms' problem

Technology of firms in Sector A is represented by Cobb-Douglas production function with inputs of labor, capital, and land. Assuming that land is a fixed factor, we standardize the size of land to be one. The production function is given by

$$F_A(A_1, A_2, L_A, K_A) = A_1 L_A^{\alpha_1} K_A^{\alpha_2} + A_2 L_A \quad \text{(1a)}$$
$$\text{where} \quad A_2 = \bar{A}_2 \cdot (1 + \varepsilon) \quad \text{(1b)}$$
$$\mathrm{E}[\varepsilon] = 0, \quad \mathrm{Var}[\varepsilon] = \sigma^2 \quad \text{(1c)}$$

where L_A is labor, and K_A, capital. α_1 and α_2 are share parameters of the Cobb-Douglas function satisfying $0 < \alpha_1 + \alpha_2 < 1$. The production technology is homogeneous of degree one in labor, capital, and land. A_1 and A_2 are parameters of productivity, and A_2 is a ramdom variable given by Eq.(1b), where $\bar{A}_2$ is the expected value of A_2, and ε is a random variable with mean, zero, and variance, σ^2.

Considering that price of Good-A is one, contingent profit of a representative firm of Sector A is represented by

$$\Pi_A = \left\{A_1 L_A^{\alpha_1} K_A^{\alpha_2} + \bar{A}_2(1+\varepsilon)L_A\right\} - \{w_{1A}L_A + rK_A\}, \tag{2}$$

where w_{1A} is the wage rate in Sector A, and r is the interest rate. Since capital market is assumed to be open to Region B that is large, and productivity of capital is not stochastic, r is exogenously given, while w_{1A} is determined as a market equilibrium. Assuming that the firm maximizes the expected profit, $\bar{\Pi}_A$, before the value of ε is determined, the optimization problem is represented by

$$\max_{L_A, K_A} \bar{\Pi}_A = \left\{A_1 L_A^{\alpha_1} K_A^{\alpha 2} + \bar{A}_2 L_A\right\} - \{\bar{w}_{1A}L_A + rK_A\}, \tag{3}$$

where $\bar{w}_{1A}$ is the expected wage rate in Sector A that satisfies

$$w_{1A} = (1+\varepsilon)\bar{w}_{1A}. \tag{4}$$

From the first-order optimal conditions with respect to L_A and K_A, we obtain

$$L_A^*(\bar{w}_{1A}, r) = \left\{A_1 \left(\frac{\alpha_2}{r}\right)^{\alpha_2} \left(\frac{\alpha_1}{\bar{w}_{1A} - \bar{A}_2}\right)^{1-\alpha_2}\right\}^{\frac{1}{1-\alpha_1-\alpha_2}}, \tag{5a}$$

$$K_A^*(\bar{w}_{1A}, r) = \left\{A_1 \left(\frac{\alpha_2}{r}\right)^{1-\alpha_1} \left(\frac{\alpha_1}{\bar{w}_{1A} - \bar{A}_2}\right)^{\alpha_1}\right\}^{\frac{1}{1-\alpha_1-\alpha_2}}, \tag{5b}$$

and the optimal level of the production of A-Goods, $Y_A^*(\bar{w}_{1A}, r, \varepsilon)$, and the maximized profit $\Pi_A^*(\bar{w}_{1A})$ as follows;

$$\begin{aligned} Y_A^*(\bar{w}_{1A}, r, \varepsilon) &= \left\{A_1 \left(\frac{\alpha_2}{r}\right)^{\alpha_2} \left(\frac{\alpha_1}{\bar{w}_{1A} - \bar{A}_2}\right)^{\alpha_1}\right\}^{\frac{1}{1-\alpha_1-\alpha_2}} \\ &+ \bar{A}_2(1+\varepsilon)\left\{A_1 \left(\frac{\alpha_2}{r}\right)^{\alpha_2} \left(\frac{\alpha_1}{\bar{w}_{1A} - \bar{A}_2}\right)^{1-\alpha_2}\right\}^{\frac{1}{1-\alpha_1-\alpha_2}}, \end{aligned} \tag{6a}$$

$$\Pi_A^*(\bar{w}_{1A}, r) = (1-\alpha_1-\alpha_2)\left\{A_1 \left(\frac{\alpha_2}{r}\right)^{\alpha_2} \left(\frac{\alpha_1}{\bar{w}_{1A} - \bar{A}_2}\right)^{\alpha_1}\right\}^{\frac{1}{1-\alpha_1-\alpha_2}}. \tag{6b}$$

The profit of Sector A is divided equally among households in Region 1, that is, $\pi_A^*(\bar{w}_{1A}, r) = \Pi_A^*/N$ where π_A^* represents the dividend of the profit to each household, which is incorporated into its income.

