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Economic Restoration after a Catastrophic Event: Heterogeneous Damage to Infrastructure and Capital and Its Effects on Economic Growth

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ABSTRACT

Economic restoration after a large catastrophic event in which the economy is described by an endogenous economic growth model consisting of two regions was investigated. Since a natural catastrophe is local and a large-scale event, it destroys the accumulated infrastructure and production capital in the economy instantaneously, but damages to capital is not homogeneously distributed in space. Two types of capital are assumed; infrastructure and production capital. Infrastructure is formulated as a common capital good in all the area's economic regions. Production capital consists of the private goods used for production in each region. This paper investigates how heterogeneous damage to different types and locations of capital affects economic restoration after a catastrophic event. Implications for disaster risk management policy are discussed based on analysis of the model.

1. INTRODUCTION

A natural catastrophe causes a discrete downward drop in the production capacity of an economy. This is because some portion of the capital accumulated in the economy is destroyed. Tatano et al. [2000] reported that economic losses caused by a natural disaster consist of "stock losses" and "flow losses". Stock losses are the lost values of economic stocks.

Flow losses are secondary ones caused by the shift in economic growth triggered by the occurrence of a disaster. These two types of losses are interconnected with restoration effort investments after the event. If no investment to restore destroyed stocks can be made, i.e., no investment for the accumulation of capital, the economy will remain at the same level or lower. To avoid such losses, investment to restore destroyed capital must be made in the real world. Economic losses observed as flow in the real world therefore reflect the lost value of products of destroyed capital minus the benefit of the restoration investment.

Reducing both stock and flow losses is important when designing effective disaster risk management strategies. Mitigation investment contributes to decrease damage to stock, and risk financing arrangements and the restoration policy utilized after the disaster affect the levels of production and economic growth of the economy. This research focused on restoration policies implemented after a catastrophic event in order to identify desirable policies.

The economy is described by an endogenous economic growth model consisting of two regions. The natural catastrophe is local but a large-scale event. It destroys both the accumulated infrastructure and production capital of the economy instantaneously, but the damage to capital is not homogeneously distributed in space. It is assumed that there are two types of capital in the economy; infrastructure and production capital. Infrastructure is defined as a common capital good used for production in both regions of the economy, and production capitals as private goods which can be used for production exclusively in a region. This study investigated how the heterogeneity of damage to the different types and allocations of capital affects the economic restoration and growth of the economy as a whole. It also provides clues for disaster risk management policies based on an analysis of the model.

2. RESTORATION POLICIES AND ECONOMIC GROWTH

Disaster risk management options consist of "risk control" and "risk financing" countermeasures. **Fig. 1** shows the disaster risk management options for seismic risk management. These options consist of two categories; risk avoidance and mitigation countermeasures. Risk avoidance countermeasures center on the decrease in population and assets exposed to a disaster risk ("exposure"); e.g., land use regulation. Mitigation countermeasures can aid in decreasing "vulnerability" to that exposure. Risk control countermeasures can decrease damage to capital stocks in the

KEY WORDS: natural catastrophe, endogenous economic growth, economic restoration path, heterogeneous damage

