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Economic Impacts of Disasters Taking into Account the Costs of Substitution of Intermediate Goods

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***Abstract*—This paper focuses on the cost of substitution of intermediate goods and investigates how it affects macroeconomic dynamics after a natural disaster. This paper developes a macroeconomic model to show that the cost of substitution of intermediate goods is an important factor for expanding economic loss by inducing the "cascade effect." In addition, it illustrated that the cost of substitution can affect not only the amount of economic loss but also economic recovery speed.**

***Index Terms*—Natural disaster, Economic impact, Cost of substitution, Cascade effect**

I. Introduction

There have been a lot of efforts to develop regional economic models for estimation of economic impacts of natural disasters in the last decades (e.g. [1][2][3][4]). These literature mainly focused on short-term impacts, like lifeline disruption. On the other hand, many empirical surveys of natural disasters have pointed out that the negative impact on the GDP is not large when the reconstruction process is taken into account (e.g.[5][6][7]).

However, in reality, capital inflow from other regions for the reconstruction of capital stock can induce an increase in the amount of external debt. It can affect the economy negatively in the long run, even after the flow of the economy (GDP) recovers. Therefore, in order to measure the economic impact as a whole, the reconstruction process and its long term effect should be investigated by taking into account the effect of external debt. Nakano and Tatano [8] developed a dynamic macroeconomic model to illustrate that household consumption decreases in the long run due to an increase in external debt caused by a sudden disaster.

In addition, Nakano and Tatano [8] pointed out that the "cascade effect" is a crutial component of the economic losses of natural disasters, and they modeled the cascade effect. However, they [8] did not clarify what factors induce the cascade effect.

This paper shows that one of the factors involved in the cascade effect is the cost of substitution of intermediate goods, which is one of the main aims of this paper. If an intermediate goods sector is damaged, the supply of intermediate goods decreases, which can affect production in the final goods sectors. This relationship is called the "cascade effect." If firms can import substitutable intermediate goods alternatively from outside the affected region, the effect would be reduced. Therefore, the cost of substitution of intermediate goods is an important factor in examining the cascade effect.

In addition, this paper explains that the cost of substitution of intermediate goods can affect not only the amount of economic loss but also the economic recovery process. This paper focuses on the following structure. If the cost of substitution of intermediate goods is high, then economic loss will increase as a result of the cascade effect. In this case, the incentive for recovery would be high. On the other hand, if the cost of substitution is low, the cascade effect will not be induced. In this case, the incentive for recovery would be relatively low. Thus, the recovery process is also affected by the cost of substitution of intermediate goods.

This paper is organized as follows. In Section 2, we discuss a basic dynamic macroeconomic model that is an extension of Nakano and Tatano [8]. In Section 3, the economic growth path before a disaster. Section 4 investigates the economic impact of a disaster is considered. Two cases are compared so as to demonstrate the effect that the cost of substitutution has on both economic loss and economic recovery speed. In section 5, we summarize the results of this paper.

II. The Model

A. Basic Concept

This paper focuses on the cost for obtaining substitutable intermediate goods from outside the affected region in the aftermath of natural disasters. If a firm producing intermediate goods is damaged as a result of a disaster, the firms in the final goods sector may start to import the substitutable intermediate goods from outside the affected regions to prevent production rates from falling. It might cause an increase of cost for obtaining intermediate goods because it would be necessary for the firms in the final goods sector to adjust some operation processes so as to adopt the new products. On the other hand, the affected firms in intermediate goods sector may make effort to provide their products by expanding the production of factories outside the affected region or by borrowing the facilities from companies outside the affected region. It might cause an increase of cost for production of the affected firm in the intermediate good sector because it would be necessary to transfer technology from the affected factories. These means that the price of intermediate goods, which are made available after the disaster by importing or obtaining them, might be higher than that before the disaster. Therefore, the cost of substitution can be expressed as the level of price at which products are imported from outside the affected region.