The production function of Sector B is assumed to be a Cobb-Douglas function with labor L_B, capital K_B and land whose size is one as follows;

$$F_B(B_0, L_B, K_B) = B_0 L_B^{\beta_1} K_B^{\beta_2}, \tag{7}$$

where β_1 and β_2 are parameters that satisfy $0 < \beta_1 + \beta_2 < 1$, and B_0 is the total factor productivity.

Assuming that a representative firm in Sector B is not faced with risks, its problem is given by profit-maximization problem like

$$\max_{L_B, K_B} \Pi_B = pB_0 L_B^{\beta_1} K_B^{\beta_2} - \{w_{1B}L_B + rK_B\}, \tag{8}$$

where w_{1B} is the wage rate. From the first-order conditions, the optimal demands of labor and capital are introduced like

$$L_B^*(w_{1B}, r) = \left\{\frac{\left(\frac{\beta_1}{w_{1B}}\right)^{\frac{1-\beta_2}{\beta_2}} (pB_0)^{\frac{1}{\beta_2}} \beta_2}{r}\right\}^{\frac{\beta_2}{1-\beta_1-\beta_2}}, \tag{9a}$$

$$K_B^*(w_{1B}, r) = \left\{\frac{\left(\frac{\beta_2}{r}\right)^{\frac{1-\beta_1}{\beta_1}} (pB_0)^{\frac{1}{\beta_1}} \beta_1}{w_{1B}}\right\}^{\frac{\beta_1}{1-\beta_1-\beta_2}}, \tag{9b}$$

respectively, and the optimal level of the production, $Y_B^*(w_{1B}, r)$, and the maximized profit, $\Pi_B^*(w_{1B}, r)$, are derived as follows;

$$Y_B^*(w_{1B}, r) = \left\{p^{\beta_1+\beta_2} B_0 \left(\frac{\beta_1}{w_{1B}}\right)^{\beta_1} \left(\frac{\beta_2}{r}\right)^{\beta_2}\right\}^{\frac{1}{1-\beta_1-\beta_2}}, \tag{10a}$$

$$\Pi_B^*(w_{1B}, r) = (1-\beta_1-\beta_2)\left\{pB_0 \left(\frac{\beta_1}{w_{1B}}\right)^{\beta_1} \left(\frac{\beta_2}{r}\right)^{\beta_2}\right\}^{\frac{1}{1-\beta_1-\beta_2}}. \tag{10b}$$

The above profit is divided equally among households in Region 1 like $\pi_B^*(w_{1B}, r) = \Pi_B^*/N$ where π_B^* represents the dividend of the profit to each household.

(2) Communities' problem

Suppose that the productivity of household i in community work, z_{3i}, depends on the amount of labor it allocates, l_{3i}, and how it is involved into the social network of the community such like

$$z_{3i}(l_{3i}) = -\frac{1}{2}C_{iz}(x_i)l_{3i}^2 + \theta_{iz}\sum_{j=1}^{N} g_{ij}l_{3i}l_{3j}, \tag{11}$$

where $C_{iz}(x_i)$ is the transportation cost to work-site that depends on its geographical location x_i[8], and θ_{iz} is household i's strength in social ties with the community.

Production functions of community work for producing A-goods and B-goods are given by

$$F_A^C(Z_A) = A^C Z_A^{\gamma_1}, \tag{12a}$$

$$F_B^C(Z_B) = B^C Z_B^{\gamma_2}, \tag{12b}$$

where Z_A (Z_B) is the effective labor input for producing A-goods (B-goods) that is given by sum of z_{3i} allocated to production of A-goods (B-goods). γ_1 and γ_2 are parameters satisfying $0 < \gamma_1 < 1$, $0 < \gamma_2 < 1$. A^C and B^C are parameters representing the productivity of community work in each sector.

Let Y_A^C and Y_B^C be A-goods and B-goods that are produced by community work, respectively, and w_3 is the wage rate for one unit of z_{3i} for each community work. The profit maximization problem of the community is represented by

$$\max_{Z_A, Z_B} \quad \Pi_C = Y_A^C + pY_B^C - w_3(Z_A + Z_B) \tag{13}$$

From the first-order conditions, demands of the effective labor are introduced like

$$Z_A^*(p, w_3) = \left(\frac{\gamma_1 A^C}{w_3}\right)^{\frac{1}{1-\gamma_1}}, \tag{14a}$$

$$Z_B^*(p, w_3) = \left(\frac{p\gamma_2 B^C}{w_3}\right)^{\frac{1}{1-\gamma_2}}. \tag{14b}$$