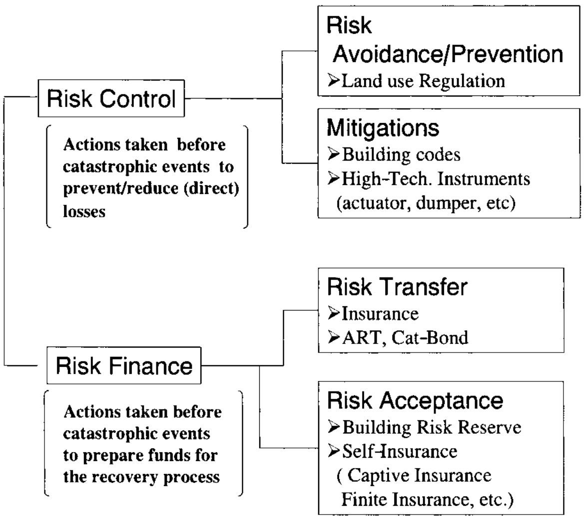

Fig. 1 Possible options for disaster risk management

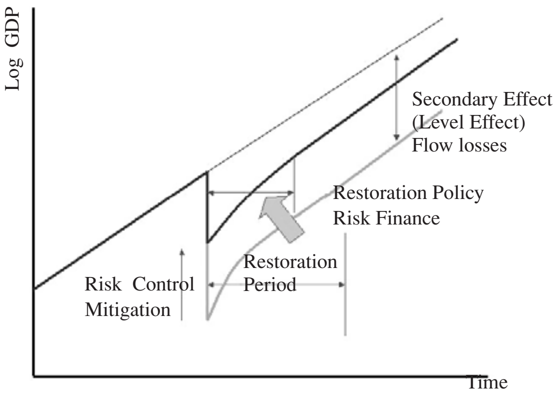

Fig. 2 Roles of risk control and risk financing in economic growth

economy. Risk financing countermeasures are ex ante financial preparations for a catastrophic event in order to decrease losses that ensue after the event such as a decrease in production and consumption in flow terms. Representative measures include insurance and alternative risk transfer (ART); e.g., CAT security. The purpose of risk financing is to increase the economy's capacity for rapid recovery after the event.

Fig. 2 shows the role of risk control and risk finance in relation to economic growth. A risk control countermeasure, if properly designed and implemented, contributes to a decrease in damage to stock in the economy. A risk financing countermeasure contributes to a decrease in flow losses within the economy. Restoration policy also contributes to decreased flow losses, subject to available resources after the event. This study focused on optimal restoration policies, especially the relationship between the heterogeneity of damage and restoration period length.

The literature dealing with catastrophic losses and economic growth basically has had a Neo-classical framework [Tatano et al., 2000, Kobayashi et al., 2002]. Catastrophic events in the economy have been modeled as unexpected downward drops in production due to the sudden decrease in capital as discussed above. Such models show that a catastrophic event brings about a permanent shift in the growth of an economy, called the "level effect".

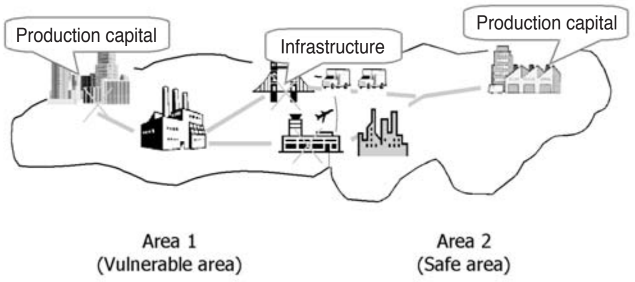

Fig. 3 Illustration of the model's assumed economy

These models assume only one type of capital in an economy, therefore heterogynous damage cannot occur. This assumption is justifiable to obtain basic figures such as the "level effect" [Barro and Sala-i-Martin (1995)], which explains the relationship between economic growth and catastrophic risk. On the basis of the models, we cannot analyze the restoration path after an event. In a single capital economy, the shock produced by a catastrophe simply would return the economy to its past stage of capital accumulation, and growth after the shock would be exactly the same as that in the past. The restoration period is defined as the transition period during which economic growth of an economy catches up with the original growth trajectory, turned downward by the catastrophe. In this sense, the literature does not discuss the restoration path after an event, and it can be said that the published studies implicitly assume that restoration can be finished immediately after the event.

Heterogeneous damage to capital is divided to two groups in this paper; heterogynous damage to different types of capital and localization differences in damage. **Fig. 3** shows the economy modeled in this study. There are two regions. One may suffer direct catastrophic losses. Without loss of generality, it is assumed that such a catastrophic event could occur only in area 1, and that area 2 is always safe in such an event. Each area has accumulated capital for production. Production efficiency also depends on the infrastructure level and labor for in an area. To avoid excessive complexity, people and firms are assumed not to change their locations, and that the population of each area is fixed. Production technology in each area is assumed to be constant return-to-scale and a function of infrastructure and production capital. Based on these assumptions, the economy grows steadily at a constant growth rate if the initial values of the types of capital are in the "optimal capital component ratio" (defined later). The capital component ratio is assumed to be optimal in the normal state (before the catastrophe), but a reduction in capital may occur heterogeneously in stock types and places when the event happens, and the capital component ratio after the event therefore will not be at the optimal ratio, at least for some time. The restoration period is the interval in which the capital component ratio varies from the original ratio.

The restoration policy is the resource allocation policy utilized during the transient period. Here, investigation of the optimal restoration policy is based on a two-region, endogenous economic growth model with heterogeneous capital damage.

3. THE MODEL

A social planner's model is formulated to investigate the optimal restoration policy. In this model, the social planner decides investment policies for the allocation of production capital and infrastructure resources from now on to maximize household welfare in both areas subject to production technology and the initial endowments of production factors. People and firms are assumed not to change their locations and that the population of each area is fixed.