B. Preliminary Settings

As was the case with Nakano and Tatano [8], this paper assumes a country with two industrial sectors - one that produces intermediate good, herein referred to as the *intermediate good sector*, and the other that produces the final good for consumption, herein referred to as the *final goods sector*- and a representative household. The intermediate good sector provides intermediate good to the final good sector. The final consumption good is traded at the price p. The intermediate goods market is in perfect competition and is open. The main difference between this paper and that of Nakano and Tatano [8] is that the intermediate goods market is open. Intermediate good can be traded between countries. The capital market is open and the interest rate r is determined by equilibrium in the international market. The amount of capital of the country is smaller than that of the whole world so that its change cannot affect the world interest rate. In this case, the world interest rate r is an exogenous parameter to the country. The firm possesses the capital and the household possesses all the stocks of the firms. Firms give their residual cashflows, which is profit minus investment, to the household. If the investment exceeds the profit, firms obtain funds from the household. Firms are assumed not to borrow from the household. Population and labor are immobile between countries, and population movement is not considered. Fig.1 illustrates the outline of this model.

In this paper, the macroeconomic model is based on the dynamic optimization problem in continuous time (see Ramsey, [9]; Cass, [10]; Koopmans, [11]; Barro and Sala-i-Martin, [12]; Turnovsky, [13]).

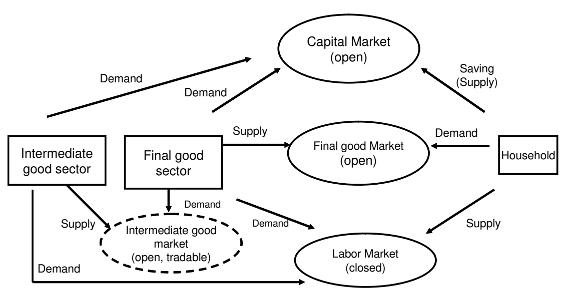

Fig. 1. Outline of the model

C. Formulation of the Intermdiate Good Sector

The intermediate good sector produces intermediate good with capital and labor. The price of capital is determined by equilibrium in the international market and the price is 1. The firm possesses its capital and decides the investment path. An adjustment cost[12] is necessary for investment. Production at time t is $Y_1(t)$; investment, $I_1(t)$; capital, $K_1(t)$; the price of the intermediate good, $q(t)$; wage rate, w; adjustment cost function, T; and employed labor, L_1. In the following context, t is ignored as long as it is not needed. The maximization problem is formulated as follows:

$$\max_{I_1,K_1} \int_0^\infty (qY_1 - I_1(1+T(I_1/K_1)) - wL_1)e^{-rt}dt, \tag{1}$$

$$s.t.\ \dot{K}_1 = I_1, \tag{2}$$

$$K_1(0) = given, \tag{3}$$

$$I_1 \geq 0. \tag{4}$$

Equation (2) is the capital accumulation equation. According to Hayashi[14], adjustment cost $I_1T(I_1/K_1)$ is assumed to be homogenous of degree one for investment I_1, capital K_1. Equation(4) describes the assumption that a capital once installed cannot be sold at the same price as at that during the installed time; this is referred to as the assumption of irreversibility. L_1 and w are fixed as the values at equilibrium, which is explained below. This maximization problem can be solved by the *maximum principle of optimal control*, using the Hamiltonian.

Note that the $F(K_1, L_1)$ denotes the production function and the $\mu(t)$ denotes the shadow price of capital in the intermediate good sector. If condition $I_1 \geq 0$ is ignored, the first order conditions for maximization are equation (2) and the following conditions:

$$q(\partial F/\partial K_1) + \dot{\mu} + (I_1/K_1)^2 T'(I_1/K_1) = \mu r, \tag{5}$$

$$-1 - T(I_1/K_1) - (I_1/K_1)T'(I_1/K_1) + \mu = 0, \tag{6}$$

$$\lim_{t\to\infty} K_1 \mu e^{-rt} = 0. \tag{7}$$

Equation (5) shows that the marginal revenue for capital accumulation is coincident to the interest rate. The first term of the left hand side in (5) is marginal products, the second is capital gain , and the third is increased revenue due to the reduction of the adjustment cost. Equation (6) implies that marginal cost is coincident to the shadow price. Equations (5) and (6) form a system of differential equations in which investment is a control variable and capital is a state variable. Now, let

$$F(K_1, L_1) = A_1 K_1^\alpha L_1^{1-\alpha}\ ,\ T(I_1/K_1) = (\gamma I_1)/(2K_1) \tag{8}$$

