2014 IEEE International Conference on Systems, Man, and Cybernetics
October 5-8, 2014, San Diego, CA, USA

An Economic Growth Model for Disaster Risk Reduction in Developing Countries

Muneta Yokomatsu
Disaster Prevention Research Institute
Kyoto University
Kyoto, Japan

Hiroyuki Wada, Hiroaki Ishiwata, and Takeshi Kono
Transportation Planning Dept.
Pacific Consultants Co., Ltd.
Tokyo, Japan

Katsumi Wakigawa
Water Resources Policy Group
Japan Institute of Country-ology and Engineering
Tokyo, Japan

***Abstract*—This paper presents a dynamic stochastic macroeconomic model to investigate the long-term effect of the investment in disaster risk reduction on economic growth of developing countries. The model describes the possibility of a disaster-induced poverty trap, particularly caused by disasters that hinder investment in human capital such as education. This study pays attention to the possibility that disaster risk reduction (DRR) investment has the potential for enhancing economic growth and improving equality within a society. The study further demonstrates the numerical simulation developed for analyzing the economy of Pakistan to investigate that DRR investment motivates households to increase investment in human capital and enhances economic growth.**

***Keywords*— Disaster risk reduction, Economic growth model, Poverty trap, Human capital, Pakistan**

I. INTRODUCTION

There exists a divergence in views regarding the impact of natural disasters on macroeconomic growth, although macroeconomic research on natural disasters and their consequences is limited. There still seems to be some consensus that natural disasters have a negative impact on short-term economic growth [1]-[4]. On the other hand, the literature on the long-run effects of natural disasters is scant and inconclusive; some describe the expansionary disaster effects caused by, for example, Schumpeterian “creative destruction” [5]-[6] while others note that the effect of creative destruction is limited in developing countries [6]. A contrasting conclusion is also found, stating that natural disasters have a negative long-term impact [7]-[8]. It is indicated that compared to advanced societies, developing societies suffer from a greater magnitude of disaster damage in the long-term [9].

The long-term effect of disaster mitigation or disaster risk reduction (DRR) investments is a question that remains unanswered. This study formulates a stochastic economic growth model to quantitatively investigate the effect of a large-scale disaster and DRR investments on the dynamic processes of the economy that is consistent with the rational behavior of representative households, with an infinite time horizon. The model further enables a comparison of DRR benefits among different income classes, which implies the effect of DRR on the socio-economic equality of the society.

Once a large-scale disaster hits a developing society, the lower-income households, having smaller amounts of savings and limited capability for acquiring loans, are more likely to be forced into working longer hours for their livelihoods and recovery of habitation; thus, the amount of time available for education is reduced. This impedes the development of human capital and slows down future economic growth, which, in turn, results in increased income disparity, because the lower-income households are more vulnerable to disasters. Considering this problem framework, the benefits from DRR, such as the provision of dykes, are larger for lower-income households and developing societies. We apply the real business cycle (RBC) model to develop a simple framework for the evaluation of DRR.

Our stochastic growth model is characterized by a disaster-triggered poverty trap and human capital investment. If a disaster destroys the factors of production, consequently, production and income are reduced, then the consumption levels of households of the lowest income class is dropped to a subsistence level. At this level, they can neither afford to accumulate savings nor invest in their human capital, but must prioritize consumption to continue to survive. Subsequently, their income does not increase and economic growth is decelerated, due to the inadequacy of the reduced human capital. The low-income households and their communities could be caught in a poverty trap, which also causes an expansion of a cycle of disparity.

A large number of empirical and theoretical studies have focused on the relationship between natural disasters and the poverty trap [10]-[11]. This study formulates the structure of a poverty trap that is caused by the subsistence constraint [12]-[13]. There also exist economic growth models using human capital as a function [14]. Here, we deal with two types of capital: physical and human. Each type of capital responds differently to natural disasters. The level of physical capital stock is assumed to decrease following a disaster and to be built up again from that level. On the other hand, human capital, which is defined as knowledge and skills for production in this study, is not deprived by natural disasters, although the provision of labor is temporarily reduced because of morbidity and mortality. However, natural disasters have a negative impact on the educational investments that are made for the development of human capital, as learning conditions are deteriorated by the occurrence of a disaster. The existing literature shows that natural disasters can have an important yet detrimental effect on the education stock of a country by affecting complementary infrastructure such as school buildings and access roads [15]-[16] and increasing child work participation rates resulting in the removal of children from schools [17]-[19]; moreover, nutritional deficiencies may occur, creating a negative effect on education [20], [21]. We take these findings into account and formulate our model so that the marginal cost of the human capital investment is increased in the aftermath of natural disasters. The model in this study is unique in that, as mentioned above, two types of capital stocks are characterized in different ways for the response to the natural disasters.

Recently, applications of dynamic macroeconomic models to natural disaster issues are being developed. The strand of stochastic growth models [22]-[24] includes some applications to rare disaster issues. Some studies pay exclusive focus on the behavior of the financial markets [25]-[29]. Others include impacts of disasters on real assets and production into dynamic models such as the dynamic stochastic general equilibrium (DSGE) model [30]-[31], [32] and the endogenous business cycle (EnBC) model [33], [34]-[35]. A simulation model that helps policy makers devise public financing strategies is also being developed [36], [37]-[38].

We follow the genealogy of the RBC models that stems from Kydland and Prescott (1982) [23] and are associated with the general equilibrium framework with rational expectations. We assume that economic fluctuations arise from disasters as an exogenous shock and that the economic system is otherwise stable in order to identify the normative solution that the market mechanism can achieve. Referring to this dynamic general equilibrium as a benchmark, the benefit of DRR investments is measured by improvements in GDP, economic growth rates, and other indices. Because of the Pareto efficiency of the dynamic equilibrium, where the private sector behaves as rationally as possible, further improvements can only be attained through public policy provisions for DRR infrastructure. The benefit of the DDR Investment evaluated in such a model is regarded as a significant indicator that is consistent with the normative solution of the economy.

