MEASURING ECONOMIC IMPACT OF A DISASTER WITHOUT DOUBLE COUNTING: A THEORETICAL ANALYSIS

H. Tatano[1] and K. Nakano[2]

[1] *Professor, Disaster Prevention Research Institute, Kyoto University, Uji. Japan*
[2] *Ph.D Candidate, Graduate School of Informatics, Kyoto University, Kyoto, Japan*
Email: tatano@imdr.dpri.kyoto-u.ac.jp, nakano@imdr.dpri.kyoto-u.ac.jp

ABSTRACT :

This paper proposes a methodology for consistent measurement of economic losses caused by natural hazards. A two-sector economic growth model is used to describe recovery process after a disaster. It is shown that sum of the differences of discounted cash-flow in industrial sectors is consistent measure as total economic loss. It consists of *Foregone Net Revenue* and *Restoration Investment*. This paper also proposes how to measure the cascade effect, which is the spillover effect of economic impacts induced by mutual relation ships between industrial sectors A numerical simulation demonstrates how much cascade effect enlarges the total economic loss and the incidents

KEYWORDS: double counting of economic loss, cascade effect, economic growth model

1. INTRODUCTION

As to avoid double counting economic losses caused by disasters (Rose, 2004), it is important to find the way to measure total economic losses which includes economic effects of lost values of stocks and recovery investment in a consistent way. In the past studies (Tatano et al. 2000, Nakano et al 2007), authors showed that net present value of the difference of the cash flows between with and without a disaster is a consistent measure of the total economic losses over industrial sectors. This paper investigates the measure of the total economic loss in an entire economy which includes industrial sectors, households and outside of the region by use of a economic growth model. The methodology can take into account "cascade effect", which is the spillover effect of economic impacts induced by mutual relation ships between industrial sectors.

The paper is structured as follows: The economic growth model with two industrial sectors is formulated and economic growth path before a disaster is investigated in section 2. An open economic model with two industrial sectors is developed by Turnovsky and Sen (1995). The model developed in this paper deals with intermediate good, which have not been observed in any previous researches. In section 3, a disaster is assumed as unexpected shock and its impacts to the economy are investigated. By comparison of the objective function between cases with and without disaster, a methodology for consistent measurement of economic loss is investigated in section 3. How to measure cascade effect separately is investigated and a numerical simulation demonstrates how much cascade effect can enlarge the total economic loss in section 4.

2. FORMULATION OF AN ECONOMIC GROWTH MODELS WITH TWO SECTORS

2.1. Preliminary Settings

It is assumed that an economy has two industrial sectors and a household sector. The first industrial sector produces an intermediate good (the intermediate goods sector) and the second produces an final consumption good (the final goods sector). The final good sector inputs intermediate good from the domestic market. Intermediate good market is assumed to be in perfect competition and closed in the country. It is assumed that final consumption good market is open to the competitive international market and its production share of the economy is small. The assumption means that the price of the final consumption good is traded at fixed price p determined in the competitive international market. The capital market is open and the interest rate r is determined by equilibrium in the international market. The amount of the capital of the economy is much smaller than that of the whole world so that its change cannot affect the world interest rate. Labor is assumed to be immobile between countries.

2.2. Formulation of the Intermediate Good Sector

The maximization problem of the intermediate good sector is to choose capital (K_1) and labor (L_1) to maximize the net present value of the cash flows. Let Y_1 denote the production of the intermediate good sector and $F(K_1, L_1)$ denote its production function which is assumed to be constant return-to-scale. Adjustment cost (Barro and Sala-i-Martin, 2004) is assumed to be necessary for investment. The maximization problem for the intermediate good sector is the following:

$$\max \int_0^\infty (qF(K_1, L_1) - I_1(1 + T(I_1 / K_1)) - wL_1)e^{-rt} dt, \tag{2.1}$$