be the production and adjustment cost function, respectively. This implies that (5) and (6) can be rewritten as

$$qA_1\alpha K_1^{\alpha-1} L_1^{1-\alpha} + (-1+\mu)^2/(2\gamma) - \mu r = -\dot{\mu}, \tag{9}$$

$$\gamma I_1/K_1 = -1 + \mu. \tag{10}$$

D. Formulation of the Final Good Sector

The firm of the final good sector is assumed to produce with capital, intermediate good and labor. It maximizes the net present value of the cash flow. Let $Y_2(t)$ denote the production, $K_2(t)$ denote the capital, $Z_1^2(t)$ denote the intermediate input, $I_2(t)$ denote the investment, $\lambda(t)$ denote the shadow price of capital in the final good sector, and L_2 denote the labor employed. In the following context, t is ignored as long as it is needed. The maximization problem is formulated as follows:

$$\max_{I_2,Z_1^2,K_2} \int_0^\infty (pY_2 - qZ_1^2 - I_2 - wL_2)e^{-rt}dt, \quad (11)$$

$$s.t.\ \dot{K_2} = I_2, \quad (12)$$

$$K_2(0) = given, \quad (13)$$

$$I_2 \geq 0. \quad (14)$$

Note that the $H(K_2, Z_1^2, L_2)$ is the production function of the final good sector. If condition $I_2 \geq 0$ is ignored, the first order conditions of the maximization are equation (12) and the following conditions:

$$p(\partial H/\partial K_2) - \lambda r = -\dot{\lambda}, \quad (15)$$

$$-1 + \lambda = 0, \quad (16)$$

$$p(\partial H/\partial Z_1^2) - q = 0, \quad (17)$$

$$\lim_{t\to\infty} K_2 \lambda e^{-rt} = 0. \quad (18)$$

Equation (15) denotes that the marginal revenue for capital accumulation is coincident to the interest rate, which is claimed by the household. Equation (17) implies that the marginal product value is coincident to q. The solution to (16) is that the shadow price of capital is always 1. Let

$$H(K_2, Z_1^2, L_2) = A_2 K_2^\beta (Z_1^2)^{1-\beta-\eta} L_2^\eta \quad (19)$$

be the production function. Equation(15)(16)(17) in the first order conditions are transformed as follow;

$$pA_2\beta K_2^{\beta-1}(Z_1^2)^{1-\beta-\eta}L_2^\eta = r, \quad (20)$$

$$pA_2(1-\beta-\eta)K_2^\beta(Z_1^2)^{-\beta-\eta}L_2^\eta = q. \quad (21)$$

E. Household

The household consumes the consumption good with labor income, interest income from foreign assets, and dividend income, and it saves the residual as foreign assets. Let $As(t)$ denote foreign assets; $C(t)$, its consumption; ρ, the the time preference rate; $\pi_1(t)$, the dividend of the firm from the intermediate good sector; and $\pi_2(t)$, the dividend of the firm from the final good sector. The maximization problem of the household is formulated as follows:

$$\max_C \int_0^\infty u(C)e^{-\rho t}dt, \quad (22)$$

$$s.t.\ \dot{As} = wL + rAs + \pi_1 + \pi_2 - pC, \quad (23)$$

$$As(0) = given, \quad (24)$$

$$\lim_{t\to\infty} As(t)e^{-rt} = 0. \quad (25)$$

Equation (25) is a non Ponzi game (NPG) condition [12], which is a condition that limits the household from infinitely expanding its utility by borrowing. Dividends are the residual cashflows of the firms, that is, the firms' profit minus investment. It implies the following equation:

$$\pi_1 = qY_1 - I_1(1 + T(I_1/K_1)) - wL_1, \quad (26)$$

$$\pi_2 = pY_2 - qZ_1^2 - I_2 - wL_2. \quad (27)$$

In order to avoid extreme behavior of the model due to the assumption of an exogenous interest rate, we set $\rho = r$, which is similar to previous studies [15][13]. The first order condition is

$$-u''(C)\dot{C}/u'(C) = r - \rho. \quad (28)$$

We now assume $\rho = r$. The consumption is consistent.