The remainder of this paper is organized as follows: Section II introduces the model, Section III derives the optimal conditions, Section IV presents the numerical simulation based on parameters of Pakistan, and Section V concludes the paper.

II. Model

One good is produced in each period using inputs of human capital, physical capital, and land. Production is quantitatively equivalent to household income. The produced good is either consumed or invested to develop household assets, or is spent on education, or saved. There is perfect competition in all markets, and there is no tax. Households are assumed to have an infinite time horizon and to be forward-looking and rational, including perfect perception of the disaster risks, and maximize expected lifetime utility.

Each firm has a neoclassical type of production technology that is represented by a homogeneous function of degree one, with respect to human capital, physical capital, and land, and maximizes the contingent profit in each period. The factor markets are perfectly competitive. Household saving is borrowed by firms in the capital market and invested in physical capital for production.

A. Disaster and Event Sequence

The natural disaster occurs, at most, once in each time period, although its scale of intensity varies. The scale of the disaster $l\ (=1,2,\ldots,L)$ is defined by the negative impacts on labor, physical capital, land, and households' physical assets in terms of the damage rates: $(\omega^l,\psi^l,\tau^l,\varphi^l)$, respectively. The probability that a scale-*l*-disaster occurs in each period is a constant μ^l that satisfies $\sum_{l=0}^{L}\mu^l=1$, where $l=0$ represents the year that no disaster occurs.

The sequence of events in each period t is assumed as follows:

1) Each household identifies its stocks of human capital $h(t)$, financial assets $b^-(t)$, and physical household assets $z^-(t)$, at the beginning of each period.
2) Each household invests $\xi(t)$ in physical assets by transferring financial assets, such that the position of financial and physical assets are changed to $b(t)=b^-(t)-\xi(t)$ and $z(t)=z^-(t)+\xi(t)$, respectively.
3) When the disaster occurs, the scale of the disaster in period *t* is determined, which we often denote as $\hat{l}$ when it is necessary to clarify that it is the realized scale. Household labor, physical capital, land, and physical assets are given the negative impacts that depend on the scale $\hat{l}$.
4) Production is implemented with available factors of profuction. Each household determines the consumption $c^{\hat{l}}(t)$, human capital investment $m^{\hat{l}}(t)$, and savings, which accordingly determine the supply of production factors, human and physical capital, for production in the next period. Each firm determines the demand level of factors of production in the next period, and the markets clear at equilibrium. The utility level of period *t* is also determined.
5) The stock variables are updated to $h(t+1)$, $b^-(t+1)$, and $z^-(t+1)$, the time moves to the next period $t+1$, and the cycle restarts at 1).

B. Financial Assets

Household financial assets $b(t)$, develops in the following way:

$$b^-(t+1)=\{1+r_l(t)\}(1-\psi^l)\mathrm{b}(t)+w_l(t)\cdot(1-\omega^l)\mathrm{h}(t) +\pi_l(t)\cdot(1-\tau^l)T-c^l(t)-\eta^l\big(m^l(t)\big), \quad (1)$$

$$b(t+1)=b^-(t+1)-\xi(t+1), \quad (2)$$

where $r_l(t)$ is the interest rate under the occurrence of the scale-*l*-disaster, and the first term of the right-hand side of (1)

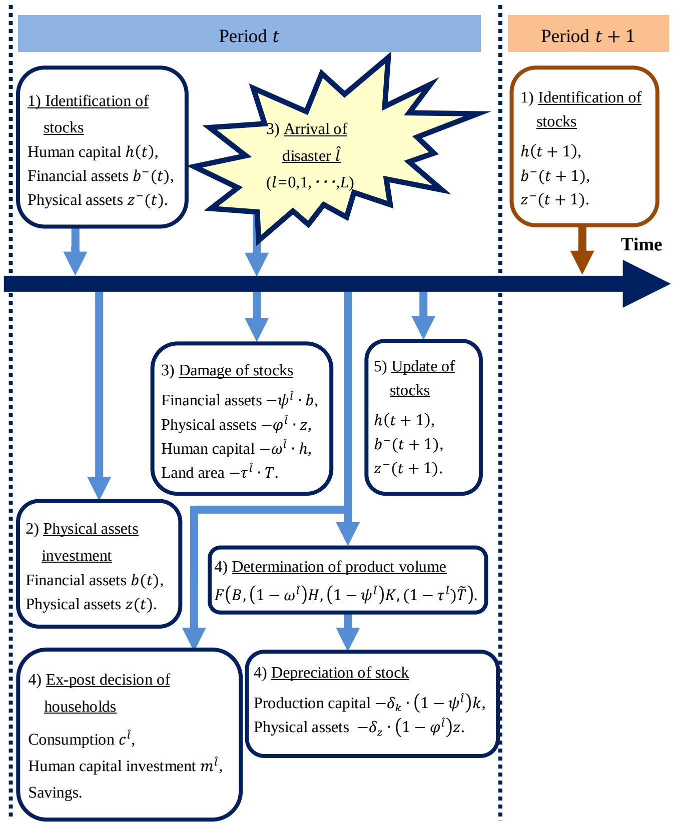

Figure1. Event Sequence

The third term is the rent revenue, where $\pi_l(t)$ is the contingent rent for the unit land and $(1-\tau^l)T$ is the available area of the land, where T is the household land rented to the firm and τ^l is the damage rate. $c^l(t)$ represents consumption after the occurrence of the scale-l-disaster and $\eta^l(m^l(t))$ is the expenditure for the human capital investment, where $\eta^l(\cdot)$ is the cost function for human capital investment $m^l(t)$, whose units of measure are the same as that for human capital, such as years of schooling. Note that the cost function $\eta^l(\cdot)$ itself also depends on the scale of the disaster, because the marginal cost of learning is increased after large-scale disasters due to, for example, collapsed school buildings, reduced road access to schools, sick and injured children, and the annexing of school facilities for evacuation and shelter purposes. Eq. (2) means that, as described in the event sequence above, the position $b(t+1)$ is obtained after physical assets investment $\xi(t+1)$.