$$\text{s.t.} \quad \dot{K}_1 = I_1, \tag{2.2}$$

$$K_1(0) = given, \tag{2.3}$$

$$I_1 \geq 0, \tag{2.4}$$

where q, w and r are the price of the intermediate good and wedge rate of labor, and I_1 denotes investment for the sector. The adjustment cost is formulated in the Eqn. 2.1 as the term $I_1 \cdot T(I_1 / K_1)$. According to Hayashi (1982), adjustment cost $I_1 \cdot T(I_1 / K_1)$ is assumed to be homogenous of degree one for investment I_1 and capital K_1. Eqn. 2.2 is the capital accumulation equation. In the equation, we do not deal with depreciation of capital because the restoration assumed in this paper takes no more than several months and has no significant effects on the restoration process even if depreciation is neglected. Eqn. 2.3 is the initial value condition. Eqn. 2.4 describes the assumption that a capital once installed cannot be sold in the capital market; that is the assumption of irreversibility investment. L_1 and w are fixed as the values at equilibrium.
The first order conditions of the optimality are the following:

$$q\partial F / \partial K_1 + \dot{\mu} + (I_1 / K_1)^2 T'(I_1 / K_1) = \mu r, \tag{2.5}$$

$$-1 + T(I_1 / K_1) - (I_1 / K_1)T'(I_1 / K_1) + \mu = 0, \tag{2.6}$$

$$\lim_{t \to \infty} K_1 \mu e^{-rt} = 0. \tag{2.7}$$

where μ is the shadow price of capital K_1. To derive the first order conditions, the irreversibility condition is ignored. It will be taken into account in the investigation of the transitional dynamics after a disaster.
Eqn. 2.5 implies that marginal revenue for capital accumulation is coincident to the interest rate. The first term of the left hand side in the Eqn. 2.5 is marginal product value, the second is capital gain and the third is increased revenue due to reduction of the adjustment cost. Eqn. 2.6 implies that marginal cost is coincident to the shadow price. Eqn. 2.7 is the transversality condition.

2.3 Formulation of Final Good Sector

The final goods sector chooses capital K_2, intermediate input Z_1^2, and the investment I_2 to maximize its net present value of the cash flow. Note that Y_2 and L_2 are the production and labor employed in the final goods sector. Production function of the final good sector is formulated as $H(K_2, Z_1^2, L_2)$, which is assumed constant return-to-scale. Maximization problem of the final good sector is formulated as,

$$\max \int_0^\infty (pY_2 - qZ_1^2 - I_2 - wL_2)e^{-rt} dt, \tag{2.8}$$

$$\text{s.t.} \quad \dot{K}_2 = I_2, \tag{2.9}$$

$$K_2(0) = given, \tag{2.10}$$

$$I_2 \geq 0. \tag{2.11}$$

The first order conditions of the maximization are derived in the same manner with the indermediate good sector:

$$p\partial H / \partial K_2 = r, \tag{2.12}$$

$$p\partial H / \partial Z_1^2 = q, \tag{2.13}$$

$$\lim_{t \to \infty} K_2 \lambda e^{-rt} = 0. \tag{2.14}$$

Where λ is the shadow price of capital K_2. Eqn. 2.12 means that marginal revenue for capital accumulation is equal to the interest rate. Eqn. 2.13 implies that marginal product value of intermediate input is equal to *q*. Eqn. 2.14 is the transversality condition.