III. Economic Growth Path before a Disaster

A. Existence of Equilibrium

$q_d(t)$ is the price in the domestic market if it is assumed that the firm in the final good sector would obtain all of the intermediate good from the intermediate good sector in the country. From (21) and the market clearing condition:

$$Y_1(t) = A_1K_1^\alpha L_1^{1-\alpha} = Z_1^2(t), \quad (29)$$

$q_d(t)$ is expressed by following equation:

$$q_d(t) = p(1-\beta-\eta)K_2(t)^\beta(A_1K_1(t)^\alpha L_1^{1-\alpha})^{-\beta-\eta}L_2^\eta. \quad (30)$$

On the other hand, q_{im} is the price if the final good sector imports intermediate good from foreign countries. q_{im} is determined exogenously and is constant. The firm in the final good sector chooses between importing intermediate good and obtaining it from the domestic intermediate good sector. Then, the firm prefers the lower price. Thus, $q(t)$ is determined by the following condition:

$$q(t) = \min\{q_d(t), q_{im}\}. \quad (31)$$

In this paper, we assume that the economy starts from a point satisfying the following condition during the economic growth before a disaster:

$$q_d(t) \leq q_{im}. \quad (32)$$

This means K_1, K_2 satisfies condition (32) at $t = 0$. In this case, the final good sector obtains all of the intermediate good from the intermediate good sector in the country. Then, the intermediate market is clear in the country and the price of the intermediate good is determined endogenously. This case is the same situation as the case of a closed intermediate good market, which Nakano and Tatano [8] investigated. Nakano and Tatano [8] showed that this model converges to a steady state. In the following context, the value of the variables in the steady state is expressed by adding '*'. In addition, we assume that $q^* \leq q_{im}$.

It is assumed that employed labor and the wage rate in each sector are constant. Their values are fixed by the following conditions. First, the wage rate is coincident to the marginal product value of labor in both sectors in the steady state, that is, the following equation is realized at the steady state:

$$q(\partial F/\partial L_1) = p(\partial H/\partial L_2) = w. \quad (33)$$

Second, the labor market is cleared, that is, the following condition is satisfied:

$$L_1 + L_2 = L. \quad (34)$$

B. Consumption and Savings

The assumption $\rho = r$ implies that the optimum consumption path is constant consumption. Integrating the budget constraint (23) and NPG condition (25) provides the following consumption level C_0:

$$C_0 = \frac{r}{p}\int_0^\infty (pY_2 - qZ_1^2 + qY_1 - \Phi(I_1, K_1) - I_2)e^{-rt}dt + \frac{r}{p}As(0). \quad (35)$$

Note that the amount of investment including the adjustment cost $I_1(1 + T(I_1/K_1))$ is substituted by $\Phi(I_1, K_1)$.

The household saves the amount of income that remains after consumption is subtracted as foreign assets. The amount of savings is derived from (23) and (35).

C. Investment

Investment by the intermediate good sector is determined by the condition in (10). Investment by the final good sector is determined by the condition in (20) and (29) according to the value of K_1. As is typically the case with open economic growth models, investment is determined independent of savings. Note that irreversibility of investment is assumed.

IV. Economic Impacts of a Natural Disaster

A disaster is assumed to occur when the economy is in the steady state, at $t = \tau$. Disaster is assumed to be an unexpected shock. Capital stock is assumed to decrease in the intermediate sector in a discrete manner as a result of the disaster. After the disaster, household and firms replan the optimal path of consumption, investment, and capital. The economy restarts at $t = \tau^+$ immediately after the disaster. In this section, economic restoration processes after the disaster are compared under different conditions of the cost of substitution of intermediate good.

There are two kinds of economic restoration processes. The economic restoration process differs with regard to whether or not (32) is satisfied at $t = \tau^+$. This is determined by q_{im}, that is, the cost of substitution of the intermediate good, as long as the degree of damage is the same. If the cost of substitution is so high that (32) is satisfied at $t = \tau^+$, the final good sector would not import intermediate good from outside the affected region. If the cost of substitution is so low that (32) is not satisfied at $t = \tau^+$, the final good sector would import intermediate good alternatively from outside the affected region. The two cases are investigated in detail below.