The optimal levels of the production, $Y_A^C(p, w_3)$ and $Y_B^C(p, w_3)$, are given by

$$Y_A^{C*}(p, w_3) = F_A^{C*}(Z_A^*) = \left\{A^C\left(\frac{\gamma_1}{w_3}\right)^{\gamma_1}\right\}^{\frac{1}{1-\gamma_1}}, \tag{15a}$$

$$Y_B^{C*}(p, w_3) = F_B^{C*}(Z_B^*) = \left\{B^C\left(\frac{p\gamma_2}{w_3}\right)^{\gamma_2}\right\}^{\frac{1}{1-\gamma_2}}, \tag{15b}$$

The optimal profit, Π_C^*, is given by

$$\Pi_C^*(p, w_3) = \left(\frac{A^C\gamma_1}{w_3}\right)^{\frac{1}{1-\gamma_1}} \frac{w_3(1+\gamma_1)}{\gamma_1} + \left(\frac{pB^C\gamma_2}{w_3}\right)^{\frac{1}{1-\gamma_2}} \frac{w_3(1-\gamma_2)}{\gamma_2}. \tag{16}$$

The profit of the community work is divided equally among the households as $\pi_C^*(p, w_3) = \Pi_C^*/N$ that is the optimal profit per household, which is included in household income.

(3) Households' problem

Total labor of household i, L_i, is allocated into four types of labor: Sector A, l_{1Ai}, Sector B, l_{1Bi}, Region 2, l_{2i}, and community work, l_{3i}, namely the following equation holds;

$$l_{1Ai} + l_{1Bi} + l_{2i} + l_{3i} = L_i. \tag{17}$$

We suppose that household i consumes the composite goods that include the initial endowment, C_{0i}, which is determined after redistribution based on the mutual insurance system after a disaster as well as the physical assets, $h_{0i} + h_i$, where h_{0i} is remaining physical assets and h_i is purchased after disaster. h_{0i} is a parameter in the model where the larger its value is, the less damage its house takes from disaster. We also assume that household i has financial assets, a_i, and deposits all of the assets in a bank.

Households gain utility by consuming the composite goods and the physical assets; utility function is assumed to be the Cobb-Douglas function as follows:

$$u(C_{0i} + C_i, h_{0i} + h_i) = (C_{0i} + C_i)^\theta (h_{0i} + h_i)^{1-\theta}, \tag{18}$$

where θ is a parameter satisfying $0 < \theta < 1$. Income of household i, m_i, and its expected value, $\bar{m}_i$, are given by

$$m_i = w_{1A}l_{1Ai} + \pi_A + w_{1B}l_{1Bi} + \pi_B + w_3 z_i(l_{3i}) + \pi_C + w_2 l_{2i} + ra_i, \tag{19a}$$

$$\bar{m}_i = \bar{w}_{1A}l_{1Ai} + \pi_A + w_{1B}l_{1Bi} + \pi_B + w_3 z_i(l_{3i}) + \pi_C + w_2 l_{2i} + ra_i \tag{19b}$$

Therefore deviation from the mean is represented by

$$\Delta m_i = m_i - \bar{m}_i = \varepsilon \cdot \bar{w}_{1A} l_{1Ai} := \varepsilon M_1 \tag{20}$$

We further assume that households sign an insurance contract with an insurance company that locates in Region 2 to hedge the risk of wage of Sector A. The risk premium of this insurance, which is often termed by "additional loading" included in insurance premium, is assumed to be an increasing function of the variance of the income change. Considering that the variance of the risk, ε, is σ^2, the risk premium, Ω, is assumed to be like

$$\Omega_i := \frac{\delta}{2}\mathrm{E}[(\Delta m_i)^2] = \frac{\delta}{2}\sigma^2 M_1^2. \tag{21}$$

The utility maximization problem of household i is represented as follows;

$$\max_{C_i, h_i} \quad u(C_{0i} + C_i, h_{0i} + h_i) = (C_{0i} + C_i)^\theta (h_{0i} + h_i)^{1-\theta} \tag{22a}$$

$$\text{subject to} \quad C_i + ph_i = \psi \cdot (\bar{m}_i - \Omega_i), \tag{22b}$$

$$l_{1Ai} + l_{1Bi} + l_{2i} + l_{3i} = L_i, \tag{22c}$$

where ψ is the ratio of expenditure to income that is given as a constant parameter. Namely, $(1-\psi)\cdot(\bar{m}_i - \Omega_i)$ is saving for the next period. Lagrangian for the problem is represented by