2.4 Household

A representative household is assumed. The household choose the consumption C and saving in foreign bond As to maximize the intertemporal utility. The household earns from the labor, foreign bond, and the dividend of the firm. Let ρ be the time preference rate, π_1 be the dividend of the firm of the intermediate goods sector and π_2 be the dividend of the firm of the final goods sector. The intertemporal utility maximization problem of the household is formulated as:

$$\max \int_0^{\infty} u(C)e^{-rt}dt\,, \tag{2.15}$$

$$\text{s.t.} \quad A\dot{s} = wL + rAs + \pi_1 + \pi_2 - pC\,, \tag{2.16}$$

$$As(0) = given\,, \tag{2.17}$$

$$\lim_{t\to\infty} As(t)e^{-rt} = 0\,. \tag{2.18}$$

Eqn. 2.18 is a Non Ponzi Game (NPG) condition, which is the condition that limits the household from expanding the utility infinitely by borrowing. In order to avoid extreme behavior of the model due to the assumption of an exogenous interest rate, we set $\rho = r$ as in previous researches; see Turnovsky (1997). The first order condition is:

$$-u''(C)\dot{C}/u(C) = r - \rho\,. \tag{2.19}$$

The outline of the model is summarized in Figure 1.

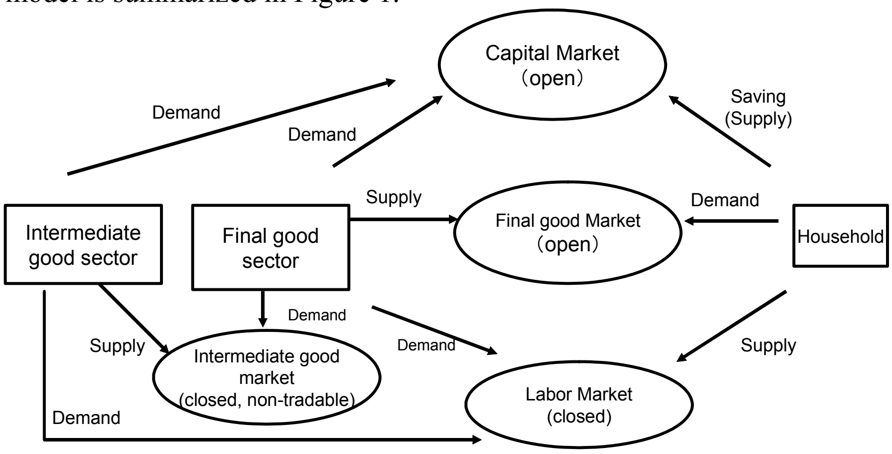

Figure 1 Outline of the model

2.5. Economic Growth Path before a Disaster

2.5.1 Steady state

The production function and adjustment cost function are assumed as:

$$F(K_1, L_1) = A_1 K_1^{\alpha} L_1^{1-\alpha}\,,\ H(K_2, Z_1^2, L_2) = A_2 K_2^{\beta}(Z_1^2)^{1-\beta-\eta} L_2{}^{\eta}\,,\ T(I_1/K_1) = (\gamma I_1)/(2K_1)\,. \tag{2.20}$$

The first order conditions of the industrial sectors consist of Eqn. 2.5-2.7, 2.11-2.14. These conditions and the market clearing condition for the intermediate goods give the Eqn. 2.2, 2.9, transversality conditions(Eqn.2.7, 2.14), and following differential equations:

$$I_1/K_1 = (-1+\mu)/\gamma \tag{2.21}$$

$$pB\beta K_2{}^{\beta-1} K_1{}^{\alpha(1-\beta-\eta)}\Theta = r \tag{2.22}$$

$$pB\alpha(1-\beta-\eta)K_2{}^{\beta} K_1{}^{\alpha(1-\beta-\eta)-1}\Theta + (-1+\mu)^2/2\gamma - \mu r = -\dot{\mu} \tag{2.23}$$

Note that $B = A_1^{1-\beta-\eta}A_2$ and $\Theta = L_1^{(1-\alpha)(1-\beta-\eta)}L_2$. By setting $\dot{K}_1 = 0$ and $\dot{\mu} = 0$, capital, intermediate good price and other variables in the steady state are obtained. Shadow price of the capital in the intermediate sector is equal to 1 in the steady state. It is assumed that employed labor and wage rate of each sector is constant at the value in the steady state. In equilibrium of this labor market, wage rate is equal in the both sectors and marginal product value is equal to the wage rate. In the previous study, authors (2008) demonstrated the steady state and saddle path exists in this model.