C. Physical Assets

Physical assets $z(t)$ includes durable goods such as houses and household goods that are exposed to disaster risks. The physical assets formation process is represented by

$$z^-(t+1) = (1-\delta_z)(1-\varphi^l)z(t), \tag{3}$$
$$z(t+1) = z^-(t+1) + \xi(t+1), \tag{4}$$

where δ_z is the depreciation rate of physical assets, φ^l is the damage rate caused by the scale-l-disaster, and $\xi(t+1)$ is investment.

D. Human Capital

The concept of human capital encompasses the population's knowledge, skills, physical energy, and health, including mental health. In this study, we restrict the concept of human capital and define it only as the knowledge and skills useful for production. Hence, it is reasonable to assume in this model that human capital does not suffer from disaster damage, and in the case study, we take the average years of schooling as a proxy variable. The formation process for human capital is represented as follows:

$$\begin{aligned} h(t+1) &= (1-\delta_h)\cdot h(t) + \varsigma \cdot m^l(t) \\ &= h(t) + H^l(t), \end{aligned} \tag{5}$$
$$H^l(t) := -\delta_h \cdot h(t) + \varsigma \cdot m^l(t), \tag{6}$$

where δ_h is the depreciation rate of human capital, which reflects the obsolescence of knowledge and skills and retirement of the elder generation from production activity. ς (≤ 1) is the correction coefficient associated with the adjustment cost, which may be necessary to be less than unity in the case study calibration process. $m^l(t)$ is the investment after the scale-l-disaster hits the economy in period t.

E. Land

Land is endowed uniformly among all households in each group economy. Since the population is assumed to be unchanged, the land area per household is also constant at $T = \tilde{T}/n$, where $\tilde{T}$ is the total land area in a group economy and n is the population. Each household lends their land to firms and receive rent revenue. The productive land area per household is decreased to $(1-\tau^l)T$ after land is damaged by the scale-l-disaster, although it is recovered without cost by the beginning of the next period.

F. Preference

Household preference is assumed to be identical. Representative households enjoy utility by consuming composite goods and using the physical assets in every period of time following the arrival of the scale-l-disaster. The one-period utility function is given by

$$\begin{aligned} &u\left(c^l(t),(1-\varphi^l)z(t)\right) \\ &:= \frac{[(c^l(t)-\bar{c})^{\gamma_1}\{(1-\varphi^l)\cdot z(t)\}^{\gamma_2}]^{1-\theta}-1}{1-\theta}, \end{aligned} \tag{7}$$
$$0 < \gamma_1, \gamma_2 < 1, \gamma_1 + \gamma_2 = 1, \theta > 0,$$

where $(1-\varphi^l)z(t)$ is the ex-post level of physical assets after being partially collapsed by the disaster. $\bar{c}$ is the subsistence level of consumption, γ_1 and γ_2 are the weights on consumption and physical assets, respectively, and θ is the degree of relative risk aversion. With $c^l(t)-\bar{c}$, we apply the structure of the Stone–Geary utility function, which is capable of expressing households falling into the poverty trap; that is, when the level of consumption $c^l(t) (> \bar{c})$ approaches $\bar{c}$, marginal utility increases, and consumption is given a higher priority, which results in the sacrifice of other investments that could increase future income.

Representative households maximize the expected life-time utility, discounted at rate ρ, that is:

$$\max E\left[\sum_{t=0}^{\infty} u(c^l(t),(1-\varphi^l)z(t))\left(\frac{1}{1+\rho}\right)^t\right], \tag{8}$$

where $E[\cdot]$ represents the expectation operator, and each household is assumed to be aware of all risks.

G. Production

Firms' production technology is assumed to be identical and homogeneous of degree one with respect to human capital, physical capital, and land. Production takes place after the occurrence of a natural disaster in each period. The rates of return to the factors are dependent on the scale of disaster *l*; namely, the factor market determines the contingent returns: wage rate, interest rate, and rent per unit of land. The production function is represented by

$$F(B, \widehat{H}, \widehat{K}, \widehat{T}) := B\widehat{H}^{\alpha 1}\widehat{K}^{\alpha 2}\widehat{T}^{\alpha 3}, \quad 0 < \alpha_1, \alpha_2, \alpha_3 < 1, \alpha_1 + \alpha_2 + \alpha_3 = 1 \tag{9}$$

where $\widehat{H}, \widehat{K}, \widehat{T}$ are the ex-post (available) levels of human capital, physical capital, and land, respectively. B is the total factor productivity (TFP) that develops exogenously, and $\alpha_1, \alpha_2, \alpha_3$ are the share parameters. As the technology is homogeneous of degree one with respect to all the factors, the number of firms does not matter; we can even assume that the number of firms is one and describe a resource allocation that is consistent with allocation in a perfectly competitive market. The total amount of production $Y(t)$ in the economy after the occurrence of the scale-*l*-disaster in period *t* is given by

$$Y(t) = F(B(t), (1-\omega^l)H(t), (1-\psi^l)K(t), (1-\tau^l)\tilde{T}), \tag{10}$$

where $H(t)$ and $K(t)$ are the aggregate amounts of human and physical capital demanded by firms in the economy, and $\tilde{T}$ is the total land area.