A. Case 1: Higher Cost of Substitution

First, we consider the case in which cost of substitution is so high- that is, where q_{im} is high- that (32) is satisfied at $t = \tau^+$. In this case, the final good sector would not import any intermediate good. Thus, the market clearing condition (29) is satisfied. If the irreversibility condition is ignored, the first order conditions and the market clearing condition of the intermediate good market are (2), (9), (10), (13), (15), (18), (20), and (21). The restoration process is determined by these conditions and the initial values. However, in fact, the production of the intermediate good sector cannot recover immediately due to the adjustment cost. Because the capital of the final good sector is not damaged under our scenario, the amount of capital of the final good sector is in excess at the optimum level and its marginal productivity declines. This implies that the shadow price of the capital of the final goods sector falls below 1. In this case, the optimal decision is to sell the excess capital, that is, undertake negative investment. If the adjustment cost for negative investment is zero, the final goods sector sells the excess capital in order to adjust the amount of capital to the optimal value. However, once capital is installed, it is difficult to sell at the same price. This paper assumes that a capital once installed can be sold at a price much lower than that at which it was purchased. In this case, the final goods sector does not sell the installed capital and keeps it as it is, that is, $I_2 = 0$. This case is similar to the restoration process stated by Nakano and Tatano [8]. Nakano and Tatano [8] showed that these conditions derive differential equations of K_1, μ , and the economy converges to a steady state.

Fig.2 illustrates an numerical simulation result of ecnomic restoration process in this case. The parameters are set as α=0.75, β=0.65, $\eta = 0.25$, γ=0.5, p=1000, $r = 0.04$, $L = 1$, $A_1 = 20$, $A_2 = 1$. 99 % of capital of the intermediate good sector is assumed to be damaged. The Time-Elimination Method (Mulligan and Sala-i-martin, [16]) is used for the calculation. Panel (a) and (b) in Fig.2 illustrate capital recovery process in the intermediate good sector and final good sector, respectively. The horizontal axis is time after a disaster. The value is normalized by the steady state value. Panel (b) shows that capital in the final good sector is not damaged in the scenario and it is constant even after the disaster. Panel (c) and (d) in Fig.2 illustrate the production recovery process in the Intermediate good sector and the GDP recovery process, respectively. Panel (d) demonstrates that production of the final good sector, whose capital is not damaged, declines after the disaster. At the same time, from the market clear condition on the intermediate good, panel (d) also illustrates the GDP recovery process after the disaster. Panel (e) illustrates the restoration investment path in the intermediate good sector. Panel (f) in the Fig.2 demonstrates that price of the intermediate good rise after the disaster. It is induced by marginal productivity of intermediate good in final good sector rising. Panel (g) in the Fig.2 illustrates the household savings in foreign asset after the disaster. Panel (g) demonstrates that the household increases its debt after the disaster. This is because the household supplies the recovery funds to the intermediate good sector by borrowing. Panel (h) in the Fig.2 illustrates that the household consumption. Panel (h) demonstrates that the household consumption decreases even after the production recovers. This is because debt of the household increases.

B. Case 2: Lower Cost of Substitution

If q_{im} is sufficiently low - that is, if the cost of substitution is low- (32) can not be satisfied at $t = \tau^+$ even if the capital damage is the same as case 1. In this case, (31) derives $q(t) = q_{im}$ immediately after the disaster. The final good sector in