2.5.2 Consumption and Savings

The assumption $\rho = r$ implies that the optimum consumption path is constant consumption. Integrating the budget constraint and NPG condition gives the consumption level C_0 as:

$$C_0 = \frac{r}{p}\left(As(0) + \int_0^\infty (pY_2 - I_1 T(I_1 / K_1) - I_2)e^{-rt} dt \right). \tag{2.27}$$

Saving is derived as follows by using budget constraint and Eqn. 2.27:

$$A\dot{s} = wL + \pi_1 + \pi_2 - r\int_0^\infty (wL + \pi_1 + \pi_2)e^{-rt} dt . \tag{2.28}$$

This implies that the household saves when income exceeds consumption, determined by the present value of future income and drain upon it otherwise.

2.5.3 Investment

Investment of intermediate goods sector is determined by the Eqn. 2.21. Investment of final goods sector is determined by the Eqn.2.22 according to the value of K_1. As usual result of open economic growth models, Investment is determined independently from saving. Note that irreversibility of investment is assumed.

2.5.4 Transitional Dynamics

Once initial capital $K_1(0)$, $K_2(0)$ is given, μ is determined by saddle point path. Then investment of intermediate goods sector is determined by the Eqn. 2.21. In the case of $K_1(0) < K_1^*$, for example, capital is accumulated by investment and the production increases. This leads to the decline of μ and reach the steady state finally.

3. CONSISTENT MEASUREMENT OF ECONOMIC LOSSES CAUSED BY NATURAL HAZARDS

3.1. Economic Impact of a Disaster

A disaster event is assumed to occur when the economy is in its steady state. Disaster is assumed as unexpected shock. Capital stock is assumed to be decreased in the intermediate sector in a discrete way by a disaster event. After the disaster, household and firms replan the optimal path of consumption, investment and capital. If the irreversibility condition is ignored, first order conditions and the market clearing condition of the intermediate goods market gives Eqn.2.2, 2.9, transversality conditions (Eqn.2.7, 2.14), and Eqn.2.21-23. Restoration process is determined by these conditions and initial values. However, in fact, the production of the intermediate sector can not 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 of the optimum level determined by the Eqn. 2.20 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 negative investment. If the adjustment cost for negative investment is zero, the final goods sector sells the excess capital 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 the price at which it was purchased. In this case, the final goods sector does not sell the capital installed and keeps it as it is; that is $I_2 = 0$. Then the first order conditions are the transversality conditions (Eqn.2.7, 2.14), capital accumulation equations (Eqn.2.2, 2.9), Eqn.2.21, and the following equation:

$$pB\alpha(1-\beta-\eta)(K_2^*)^\beta K_1^{\alpha(1-\beta-\eta)-1}\Theta + (-1+\mu)^2 / 2\gamma - \mu r = -\dot{\mu} . \tag{3.1}$$

Authors(2008) investigated the transitional dynamics after a disaster with phase diagram. Due to the damage of capital of the intermediate goods sector, productivity of capital of the sector rises. It leads to the rise of the shadow price of capital of the sector and restoration investment is induced. Capital and production recover by the investment. Delay of the recovery of the intermediate sector leads to not only the decrease of the production of the intermediate good sector but also that of the final good sector. Figure 3 shows a numerical simulation for a restoration process after a disaster. The parameters are set as α=0.75, β=0.65, η=0.25, γ=10, p=1000, L=1, A_1 = 20, A_2= 1. The cases in which 99 % and 20% of capital of the intermediate good sector is damaged are investigated. The Time-Elimination Method (Mulligan and Sala-i-Martin, 1993) is used for the calculation. Panel (a) and (b) in Figure.3 show 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.