The land area is a fixed factor and is equally shared by households in the economy. Firm's ex-post profit is given by

$$\widetilde{\Pi}_l(t) = F(B(t), (1-\omega^l)H(t), (1-\psi^l)K(t), (1-\tau^l)\tilde{T}) - w_l(t)\cdot(1-\omega^l)H(t) - \{r_l(t)+\delta_k\}\cdot(1-\psi^l)K(t). \tag{11}$$

Representative firms maximize profit $\widetilde{\Pi}_l(t)$. The optimal conditions with respect to human and physical capital imply

$$\frac{\partial F(B(t), (1-\omega^l)H^D(t), (1-\psi^l)K^D(t), (1-\tau^l)\tilde{T})}{\partial \widehat{H}} = w_l(t), \tag{12}$$

$$\frac{\partial F(B(t), (1-\omega^l)H^D(t), (1-\psi^l)K^D(t), (1-\tau^l)\tilde{T})}{\partial \widehat{K}} = r_l(t) + \delta_k, \tag{13}$$

where $H^D(t)$ and $K^D(t)$ represent the optimal demands of both factors. With profit maximized, the rent for the unit land is identified by

$$\pi_l(t) = \frac{\widetilde{\Pi}_l(t)}{(1-\tau^l)\tilde{T}} = \frac{\widetilde{\Pi}_l(t)}{(1-\tau^l)nT}. \tag{14}$$

III. Optimal Conditions

A. Value Function

The model economy is characterized by many identical households, with the same preferences and rational expectations, and identical firms that produce a common output, using the same constant-returns-to-scale technologies, contingent factor returns, and household ownership of all the factors of production and all shares in the firm. That is, firms own nothing; they simply hire all the factors on a rental basis to produce the output, and then transfer any profit back to the households. Such a scenario could be described as an Arrow–Debreu economy, which attains the Pareto optimal allocation and, therefore, could be solved by dealing with "the planning problem," where one representative agent allocates all the resources over an infinite time horizon to maximize household lifetime expected utility, which describes equivalent allocation in a competitive equilibrium [39]. Following the lead of most RBC models, we analyze the equivalent first–best problem.

The problem is formulated as a dynamic stochastic optimization problem, with an infinite time horizon, where we introduce the value function as

$$V(a(t), h(t), B(t)) = \max\ E\left[\sum_{t=0}^{\infty} u(c^l(t), (1-\varphi^l)z(t)) \cdot \Lambda^t\right], \tag{15}$$

where Λ is the discount factor, that is, $\Lambda := 1/(1+\rho)$. $a(t)$ is the total assets, defined by the sum of financial and physical assets, namely, $a(t) := b(t) + z(t)$. As we assume the possibility of an arbitrary and cost-free allocation between financial assets $b(t)$ and physical assets $z(t)$ by physical investment $\xi(t)$, their sum $a(t)$ is a mathematically meaningful state variable in the optimization problem. The development process of $a(t)$ is derived from (2) and (4) as follows:

$$a(t+1) = a(t) + A^l(t), \tag{16}$$

$$\begin{aligned} A^l(t) &:= F(B(t), (1-\omega^l)h(t), (1-\psi^l)\{a(t)-z(t)\}, (1-\tau^l)T) \\ &\quad - \{\delta_k + (1-\delta_k)\cdot\psi^l\}a(t) - c^l(t) - \eta^l(m^l(t)) \\ &\quad - \{(1-\psi^l)(1-\delta_k) - (1-\varphi^l)(1-\delta_z)\}z(t), \end{aligned} \tag{17}$$

where we utilize the relation such as

$$\begin{aligned} &b(t) = a(t) - z(t) = k(t), \\ &F(B(t), (1-\omega^l)h(t), (1-\psi^l)\{a(t)-z(t)\}, (1-\tau^l)T) \\ &\quad = w_l(t)\cdot(1-\omega^l)h(t) + \{r_l(t)+\delta_k\}\cdot(1-\psi^l)k(t) \\ &\qquad + \pi_l(t)\cdot(1-\tau^l)T, \end{aligned}$$

which is derived from (11)–(14).

Now, $z(t)$ can be treated as a control variable and we no longer explicitly have $b(t)$ and $\xi(t)$ in the optimization problem both of which can be derived indirectly from the optimal solutions of the other variables. Assuming the first-order differentiability of the value function, the recursive equation is derived as follows:

$$V\big(a(t),h(t),B(t)\big) = \max E\begin{bmatrix} u\big(c^l(t),(1-\varphi^l)z(t)\big) \\ +\Lambda\cdot V\big(a(t+1),h(t+1),B(t+1)\big)\end{bmatrix}$$
$$= \max\left\{\sum_l \mu^l\big[u\big(c^l(t),(1-\varphi^l)z(t)\big)+\Lambda \cdot\big\{V\big(a(t),h(t)\big)+V_a\cdot A^l(t) + V_h\cdot H^l(t)+V_B\cdot B^{\circ}(t)\big\}\big]\right\}, \quad (18)$$

where $V_a := \frac{\partial V(a(t),h(t),B(t))}{\partial a(t)}$, $V_h := \frac{\partial V(a(t),h(t),B(t))}{\partial h(t)}$, $V_B := \frac{\partial V(a(t),h(t),B(t))}{\partial B(t)}$, $B^{\circ}(t) := B(t+1) - B(t)$, and A^l(t) and H^l(t) are given by (17) and (6), respectively. By transforming the above equation, we have the equiv alent maximization problem as follows:

$$(1-\Lambda)\cdot V\big(a(t),h(t),B(t)\big) = \max\left\{\sum_l \mu^l \begin{bmatrix} u\big(c^l(t),(1-\varphi^l)z(t)\big) \\ +\Lambda\cdot\{V_a\cdot A^l(t)+V_h\cdot H^l(t)+V_B\cdot B^{\circ}(t)\}\end{bmatrix}\right\}. \quad (19)$$

The right-hand side of (19) is maximized by the vector of the control variables $(\mathbf{c}(t), z(t), \mathbf{m}(t))$, where $\mathbf{c}(t) := (c^0(t), c^1(t), \cdots, c^L(t))$ is the list of contingent (disaster-scale-dependent) consumption, $c^l(t)$ $(l = 0,1,\cdots,L)$, after the occurrence of the scale-*l*-disaster, $z(t)$ is the level of physical assets, and $\mathbf{m}(t) := (m^0(t), m^1(t), \cdots, m^L(t))$ is the list of contingent investments in human capital $m^l(t)$ $(l = 0,1,\cdots,L)$ after the occurrence of the scale-*l*-disaster. Only the level of the physical assets $z(t)$ is independent of disaster scale *l*; that is, each household invests in physical assets before the occurrence of a disaster, whereas consumption and human capital investment are "the ex-post behaviors," meaning that they are taken after the disaster in each period. The contingent level of saving is determined accordingly, as is the development of total assets.