Production technology is represented by a constant return-to-scale production function of capital $K_i\,(i=1,2)$ and infrastructure G;

$$Y_i = F(K_i,G) = (A_i L_i G)^{1-\alpha} K_i^{\alpha} \ \ (i=1,2) \tag{1}$$

where L_i is the labor available in area i and A_i and $\alpha (0 \le \alpha \le 1)$ are parameters. Infrastructure is regarded as a common production factor in all areas of the economy and contributes to the production efficiency of labor.

The instantaneous utility function of a household in area i, $u(C_i)$, is a non-decreasing function of consumption C_i. Each household in each area is assumed to supply unit labor for production. A social welfare function is set as a Bentham type one: $L_1 u(C_1) + L_2 u(C_2)$. The social planner is assumed to maximize the discounted present value of the social welfare function:

$$U = \int_0^{\infty} \{L_1 u(C_1) + L_2 u(C_2)\} e^{-\rho t} dt \tag{2}$$

The social planner can decide what parts of the economy's production should be invested in capital $I_{Ki}(i = 1,2)$ and infrasructure I_G and consumed in each area. The balance for production, consumption, and investment is

$$Y_1 + Y_2 = L_1 C_1 + L_2 C_2 + I_{K_1} + I_{K_2} + I_G \tag{3}$$

Capital accumulation conditions are

$$\dot{K}_i = I_{K_i} - \delta_K K_i \ (i=1,2) \tag{4}$$

$$\dot{G} = I_G - \delta_G G \tag{5}$$

where δ_K and δ_G are the respective depreciation rates of production capital and infrastructure, respectively.

The social planner also faces the problem of expenditures and is allowed to spend no more for capital than the rate of that capital's return in the long run. These conditions are given by

$$\lim_{t\to\infty} \left[K_1 \cdot \exp\left\{ -\int_0^t \left(\frac{\partial Y_1}{\partial K_1} - \delta_K \right) dt \right\} \right] \ge 0$$

$$\lim_{t\to\infty} \left[K_2 \cdot \exp\left\{ -\int_0^t \left(\frac{\partial Y_2}{\partial K_2} - \delta_K \right) dt \right\} \right] \ge 0$$

$$\lim_{t\to\infty} \left[G \cdot \exp\left\{ -\int_0^t \left(\frac{\partial Y_1}{\partial G} + \frac{\partial Y_2}{\partial G} - \delta_G \right) dt \right\} \right] \ge 0$$

Based on all these conditions, the social planner's behavior is

$$\max U = \int_0^{\infty} \{L_1 u(C_1) + L_2 u(C_2)\} e^{-\rho t} dt$$

subject to

$$\begin{aligned}
& Y_1 + Y_2 = L_1 C_1 + L_2 C_2 + I_{K1} + I_{K2} + I_G \\
& \dot{K}_i = I_{K_i} - \delta_K K_i \ (i=1,2) \\
& \dot{G} = I_G - \delta_G G \\
& Y_i = F(K_i, G) = (A_i L_i G)^{1-\alpha} K_i^{\alpha} \ \ (i=1,2) \\
& \lim_{t\to\infty} \left[K_1 \cdot \exp\left\{ -\int_0^t \left(\frac{\partial Y_1}{\partial K_1} - \delta_K \right) dt \right\} \right] \ge 0 \\
& \lim_{t\to\infty} \left[K_2 \cdot \exp\left\{ -\int_0^t \left(\frac{\partial Y_2}{\partial K_2} - \delta_K \right) dt \right\} \right] \ge 0 \\
& \lim_{t\to\infty} \left[G \cdot \exp\left\{ -\int_0^t \left(\frac{\partial Y_1}{\partial G} + \frac{\partial Y_2}{\partial G} - \delta_G \right) dt \right\} \right] \ge 0 \\
& I_{K_1}, I_{K_2}, I_G, C_1, C_2 \ge 0
\end{aligned} \tag{I}$$

The path of economic growth can be specified if the initial value of each type of capital is set.