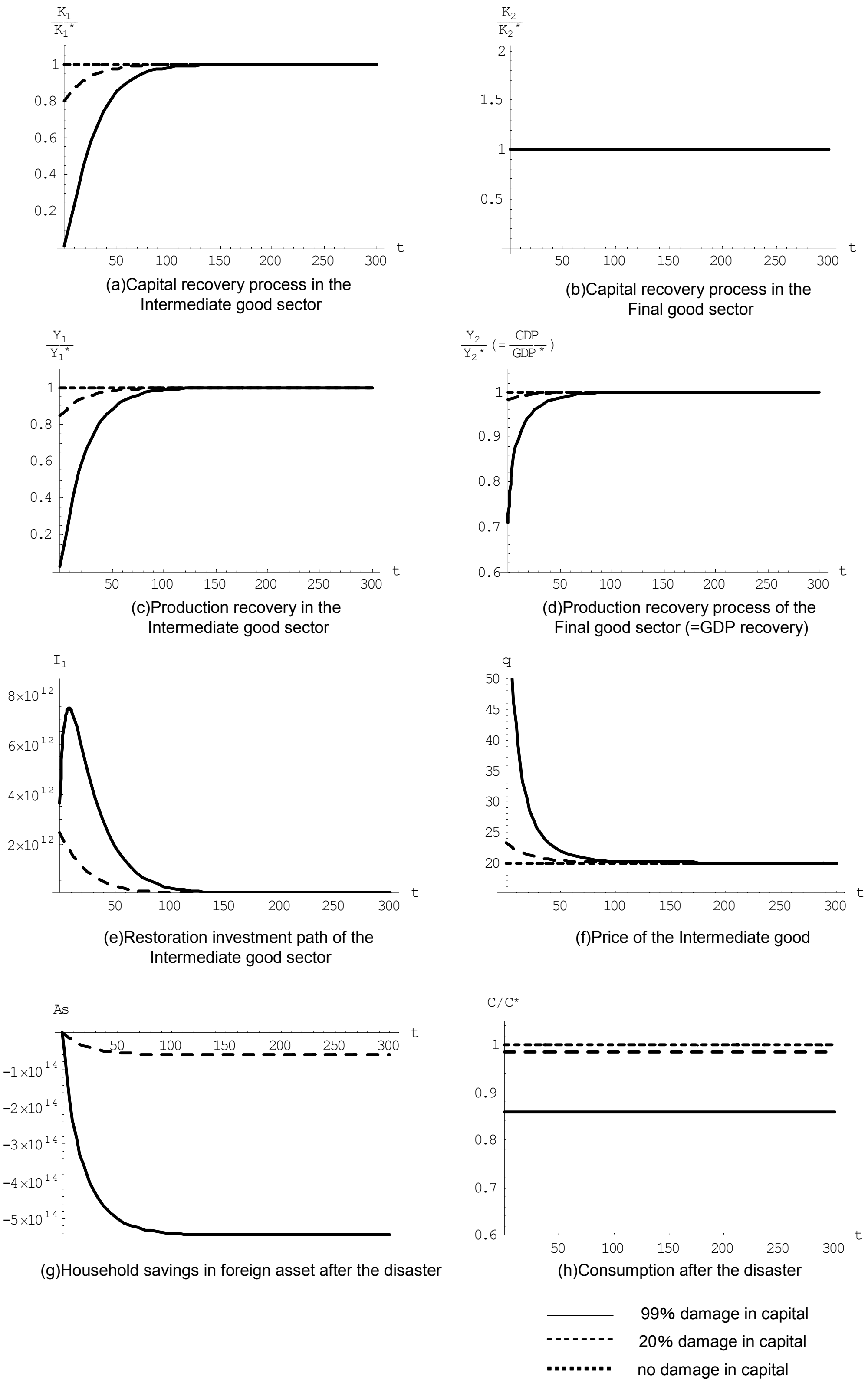

Figure 3 A numerical simulation for recovery process after a disaster

Panel (c) and (d) in Figure.3 show the production recovery process in the Intermediate good sector and the final good sector, respectively. Panel (d) shows that production of the final good sector, whose capital is not damaged, declines after the disaster. Therefore, it is demonstrated that cascade effect is induced in this model. At the same time, from the market clear condition on the intermediate good, panel (d) also shows the GDP recovery process after the disaster. Panel (e) shows the restoration investment path in the intermediate good sector. Panel (e) shows that peak of the restoration investment is delayed in the case that capital is greatly damaged (99% damage in capital in Figure.3). This delay response depends on the shape of the adjustment cost function. Panel (f) shows 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) shows that the household increase debt for foreign countries after the disaster. This is because the household supplies the recovery funds to the intermediate good sector by borrowing. This leads to the decrease of the consumption below the before level eternally. Panel (h) shows that the household consumption decrease even after the production recovers.

3.3 Consistent Measurement of Economic Losses

Losses of each industrial sector can be measured by difference of the discounted cash flows between the cases with and without a disaster. Let V_1, V_2 denote the value of the firm of intermediate goods sector and final goods sector evaluated at the time disaster occurs. Let the suffix of '*' indicate the variables in the case with disaster and '^' indicate the variables in the case without disaster. Losses of each industrial sector can be described as:

$$V_1^* - \hat{V}_1 = \int_\tau^\infty (\pi_1^* - \hat{\pi}_1) e^{-rt} dt \;=\; \int_\tau^\infty (q^* Y_1^* - \hat{q}\hat{Y}_1 + \hat{I}_1(1 + T(\hat{I}_1 / \hat{K}_1))) e^{-rt} dt\,, \tag{3.2}$$