B. Optimal Conditions

Assuming that the form of the value function $V(a,h,B)$ and its first-order partial derivatives V_a, V_h, and V_B are known, we have the first-order conditions as follows:

$$u_c(c^l,(1-\varphi^l)z) = \Lambda\cdot V_a \qquad \text{for all } l \quad (20)$$

$$\sum_l \mu^l(1-\varphi^l)\{u_{\hat z}(c^l,(1-\varphi^l)z)+\Lambda\cdot V_a\cdot(1-\delta_z)\} = \Lambda\cdot V_a\sum_l \mu^l(1-\psi^l)\{F_{\hat k}+(1-\delta_k)\} \quad (21)$$

$$V_h\cdot\varsigma = V_a\cdot\eta^{l\prime}(m^l) \qquad \text{for all } l \quad (22)$$

where $u_c := \frac{\partial u(c^l,(1-\varphi^l)z)}{\partial c^l}$, $u_{\hat z} := \frac{\partial u(c^l,(1-\varphi^l)z)}{\partial\{(1-\varphi^l)z\}}$,

$F_{\hat k} := \frac{\partial F(B,(1-\omega^l)h,(1-\psi^l)k,(1-\tau^l)T)}{\partial\{(1-\psi^l)k\}}$, and $\eta^{l\prime}(m^l) := \frac{d\eta^l(m^l)}{dm^l}$,

which represents marginal utility of consumption, marginal utility of physical assets, marginal production of physical production capital, and marginal cost of human capital investment, respectively. Eq. (20) means that the level of the consumption is determined so that the marginal utility of consumption is identical to the discounted value of total assets; that is, the opportunity cost of consumption. It is also implied that, since the cost $\Lambda\cdot V_a$ is independent of the disaster scale l, marginal utility of consumption should be equalized among the states given by the disasters in period *t*. Eq. (21) represents the optimal physical asset investment rule that expected marginal benefit and cost should be equalized, where the first term of the left-hand side is the expected marginal utility that each household enjoys in period *t*, and the second term is the value of the expected level of the assets based on $(1-\delta_z)$ that stays in the next period. On the other hand, the right-hand side represents the value of expected marginal production and the non-depreciated part of physical production capital that each household would obtain if they invested one unit of resource to physical production capital, which is equivalent to the opportunity cost of physical assets investment. Eq. (22) indicates that the marginal value of human capital investment should be equalized to its marginal cost.

IV. Numerical Simulation

A. Prerequisites

Here, we demonstrate a numerical simulation to show how the model presents the effects of disaster risk reduction (DRR) investment on the long-term development of a certain economy. Parameters are identified to represent the macro economy of Pakistan, a country that has a history of floods. The values of the parameters are listed in Table I at the end of the paper, where some data are assumptions, owing to limited availability. The list should be ameliorated by further data collection.

The year 2004 is set as the base year from which the model begins the growth simulation process, and the unit period of time is equalized to one year. There are five income groups. The first group corresponds to the poorest, while the fifth group represents the wealthiest. The population of Pakistan is divided into quintiles, based on a survey conducted by the government of Pakistan [40].

We refer to [41] to obtain parameter values of the disaster scales and the various damage rates that are given to the agents in the model. [41] includes hydrological results based on the simulation and categorizes scales of flood disaster into five classes, whose event probabilities (equivalent to μ^ls in our model) are consistent with precipitation records during 1976–2011. Moreover, under each precipitation scale, Ota simulates the geographical inundation pattern in the Indus River basin. Combining these profiles with the estimation results of the spatial distribution of stratified households permits an assessment of damage rates to physical household assets that depend on location. We use the same set of parameters that Ota identifies for the event probability μ^l and damage rates $\big(\omega_j^l, \varphi_j^l, \psi^l, \tau^l\big)$, where $l\,(=0,\cdots,4)$ and $j\,(=1,\cdots,5)$ represent the disaster scale and household group, respectively.

We apply the average schooling years as the proxy for human capital $h(t)$, and specify the human capital investment function by applying a quadratic formula:

$$\eta^l(m^l) = \eta_0 + \eta_1 \cdot m^l + \eta_2^l \cdot (m^l)^2 \quad (23)$$

The larger the disaster scale l, the larger the parameter η_2^l; thus, marginal cost of human capital investment is increased in the aftermath of large-scale disasters, owing to issues such as the degradation of educational facilities and general health. Total factor productivity (TFP) $B(t)$, is assumed to grow at a constant rate:

$$B(t) = B_0 \cdot (1 + g_b)^{t-1}. \quad (24)$$

Moreover, we assume the value function as follows:

$$V(a, h, B) = \nu_0 + \nu_1 \cdot \{Ba\}^{1-\theta} + \nu_2 \cdot \{Bh\}^{1-\theta}, \quad (25)$$

where the parameters $\nu_0 - \nu_2$ and g_b are set so that GDP, consumption, and human capital investment of 2004 and GDP of 2010 matches the actual results and the model.Two levels of DRR investments are considered: the smaller investment that has all damage rates uniformly reduced by 20% from the original rates (20%-DRR), and the larger one that has all damage rates reduced by 50% (50%-DRR).

B. Simulation Results

The progression of disaster scales, represented in Fig. 2, replicates its history from $t = 1$ (2004) to $t = 7$ (2010) and simulates one sample path after $t = 8$ (2011), which is extracted randomly from the abovementioned probability. Under this sample path, GDP, consumption, physical assets, and human capital per capita develop, as depicted in Figs. 2-5, respectively. Since the disaster scale in the seventh period is large, economic activity is decelerated. It should also be mentioned that because of the larger exposure of the physical assets of the third (middle) and the fifth (richest) income groups, they are more severely damaged by disasters; thus, the Gini coefficient of income distribution [42] decreases temporally, as seen in Fig. 2.