4. HETEROGENEOUS DAMAGE TO CAPITAL AND OPTIMAL RESTORATION POLICIES

i) Economic growth before a catastrophic event

The following conditions are derived from the first order condition of optimization of problem (I):

$$\begin{aligned}
& \alpha (A_1 L_1)^{1-\alpha} \left(\frac{G}{K_1} \right)^{1-\alpha} \\
& = \alpha (A_2 L_2)^{1-\alpha} \left(\frac{G}{K_2} \right)^{1-\alpha} \\
& = (1-\alpha)(A_1 L_1)^{1-\alpha} \left(\frac{K_1}{G} \right)^{1-\alpha} + (1-\alpha)(A_2 L_2)^{1-\alpha} \left(\frac{K_2}{G} \right)^{1-\alpha}
\end{aligned} \tag{6}$$

This means that the productivity of each type of capital should equal the optimal path. Equation (6) can be written

$$\begin{aligned}
& \left(\frac{K_2}{K_1} \right)^{*} = l^{*} = \frac{A_2 L_2}{A_1 L_1} \\
& \left(\frac{G}{K_1} \right)^{*} = m^{*} = \frac{1-\alpha}{\alpha} \left(1 + \frac{A_2 L_2}{A_1 L_1} \right)
\end{aligned} \tag{7}$$

This means that capital component ratios are constant on the optimal growth path. In contrast, the economy's growth is always the optimal if the initial value of each type of capital is within the optimal component ratio. On the path, production and consumption in both regions grow at a constant rate:

$$\gamma^{*} = (1/\sigma)\left(\alpha (A_1 L_1)^{1-\alpha} (m^{*})^{1-\alpha} - \delta - \rho \right) \tag{8}$$

That is, the economy grows at a constant rate before the event.

ii) Economic growth after a catastrophe

A catastrophic event brings about a discontinuous, heterogeneous decrease in capital. In such a situation, it is useless to assume that all capital component ratios remain optimal. Moreover, the social planner does not necessarily determine investment such that the optimal component ratios of capital are kept, but should prioritize investment for the capital that has the highest marginal productivity.

Table 1 gives the combinations of possible damage patterns in the economy and changes in marginal productivity for each type of capital. It provides the following findings.

There is a decrease in the marginal productivity of capital which has not been damaged, whereas the marginal productivity of damaged capital is increased by the event. This means that the most severely damaged capital should be given the highest priority in making the restoration policy. In some cases, restoration of the infrastructure should be promoted even if damage is not as severe as that to the production capital.

The first result is common sense, but the last is not explained in a straightforward way. The last result is related to the presence of spillovers of infrastructure to the economy in area 2. **Fig. 4** shows changes in investment priorities during the restoration period. The indifferent marginal productivity curve signifies the critical capital component ratio in area 1 where the marginal productivities of the production and infrastructure capital are same. Priority for investment in the infrastructure is focused on where the capital component ratio is smaller than the critical value, g, a decrease function of available infrastructure ex post. The optimal capital component ratio m^* equals g when the infrastructure is maintained at the value before the event; when no loss of infrastructure has occurred. Hence, for the case when some damage occurs to the infrastructure, if the capital component ratio G/K_1 is smaller than g, priority of investment is placed on the infrastructure, even for $G/K_1 > m^*$.

Fig. 5 shows changes in the marginal productivities of the types of capital and production levels in each area in damage patterns, in which either the infrastructure or production capital suffers losses when the optimal restoration policy is adopted. Pattern 1 is the case when production capital suffers losses. Pattern 2 is the case for infrastructure capital. In both patterns, damaged capital has the highest marginal productivity right after the event, and investment during the restoration period takes place only for damaged capital. Restoration paths in the affected area (area 1) are similar, whereas those in the non-affected area (area 2) differ. Damage done only to production capital in the affected area has no effect on the productivity of the non-affected area. The effect of

Table 1. Possible damage patterns and marginal capital productivities

Marginal Capital Productivity	Pattern 1	Pattern 2	Pattern 3	Pattern 4
	A single type of capital is damaged		Simultaneous damage in capitals K_1 and G	
	K_1	G	$\frac{G}{K_1} \leq g$	$\frac{G}{K_1} > g$
K_1	+	--	--	+
K_2	=	--	--	--
G	--	+	+	--