$$V_2^* - \hat{V}_2 = \int_\tau^\infty (\pi_2^* - \hat{\pi}_2) e^{-rt} dt \;=\; \int_\tau^\infty (pY_2^* - q^*(Z_1^2)^* - (p\hat{Y}_2 - \hat{q}\hat{Z}_1^2)) e^{-rt} dt\,. \tag{3.3}$$

Table 1 shows that losses of each industrial sector consist of *Foregone Net Revenue* and *Restoration Investment*. Net revenue means revenue minus costs of intermediate input. On the other hand, the consumption of household decreases as the dividend income decreases, and it leads to the decline of the household's utility. Consumption of the household decreases every period by

$$\frac{r}{p}\int_\tau^\infty (\pi_1^* - \hat{\pi}_1 + \pi_2^* - \hat{\pi}_2) e^{-r(t-\tau)} dt\,. \tag{3.4}$$

Decline of the household utility can be evaluated by Compensating Variation (CV). To keep the same utility after the disaster, it is necessary and sufficient to compensate the value of the decrease of the consumption every term. The present value of the loss of the household is coincident to the sum of the loss of the industrial sectors. This indicates that effect of the decrease of capital in the intermediate sector arrives at the household sector. Thus, it can be concluded that the total economic loss caused by natural disaster can be measured in industrial sector, occurrence side, or household sector, arrival side.

Table 1 Consistent measurement of economic losses after a disaster

Industry	**Household**
Intermediate goods sector	Decline of Utility
Foregone Net Revenue	$V_1^* - \hat{V}_1 + V_2^* - \hat{V}_2$
$\int_\tau^\infty (q^* Y_1^* - \hat{q}\hat{Y}_1) e^{-r(t-\tau)} dt$	
Restoration Investment	
$\int_\tau^\infty \hat{I}_1(1 + T(\hat{I}_1 / \hat{K}_1)) e^{-r(t-\tau)} dt$	
Final goods sector	
Foregone Net Revenue	
$\int_\tau^\infty (pY_2^* - q^* Z_1^{2^*} - (p\hat{Y}_2 - \hat{q}\hat{Z}_1^2)) e^{-r(t-\tau)} dt$	
Total $V_1^* - \hat{V}_1 + V_2^* - \hat{V}_2$	$V_1^* - \hat{V}_1 + V_2^* - \hat{V}_2$