The GDP regains growth in the eighth period, and the growth is accelerated in the thirteenth period by the increase in human capital that is developed rapidly due to the zero-scale disaster effects from the tenth to the thirteenth period. Households in the lower income groups develop their human capital more quickly, resulting in a decrease in the Gini coefficient after the thirteenth period. On the other hand, as shown in Fig. 4, the order relation of physical assets among the income groups is not completely monotonic with respect to the income level, because of the heterogeneous exposure of their physical assets to disaster; since households in the third and the fifth groups settle in more hazardous areas, they do not hold such a large proportion of their wealth in physical assets.

Finally, Figs. 6 and 7 illustrate that investments in 20%-DRR and 50%-DRR increase GDP by approximately 20% and 50% in the nineteenth period, compared to GDP without DRR. On the other hand, effects of DRR on the Gini coefficient are not completely monotonic because households in the fifth (richest) group who settle in comparatively hazardous areas receive larger benefits from DRR investments. It is also implied that DRR investments encourage poorer households to invest more in human capital after the thirteenth period, resulting in the acceleration of GDP growth. It should be emphasized that, by securing human capital investment with the contribution of DRR investment, GDP growth and improvement in equality could be compatible.

V. Conclusion

Developing countries are in a vulnerable position vis-à-vis natural disaster. The structures of these countries are such that disasters directly harm their economic underpinnings by made

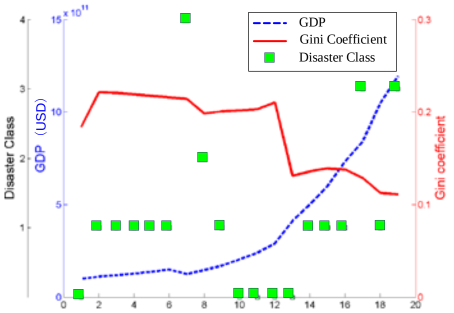

Figure2. Sample path of the disaster scales, Development of GDP and Gini coefficient.

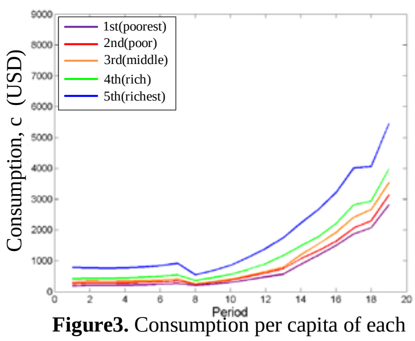

Figure3. Consumption per capita of each income group.

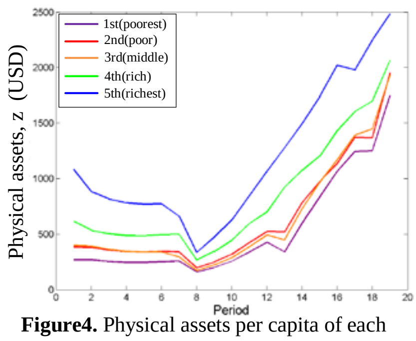

Figure4. Physical assets per capita of each income group.

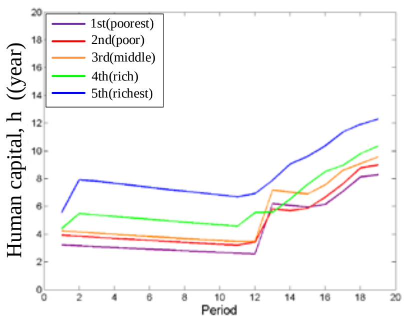

Figure5. Human capital development per capita of each income group.

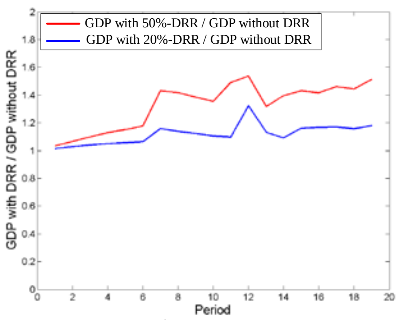

Figure6. Ratio of GDP with DRR to that without DRR.

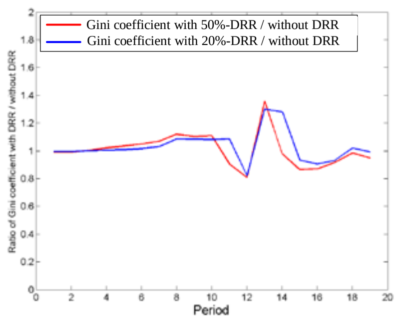

Figure7. Ratio of Gini coefficient with DRR to that without DRR.

prior to a disaster is extremely effective for preventing or ameliorating such conditions. However, few evaluation methods for decision-making have been established to quantitatively show the effects of such investment. Given this situation, we have developed a model that focuses on developing countries which allows the quantitative evaluation of DRR investment.

As a numerical example, we focused on the economy of Pakistan, and investigated the macroeconomic dynamics under the risks of natural disasters. Although we exclusively dealt with one sample path where we analyzed impacts of disasters on each endogenous variable corresponding to scales of disasters, the logical interpretation implied that DRR investment could motivate households to increase investment in human capital, which resulted in the contribution to both economic growth and improvements in income equality.

The appropriate level of DRR investment will be determined by comparing its marginal effect and marginal cost of the investment. Estimation of the cost of the investment remains to be done. The other challenges that could be faced in future include the following: first, the method for identifying the value function should be elaborated; second, the exchange between groups in one market should be dealt with by the model; third, we will formulate markets for land resource transactions and habitation. Finally, we should complete the data collection process to identify all parameters in the model including field surveys conducted by the authors.

References

J. M. Albala-Bertrand, The Political Economy of Large Natural Disasters: With Special Reference to Developing Countries, Clarendon Press, 1993. (ISBN:0198287658)

[1] C. Raddatz, "Are external shocks responsible for the instability of output in low-income countries?," Journal of Development Economics, vol. 84, pp. 155-187, 2007.

[2] I. Noy, "The macroeconomic consequences of disasters," Journal of Development Economics, vol. 88, issue 2, pp. 221-231, March 2009.