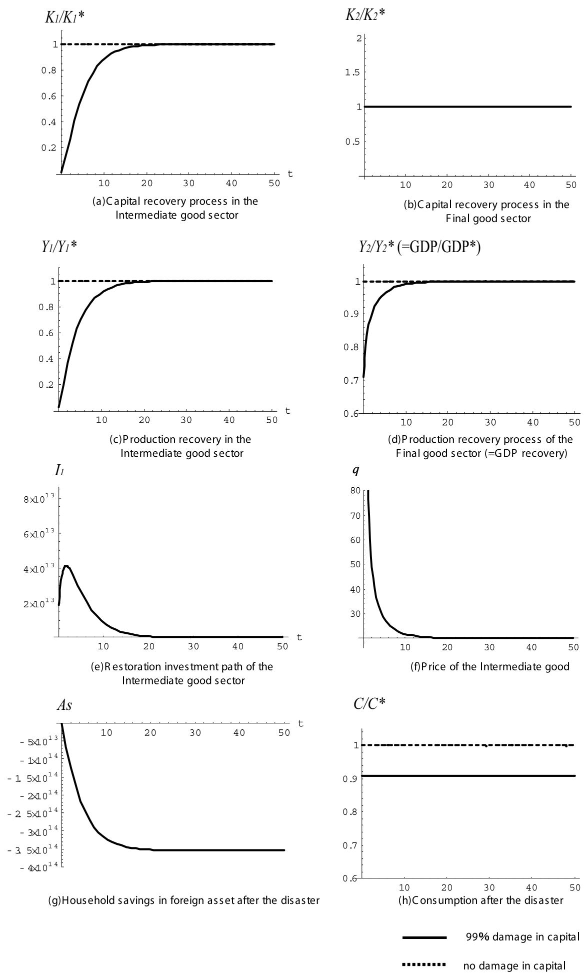

Fig. 2. Economic restoration process in case 1

the country decides to import intermediate good from foreign countries. If the irreversibility condition is ignored, the first order conditions are (2), (9), (10), (12), (15), (18), (20), and (21) under the condition, $q(t) = q_{im}$. Solving (20) and (21) with regard to K_2 and Z_1^2 derives

$$K_2 = (pA_2\beta/r)^{1/\eta}\,(r(1-\beta-\eta)/(q\beta))^{(1-\beta-\eta)/\eta}\,L_2, \quad (36)$$

$$Z_1^2 = (pA_2\beta/r)^{1/\eta}\,(r(1-\beta-\eta)/(q\beta))^{(1-\beta)/\eta}\,L_2. \quad (37)$$

From (36), the final good sector wants to decrease the amount of capital from K_2^* because q_{im} is higher than q^*. Thus, as in case 1, the irreversibility condition is constrained; that is $I_2 = 0$. Thus, the economy starts to restore according to (2), (9), (10), (21), and $K_2 = K_2^*$. Equations (2), (9), (10), and $q(t) = q_{im}$ derive

$$\dot{K}_1/K_1 = (-1+\mu)/\gamma, \quad (38)$$

$$\dot{\mu} = -q_{im}A_1\alpha K_1^{\alpha-1}L_1^{1-\alpha} - (-1+\mu)^2/(2\gamma) + \mu r. \quad (39)$$

In the following context, let K_1^{**} and μ^{**} denote the value of K_1 and μ derived by substituting $\dot{K}_1 = \dot{\mu} = 0$ for (38)(39). $\mu^{**} = 1$.

Linearizing (38) and (39) around K_1^{**} and μ^* derives

$$\begin{pmatrix} \dot{K}_1 \\ \dot{\mu} \end{pmatrix} = \begin{pmatrix} 0 & \frac{K_1^{**}}{\gamma} \\ \Omega & r \end{pmatrix} \begin{pmatrix} K_1 - K_1^{**} \\ \mu - \mu^{**} \end{pmatrix}. \quad (40)$$

Note that $\Omega = q_{im}A_1\alpha(1-\alpha)(K_1^{**})^{\alpha-2}L_1^{1-\alpha} > 0$. Thus, (38) and (39) have a steady state (K_1^{**}, μ^{**}) and K_1 and μ converge to it.

As capital is restored by investment, K_1 increases and q_d is reduced. Eventually, (32) comes to be satisfied. In the following context, K_1^{***} is the value of K_1 satisfying $q_d = q_{im}$. Once (32) comes to be satisfied and K_1 reaches K_1^{***}, the final good sector stops importing intermediate good, starts to obtain it from domestic firms and the economy starts to grow on the basis of the same equations as in case 1.

Fig.3 illustrates a numerical simulation result of the economic restoration process in this case. To simplify the simulation, an extreme case is considered in this paper, in which the cost of substitution is zero , that is, $q_{im} = q^*$. Other parameters and the scale of damage in capital are the same as case 1. Panel (c) and (d) in Fig.3 illustrate the production recovery process in the intermediate good sector and the GDP recovery process, respectively. A comparison of the panel of the GDP recovery process in Fig.2 and that in Fig.3 demonstrates the following facts. In the scenario where 99 % of capital is damaged, the decline of the GDP is larger in case 1 than case 2 immediately after the disaster. In other words, it is illustrated that if the cost of substitution of the intermediate good is high, the cascade effect is induced and the GDP decreases more severely. On the other hand, the recovery speed of the GDP is higher in case 1. This is because a larger amount of investment is made in the intermediate good sector, and the capital of the sector recovers more quickly in case 1, as illustrated by panels (a) and (e) in Fig.3. This can be explained on the basis of the following structure. Because q is higher in case 1 immediately after the disaster, the value of the marginal product of capital in the intermediate good sector is higher in case 1. This promotes recovery investment in case 1.