$$\mathcal{L} = (C_{0i} + C_i)^\theta (h_{0i} + h_i)^{1-\theta}$$

$$+\lambda_1\{\psi(\bar{m}_i-\Omega_i)-C_i-ph_i\}$$
$$+\lambda_2(L_i-l_{1Ai}-l_{1Bi}-l_{2i}-l_{3i}), \quad (23)$$

where λ_1 and λ_2 are the Lagrange multipliers. First-order conditions are introduced as follows;

$$\frac{\partial\mathcal{L}}{\partial C_i}=\theta(C_{0i}+C_i)^{\theta-1}(h_{0i}+h_i)^{1-\theta}-\lambda_1=0, \quad (24a)$$
$$\frac{\partial\mathcal{L}}{\partial h_i}=(1-\theta)(C_{0i}+C_i)^{\theta}(h_{0i}+h_i)^{-\theta}-\lambda_1 p=0, \quad (24b)$$
$$\frac{\partial\mathcal{L}}{\partial l_{1Ai}}=\lambda_1\psi(\bar{w}_{1A}-\delta\sigma^2 M_1\bar{w}_{1A})-\lambda_2=0, \quad (24c)$$
$$\frac{\partial\mathcal{L}}{\partial l_{1Bi}}=\lambda_1\psi w_{1B}-\lambda_2=0, \quad (24d)$$
$$\frac{\partial\mathcal{L}}{\partial l_{2i}}=\lambda_1\psi w_2-\lambda_2=0, \quad (24e)$$
$$\frac{\partial\mathcal{L}}{\partial l_{3i}}=\lambda_1\psi w_3 z_3'(l_{3i})-\lambda_2=0. \quad (24f)$$

Transforming the above conditions, we have

$$C_i(p)=\frac{\theta}{1-\theta}p(h_{0i}+h_i)-C_{0i}, \quad (25a)$$
$$\lambda_1(p)=\theta^\theta\left(\frac{1-\theta}{p}\right)^{1-\theta}, \quad (25b)$$
$$w_{1B}=w_2, \quad (25c)$$
$$\lambda_2(w_2)=\lambda_1\psi w_2=\psi\theta^\theta\left(\frac{1-\theta}{p}\right)^{1-\theta}w_2, \quad (25d)$$
$$l_{3i}(w_2,w_3)=\frac{\theta_{iz}\sum_{j=1}^N g_{ij}l_{3j}^- -\frac{w_2}{w_3}}{C_{iz}(x)}, \quad (25e)$$
$$\bar{w}_{1A}(w_2,M_1)=\frac{w_2}{1-\delta\sigma^2 M_1}. \quad (25f)$$

Note that the wage rate in Region 2, w_2, is exogenously given. Since Sector B in Region 1 is free of risk, its wage rate, w_{1B}, is made equal to w_2, and the allocation of labor in Sector B in Region 1 and that in Region 2 become indifferent. Therefore, we define

$$l_{4i}(l_{1Ai},l_{3i}):=l_{1Bi}+l_{2i}=L_i-l_{1Ai}-l_{3i}. \quad (26)$$

In Eq.(25e), we suppose that household i determines the allocation of community work labor in the current period considering the community work labor of other households in the previous period, l_{3j}^-.

From $M_1(\bar{w}_{1A},l_{1Ai})=\bar{w}_{1A}l_{1Ai}$ and Eq.(25f), we obtain

$$\bar{w}_{1A}=\frac{1+\sqrt{1-4l_{1Ai}\delta\sigma^2 w_2}}{2l_{1Ai}\delta\sigma^2}. \quad (27)$$

Demand of the physical assets, h_i, satisfies

$$h_i=\frac{1-\theta}{p}\left\{\psi\left(M_1+\pi_A+w_2 l_{4i}+\pi_B+w_3 z(l_{3i})\right.\right.$$
$$\left.\left.+\pi_C+ra_i-\frac{\delta}{2}\sigma^2 M_1^2\right)+C_{0i}\right\}-\theta h_{0i}. \quad (28)$$