If total economic loss is measured in industrial sector, it is necessary and sufficient to sum up the losses of the each industrial sector. It is important point to measure the foregone net revenue in the final good sector, which is caused by cascade effect, even though it is not damaged physically. Table 1 shows what should be measured in each sector for consistent measurement of total economic loss in the whole economy:

4. MEASURING CASCADE EFFECT SEPARATELY

4.1 Mechanism Inducing Cascade Effect

Although the methodology investigated above can measure the total economic loss including cascade effect consistently, it cannot measure the impact of the cascade effect itself. A methodology to measure the cascade effect separately is investigated below. In the investigation above, cascade effect occurs because the intermediate good market is closed and the intermediate good cannot be transported alternatively from outside.
If the intermediate good market is open, final good sector can obtain the intermediate good from international market without any change of its price. In this case, the intermediate good price is determined by the equilibrium in the international market. The first order conditions are Eqn.2.21, transversality conditions (Eqn.2.7, 2.14), capital accumulation equations (Eqn.2.2, 2.9) and following equations:

$$q^* A_1 \alpha K_1^{\alpha-1} L_1^{1-\alpha} + (-1+\mu)^2 / 2\gamma - \mu r = -\dot{\mu}\,, \tag{3.5}$$

$$pA_2 \beta K_2^{\beta-1} (Z_1^2)^{1-\beta-\gamma} L_2^{\eta} = r\,, \tag{3.6}$$

$$pA_2 (1-\beta-\eta) K_2^{\beta} (Z_1^2)^{-\beta-\gamma} L_2^{\eta} = q^*\,. \tag{3.7}$$

Eqn.3.7 implies that if final good sector is not physically damaged and the capital is not decreased, its demand for intermediate good is not changed from the steady state value, $Z_1^{2^*}$. Final good sector can import the amount $Z_1^{2^*} - Y_1$ and its production does not decrease. In this case, cascade effect is not induced. This implies that it is important factor to cascade effect whether the intermediate good can be obtained alternatively from outside. In other words, substitutability is a factor inducing cascade effect.

4.2. How to Separate the Cascade Effect

Cascade effect can be measured by the difference of loss between cases in which the intermediate good market is closed and open. Table 2 illustrates the cascade effect in each sector and total economic loss. Note that the suffix '~' indicates the variables in the case that intermediate good market is open.

Table 2: Table of loss measured in each sector when cascade effect is separated

Industry	Household
Intermediate goods sector	
Foregone Net Revenue (Primary Effect) $\int_\tau^\infty q^*(Y_1^* - \tilde{Y}_1) e^{-r(t-\tau)} dt$	Decline of Utility (Primary Effect) $V_1^* - \tilde{V}_1$
Foregone Revenue (Cascade Effect) $\int_\tau^\infty (q^* \tilde{Y}_1 - \hat{q}\hat{Y}_1) e^{-r(t-\tau)} dt$	Decline of Utility (Cascade Effect) $\tilde{V}_1 - \hat{V}_1 + V_2^* - \hat{V}_2$
Restoration Investment (Primary Effect) $\int_\tau^\infty \tilde{I}_1 (1 + T(\tilde{I}_1 / \tilde{K}_1)) e^{-r(t-\tau)} dt$	
Restoration Investment (Cascade Effect) $\int_\tau^\infty (\hat{I}_1(1+T(\hat{I}_1/\hat{K}_1)) - \tilde{I}_1(1+T(\tilde{I}_1/\tilde{K}_1))) e^{-r(t-\tau)} dt$	
Final goods sector	
Foregone Net Revenue (Cascade Effect) $\int_\tau^\infty (pY_2^* - q^* Z_1^{2^*} - (p\hat{Y}_2 - \hat{q}\hat{Z}_1^2)) e^{-r(t-\tau)} dt$	
Total $V_1^* - \hat{V}_1 + V_2^* - \hat{V}_2$	$V_1^* - \hat{V}_1 + V_2^* - \hat{V}_2$