In other words, this can be explained as follows. If the cost of substitution of intermediate good is high, the incentive for the recovery of the intermediate good is strong because economic loss can be enlarged by the cascade effect. On the other hand, if the cost of substitution of the intermediate good is low, the cascade effect would not be induced and the total economic loss would not be relatively large. Thus, the incentive for the recovery of the intermediate good sector is not relatively strong in this case. Thus, it is demonstrated that the cost of substitution can affect not only the amount of economic loss but also economic recovery speed.

V. CONCLUSION

This paper developed a dynamic macroeconomic model taking into account intermediate goods. This paper focused on the cost of substitution of intermediate goods and investigated

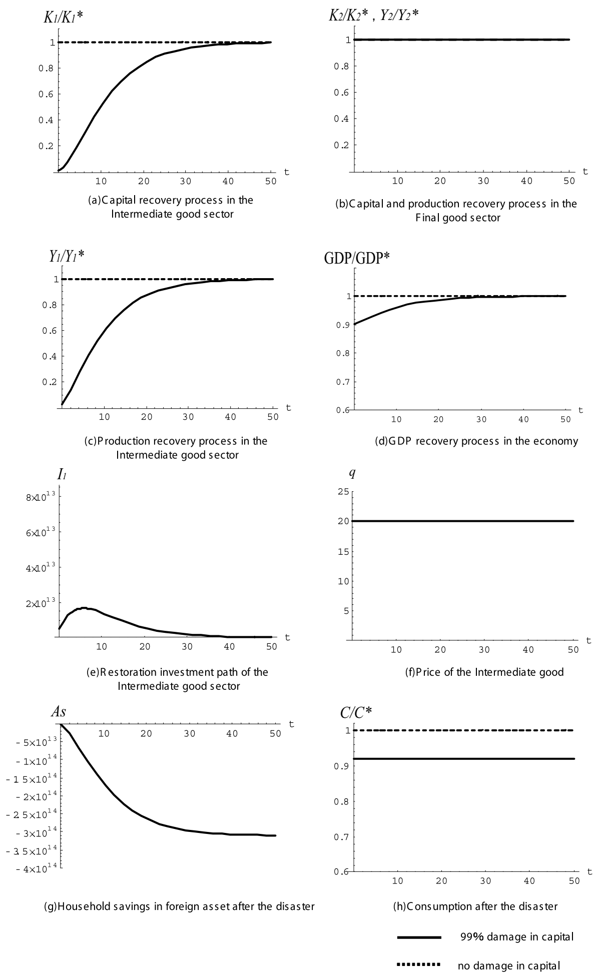

Fig. 3. Economic restoration process in case 2

how it affects macroeconomic dynamics after a natural disaster. This paper showed that the cost of substitution of intermediate goods is an important factor for expanding economic loss because it induces the "cascade effect". In addition, it was illustrated that the cost of substitution can affect not only the amount of economic loss but also economic recovery speed. This is because the value of the marginal product of capital in the intermediate goods sector would be higher if the cost of substitution is high. In other words, this can be explained as follows: if the cost of substitution of intermediate goods is high, the incentive for the recovery of the intermediate goods is strong because economic loss can be increased by the cascade effect. On the other hand, if the cost of substitution of the intermediate goods is low, the cascade effect would not be induced and the total economic loss would not be relatively large. Thus, the incentive for the recovery of the intermediate goods sector is not relatively strong in this case.

In this paper, numerical simulation was conducted for two simple cases. As part of a future research endeavor, it is necessary to investigate how the economic restoration process is determined according to different situations of the cost of substitution.

The main aim of this paper is just to illustrate our basic idea. The settings and assumptions are too simple to illustrate any actual regional economy. The proposed model in this paper cannot estimate any actual regional economic recovery process. As part of future research, it is necessary to estimate the actual regional economic recovery process by developing some regional economic models like CGE model.

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