[3] S. Hochrainer, "Assessing the Macroeconomic Impacts of Natural Disasters: Are There Any?," World Bank Policy Research Working Paper, WPS4968, 2009.

[4] M. Skidmore and H. Toya, "Do natural disasters promote long-run growth?," Economic Inquiry, vol. 40, issue 4, pp. 664-687, 2002.

[5] J. C. Cuaresma, J. Hlouskova, and M. Obersteiner, "Natural disasters as creative destruction? Evidence from developing countries," Economic Inquiry, vol. 46, issue 2,pp. 214-226, 2008.

[6] I. Noy and A. Nualsri, "What do exogenous shocks tell us about growth theories?," University of Hawaii Working Paper 0728, 2007.

[7] C. Raddatz, "The Wrath of God: Macroeconomic Costs of Natural Disasters," World Bank Policy Research Working Paper, WPS5039, 2009.

[8] UNISDR, Global Assessment Report on Disaster Risk Reduction, pp. 4-9, 2009. (ISSN: 9789211320282)

[9] F. Zimmerman and M. R. Carter, "Asset smoothing, consumption smoothing and the reproduction of inequality under risk and subsistence constraints," Journal of Development Economics, vol. 71, pp. 233-260, 2003.

[10] M. R. Carter, P. D. Little, T. Mogues, and W. Negatu, "Poverty Traps and Natural Disasters in Ethiopia and Honduras," World Development, vol. 35, issue 5, pp. 835-856, May 2007.

[11] S. Dercon, "Wealth, risk and activity choice: Cattle in Western Tanzania," Journal of Development Economics, vol. 55, pp.1-42,1998.

[12] A. Kraay and C. Raddatz, "Poverty traps, aid, and growth," Journal of Development Economics, vol. 82, pp. 315-347, 2007.

[13] R. E. Lucas, Jr., "On the mechanics of economic development," Journal of Monetary Economics, vol. 22, pp. 3-42, 1988.

[14] J. Baez, A. de la Fuente, and I. Santos, "Do natural disasters affect human capital? An assessment based on existing empirical evidence," IZA Discussion Papers, Forschungsinstitut zur Zukunft der Arbeit (IZA), Discussion Paper No. 5164, September 2010.

[15] M. Petal, Disaster Prevention for Schools Guidance for Education Sector Decision-Makers, Consultation Version, UNISDR, 2008.

[16] H. Jacoby, and E. Skoufias, "Risk, financial markets, and human capital in a developing country," Review of Economic Studies, vol. 64, issue 3, pp. 311-335, 1997.

[17] J. Baez and I. Santos, "Children's Vulnerability to Weather Shocks: A Natural Disaster as a Natural Experiment," Working Paper, 2007.

[18] A. de Janvry, F. Finan, E. Sadoulet, and R. Vakis, "Can conditional cash transfer programs serve as safety nets in keeping children at school and from working when exposed to shocks?," Journal of Development Economics, vol. 79, issue 2, pp. 349-373, 2006.

[19] H. Alderman, J. Hodditnott, and B. Kinsey, "Longterm consequences of early childhood malnutrition," Oxford Economic Papers, vol. 58, pp. 450-474, 2006.

[20] H. Alderman, H. Hoogeveen, and M. Rossi, "Preschool nutrition and subsequent schooling attainment: Longitudinal evidence from Tanzania," Economic Development and Cultural Change, vol. 57, No. 2, pp. 239-260, January 2009.

[21] W. A. Brock and L. J. Mirman, "Optimal economic growth and uncertainty: The discounted case," Journal of Economic Theory, vol. 4, pp.479-513, 1972.

[22] F. E. Kydland and E. C. Prescott, "Time to build and aggregate fluctuations," Econometrica, vol. 50, No. 6, pp.1345-1370, November 1982.

[23] P. Aghion and P. Howitt, "A model of growth through creative destruction," Econometrica, vol. 60, No.2, pp. 323-351, 1992.

[24] T. A. Rietz, "The equity risk premium a solution," Journal of Monetary Economics, vol. 22, pp. 117-131, 1988.

[25] R. J. Barro, "Rare disasters and asset markets in the twentieth century," Quarterly Journal of Economics, vol. 121, No.3, pp. 823-866, 2006.

[26] R. J. Barro, "Rare disasters, asset prices, and welfare costs," The American Economic Review, vol. 99, No.1, pp.243-264, 2009.

[27] F. Gourio, "Disasters and recoveries," American Economic Review, vol. 98, No.2, pp. 68-73, 2008.

[28] J. Wachter, "Can Time-Varying Risk of Rare Disasters Explain Aggregate Stock Market Volatility," NBER Working Paper Series 14386, 2008.

[29] B. D. Keen and M. R. Pakko, "Monetary Policy and Natural Disasters in a DSGE Model," Working Paper 2007-025D, Federal Reserve Bank of St. Louis Working Paper Series, 2007.

[30] O. Posch and T. Trimborn, "Numerical Solution of Continuous-Time DSGE Models under Poisson Uncertainty," Working Paper Series, 2011.

[31] S. Segi, T. Ishikura, and M. Yokomatsu, "Application of dynamic stochastic macroeconomic model for long-term disaster prevention planning," Journal of Japan Society of Civil Engineers, D3, vol. 68, No.3, pp.129-143, 2012.

[32] S. Hallegatte, J. C. Hourcade, and P. Dumas, "Why economic dynamics matter in assessing climate change damages: Illustration on extreme events," Ecological Economics, vol. 62, pp. 330-340, 2007.

[33] S. Hallegatte and M. Ghil, "Natural disasters impacting a macroeconomic model with endogenous dynamics," Ecological Economics, vol. 68, pp. 582-592, 2008.

[34] S. Hallegatte and P. Dumas, "Can natural disasters have positive consequences? Investigating the role of embodied technical change," Ecological Economics, vol. 68, pp.777-786, 2009.

[35] S. Hochrainer-Stigler, A. Timonina, K. Williges, G. Pflug, and R. Mechler, "Modelling the Indirect and Fiscal Risks from Natural Disasters Using the CatSim Model," Background Paper prepared for the 2013 Global Assessment Report on Disaster Risk Reduction, Geneva, Switzerland, UNISDR, 2013.