+: increase, --: decrease, =: indifferent in marginal capital productivity

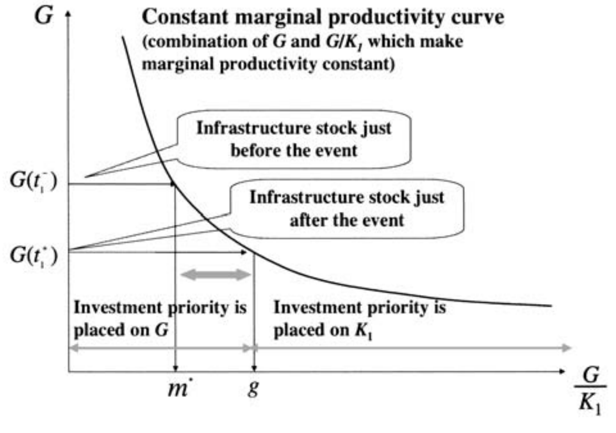

Fig. 4 Changes in investment priority during the restoration period

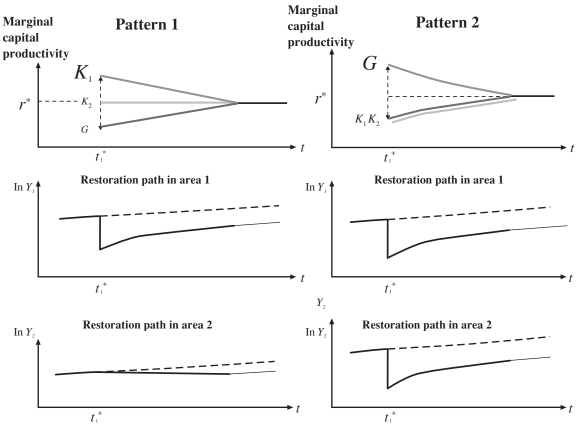

Fig. 5 Changes in marginal capital productivities and production in each area in damage patterns in which either production capital or infrastructure suffers losses when the optimal restoration policy is adopted

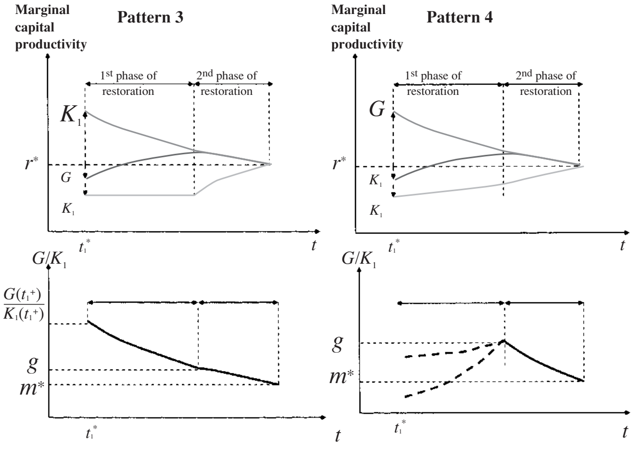

Fig. 6 Changes in Marginal Capital Productivities and the Capital Component Ratio in the Restoration Period when Both Types of Capital Suffer Losses

the event on economic growth of the non-affected area therefore is limited by the effect produced by the reduction of capital investment in area 2 during the restoration period. In contrast, damage to the infrastructure in the affected area has a spillover effect on the productivity of the non-affected area because it is capital common to both areas. Therefore, production in the non-affected area also decreases with the extent of damage to the infrastructure, and its restoration path is similar to that in the affected area.

Fig. 6 shows that changes in the marginal productivities of the types of capital and in the capital component ratio when both types of capital suffer damage during the restoration period. In both patterns, the restoration period has two phases. In the first, investment is implemented only for the most severely damaged capital. Once the capital component ratio reaches the critical value g, the restoration policy is changed, and investment is made in both types of damaged capital to maintain the same marginal productivities for the infrastructure and production capital. This is the second phase of the restoration policy, and it continues until the capital component ratio reaches the optimal ratio, m^*.

5. CONCLUSION

Economic restoration after a large catastrophic event was investigated in an endogenous economic growth model. How the heterogeneity of damage done to different types of capital and the localization affect on the economic restoration path and growth of the economy as a whole were studied.

The heterogeneity of the damage to capital was shown to be crucial to describe what restoration processes should be implemented after a catastrophic event. The analysis conducted clarifies the basic principle of restoring capital after a catastrophe and the structures of the necessary restoration processes are shown for the different damage patterns.

Infrastructure capital should be prioritized over a wider range of the economic environment rather than production capital. There is greater resistance to catastrophic risks for the infrastructure because damage to it has spillover effect on non-affected areas. To investigate mitigation policies for the use of different types of capital in different locations, it is necessary to conduct a cost benefit analysis.

The uncertainty of the occurrence of a catastrophic event was not considered in order to avoid excessive complexity. In the future, the model must be extended to include uncertainty in order to estimate the benefit of alternative mitigation measures.

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