(4) Market clearing condition

The market clearing condition of the composite goods provided by firms of Sector A is given by

$$\sum_{i=1}^N C_i(p)=Y_A^*(\bar{w}_{1A},r,\varepsilon)+Y_A^0+Y_A^{C*}(p,w_3), \quad (29)$$

equivalently,

$$\sum_{i=1}^N\left\{\frac{\theta}{1-\theta}p(h_{0i}+h_i)-C_{0i}\right\}$$
$$=\left\{A_1\left(\frac{\alpha_2}{r}\right)^{\alpha_2}\left(\frac{\alpha_1}{\bar{w}_{1A}-\bar{A}_2}\right)^{\alpha_1}\right\}^{\frac{1}{1-\alpha_1-\alpha_2}}$$
$$+\bar{A}_2(1+\varepsilon)\left\{A_1\left(\frac{\alpha_2}{r}\right)^{\alpha_2}\left(\frac{\alpha_1}{\bar{w}_{1A}-\bar{A}_2}\right)^{1-\alpha_2}\right\}^{\frac{1}{1-\alpha_1-\alpha_2}}$$
$$+Y_A^0+\left\{A^C\left(\frac{\gamma_1}{w_3}\right)^{\gamma_1}\right\}^{\frac{1}{1-\gamma_1}}. \quad (30)$$

Secondly, the market clearing condition of the physical assets in Sector B is as follows:

$$\sum_{i=1}^N h_i(p)=Y_B^*(w_{1B},r)+Y_B^{C*}(p,w_3)$$
$$=\left\{p^{\beta_1+\beta_2}B_0\left(\frac{\beta_1}{w_{1B}}\right)^{\beta_1}\left(\frac{\beta_2}{r}\right)^{\beta_2}\right\}^{\frac{1}{1-\beta_1-\beta_2}}$$
$$+\left\{B^C\left(\frac{p\gamma_2}{w_3}\right)^{\gamma_2}\right\}^{\frac{1}{1-\gamma_2}}. \quad (31)$$

Supply and demand of labor in Sector A are balanced as follows;

$$\sum_{i=1}^N l_{1Ai}=L_A^*(\bar{w}_{1A})$$
$$=\left\{A_1\left(\frac{\alpha_2}{r}\right)^{\alpha_2}\left(\frac{\alpha_1}{\bar{w}_{1A}-\bar{A}_2}\right)^{1-\alpha_2}\right\}^{\frac{1}{1-\alpha_1-\alpha_2}}. \quad (32)$$

Finally, supply and demand of labor of community work must be balanced as follows;

$$Z_A^*(p,w_3)+Z_B^*(p,w_3)=\sum_{i=1}^N z_{3i}(l_{3i}^*(w_3)), \quad (33)$$

equivalently,

$$\left(\frac{\gamma_1 A^C}{w_3}\right)^{\frac{1}{1-\gamma_1}}+\left(\frac{p\gamma_2 B^C}{w_3}\right)^{\frac{1}{1-\gamma_2}}$$
$$=\sum_{i=1}^N\left\{-\frac{1}{2}C_{iz}(x)l_{3i}^2+\theta_{iz}\sum_{j=1}^N g_{ij}l_{3i}l_{3j}\right\}. \quad (34)$$

(5) Summary of numerical simulation

Based on the conditions of market equilibrium above, we conducted numerical simulation, and figured out an impact of each environmental factor on disaster recovery process by the comparative statics. Details of results of numerical simulation are to be reported in the conference. As a summary, under a certain set of parameters, we found that 1) if the social ties in the community are strong, the amount of labor that households engage in the community work increases, and then, the outflow of labor to Region 2 is decreased and the reconstruction of the affected region gets accelerated, 2) if the damage to the physical assets is large, the market price of the physical assets increases because of an increase in recovery demand for reconstruction, resulting in an increase of the Gross Regional Products (GRP). On the other hand, 3) if industries are damaged by a disaster and their productivity decreases, they cannot employ large amount of labor and the economic recovery stagnates due to the outflow of labor, and then, physical assets such as residential houses stay unreconstructed for a long time. By the comparative statics, we obtained some results that were consistent with phenomena that were reported in previous studies. Finally, as a policy implication regarding countermeasures that should be promoted for resiliency of regional economy; 1) transportation service should be provided so that migrant workers can easily return to their home town when it is damaged by disaster, 2) the regional risk of industries should be shared and diversified by firms in a region to mitigate households' migration behaviors that intend risk diversification at household's level, 3) disaster preventive investment in infrastructure for production should be provided at sufficient level.

4. CONCLUSION

This study formulated the simple mathematical model that can describe both recovery and decline process with a focus on rural-urban labor migration, and then, analyzed the influence of various factors of a regional economy on the disaster reconstruction by the numerical simulation. It was figured out that parameters related to a social community network give a crucial impact on the economic resiliency of the affected region.

The future tasks of the study are to include 1) the subsistence constraint of households in the model, which will make a role of the mutual insurance system more effective, 2) expansion of the model into the dynamic one where we analyze the changing process of economy of the affected region and obtain some insight on phenomena caused by the appearance or disappearance of links of social network, and 3) calibration of parameters with real data so that the model can re-create what really happened in some affected region in the past.

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