Table 3 shows a numerical calculation result when the cascade effect is measured separately. The value of each parameters is the same as in the section 3.1. The focused scenario is the case that 99 % of capital of the intermediate good sector is damaged. From Table 3, it is found that the cascade effect enlarges the total economic loss. Total of the primary effect is 3.03 but the total economic loss is 5.44 because of the cascade effect. For this case, the cascade effect enlarges the total economic loss about 1.5 times larger. In table 3, "Cascade Effect" on the *Foregone Net Revenue* in the intermediate good sector is negative. There are two reasons for this fact. The first is that the recovery speed of the production in the intermediate sector is made high due to the cascade effect. The second is that the price of intermediate good rises. "Cascade Effect" on the *Restoration Investment* is positive because larger amount of restoration investment is made in the intermediate good sector immediately. *Foregone Net Revenue* in the Final good sector is positive, and it gives the most significant impact on the expanding of total economic loss.

Table 3 A numerical simulation result of measuring cascade effect and total economic loss

Intermediate good sector			
	Foregone Net Revenue	(Primary Effect)	3.01
		(Cascade Effect)	-2.70
	Restoration Investment	(Primary Effect)	0.52
		(Cascade Effect)	1.72
Final good sector			
	Foregone Net Revenue	(Cascade Effect)	2.87
Total			5.44

5. SUMMARY

This paper proposed a methodology for consistent measurement of economic losses caused by natural hazards. A two-sector economic growth model was used to describe recovery process after a disaster. It was shown that, in the case that capital is damaged in industrial sectors, sum of the differences of discounted cash-flow in industrial sectors can be a consistent measure as total economic loss. It consists of *Foregone Net Revenue* and *Restoration Investment*. This paper also proposes how to measure the cascade effect, which is the spillover effect of economic impacts induced by mutual relation ships between industrial sectors. Cascade effect can be measured separately by comparing two cases in which the intermediate good market is closed in the country and open to the world. A numerical calculation demonstrated that cascade effect can enlarge the total economic loss about 1.5 times. It indicates that, in measuring total economic loss, it is important to take into account cascade effect in order to avoid underestimation.

REFERENCES

Turnovsky (1997). International Macroeconomic Dynamics, MIT Press.

Sen, P. and Turnovsky, S.(1995). Investment in a Two-Sector dependent economy, *Journal of the Japanese and International Economics* **9**, 29-55.

Tatano, H., Isobe, W. and Okada, N.(2000). Economic Evaluation of Seismic Risks, *Proc. of 2000 Joint Seminar on Urban Disaster Management*, 36-39, Beijing, China.

Nakano.K., Tatano.H., Kajitani.Y., Fujimi.T., Tsuchiya.S.(2007). Estimation of the Economic Loss in Industrial Sectors Caused by the 2004 Mid-Niigata Earthquake, *Review of Infrastructure planning*, **24:2**, 289-298.(in Japanese)

Nakano.K. and Tatano.H.(2008) Economic Restoration Process after Natural Disasters under Mutual Relationships between Industrial Sectors, *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics*, (accepted).

Rose, A. (2004)"Economic Principles, Issues, and Research Priorities in Hazard Loss Estimation", in Okuyama, Y. and Chang, S.(eds) *Modeling Spatial and Economic Impacts of Disaster*, Advances in Spatial Science, Springer,13-36.

Barro S.J and Sala-i-Martin.X. (2004). Economic Growth, MIT Press.

Mulligun.C.B and Sala-i-Martin, X.(1993) Transitional dynamics in two-sector models of Endogenous Growth, *The Quarterly Journal of Economics*, **108:3**, 739-773.

Hayashi.F.(1982) Tobin's Marginal and Average q: A Neoclassical Interpretation., *Econometrica*, **50**, 213-224.