[36] S. Hochrainer-Stigler, R. Mechler, G. Pflug, and K. Williges, “Funding public adaptation to climate-related disasters. stimates for a global fund,” Global Environmental Change, in Press, 2014.

[37] R. Mechler, S. Hochrainer, J. Linnerooth-Bayer, and G. Pflug, Public Sector Financial Vulnerability to Disasters. The IIASA CatSim Model.In: J. Birkmann, (eds.), Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies. Revised and extended Second Edition, Tokyo, United Nations University Press, pp. 380-398, 2013.

[38] Nancy L. Stokey, Robert E. Lucas, Jr. and Edward C. Prescott, “Recursive Methods in Economic Dynamics,” Harvard University Press, 1989. (ISBN:9780674750968)

[39] Pakistan Bureau of Statistics, Gorvernment of Pakistan, Household Integrated Economics Survey, 2004-2005.

[40] A. Ota, “Assessment of Disaster Prevention Investment for Decreasing Economic Damage by Integrating Dynamic Equilibrium Model and Flood Model -Towards Contributing to Policy Making for Disaster Prevention-,” Master Thesis, University of Tokyo, 2014.

[41] C. Gini, “Concentration and dependency ratios,” 1909, Rivista di Politica Economica, vol. 87, pp. 769-789, 1997.

TABLE I. INPUT DATA

<table>
<tr><th>Variable</th><th>Setting for Pakistan</th></tr>
<tr><td colspan="2">■ Socioeconomic Data & Parameters</td></tr>
<tr><td>N</td><td>155,151,394 (2004) *Source : World Bank (website)</td></tr>
<tr><td>n</td><td>31,030,279 (2004) ⇒ 20% of the total population</td></tr>
<tr><td>ρ</td><td>5.0% ⇒By the assumption</td></tr>
<tr><td>θ</td><td>2.0 ⇒By the assumption *Reference: Kraay and Raddatz (2007)</td></tr>
<tr><td>δ_z</td><td>20% ⇒Set by 10%–30% assets write-off rate in Pakistan.
*Source: “Investment and corporate law, accounting tax, and labor in Bangladesh, Pakistan, Sri Lanka,” Y. Kuno</td></tr>
<tr><td>δ_k</td><td>2.0% ⇒By the assumption</td></tr>
<tr><td>B_0</td><td>63.0 ⇒By calibration with GDP in 2004
*Source: World Bank (website)</td></tr>
<tr><td>g_b</td><td>7.5% ⇒By the assumption</td></tr>
<tr><td>α_i</td><td>$\alpha_i \in \{\alpha_1, \alpha_2, \alpha_3\} = \{0.52, 0.40, 0.08\}$
*Source: Dorosh and Niazi (2006).</td></tr>
<tr><td>$c^l(0)$</td><td><table><tr><td>Group</td><td>1st</td><td>2nd</td><td>3rd</td><td>4th</td><td>5th</td></tr><tr><td>USD</td><td>176.0</td><td>242.2</td><td>303.8</td><td>410.3</td><td>815.1</td></tr></table>*Source: Household Integrated Economic Survey 2004–2005, Pakistan</td></tr>
<tr><td>$\bar{c}$</td><td>0 ⇒By the assumption</td></tr>
<tr><td>$z(0)$</td><td><table><tr><td>Group</td><td>1st</td><td>2nd</td><td>3rd</td><td>4th</td><td>5th</td></tr><tr><td>USD</td><td>263.0</td><td>361.8</td><td>453.9</td><td>613.1</td><td>1,218.0</td></tr></table>⇒Set to 10% from past investment rate (8.67%–9.99%) of Housing (rent & other costs) / Rural
*Source: Household Integrated Economic Survey 2004–2005, Pakistan</td></tr>
<tr><td>$b(0)$</td><td><table><tr><td>Group</td><td>1st</td><td>2nd</td><td>3rd</td><td>4th</td><td>5th</td></tr><tr><td>USD</td><td>1,104.3</td><td>1,534.4</td><td>1,906.4</td><td>2,487.6</td><td>4,579.9</td></tr></table>⇒By calibration
*Source 1: Poverty Profile: Islamic Republic of Pakistan, JBIC, 2007.
*Source 2: World Bank (website)</td></tr>
<tr><td>$h(0)$</td><td><table><tr><td>Group</td><td>1st</td><td>2nd</td><td>3rd</td><td>4th</td><td>5th</td></tr><tr><td>Year</td><td>3.22</td><td>3.92</td><td>4.24</td><td>4.39</td><td>5.57</td></tr></table>⇒By verification with average school attendance rates.
*Source 1: UNDP (website)
*Source 2: Poverty Profile: Islamic Republic of Pakistan, JBIC, 2007.</td></tr>
<tr><td>$m^l(0)$</td><td>0.45 ⇒By calibration
*Source 1: UNDP (website)
*Source 2: World Bank (website)
*Source 3: Household Integrated Economic Survey 2004–2005, Pakistan</td></tr>
<tr><td>δ_h</td><td>7.56% ⇒Estimated from average number of schooling years in Pakistan
*Source 1: UNDP (website)
*Source 2: World Bank (website)
*Source 3: Household Integrated Economic Survey 2004–2005, Pakistan</td></tr>
<tr><td>η_i</td><td>η_0: 8.43, η_1: 41.1, η_2^l: See the table below<table><tr><td>Group \ Edu. level</td><td>0</td><td>1</td><td>2</td><td>3</td></tr><tr><td>1st</td><td>2.50</td><td>12.5</td><td>27.5</td><td>50.5</td></tr><tr><td>2nd</td><td>2.70</td><td>12.7</td><td>27.7</td><td>50.7</td></tr><tr><td>3rd</td><td>2.90</td><td>12.9</td><td>27.9</td><td>50.9</td></tr><tr><td>4th</td><td>3.10</td><td>13.1</td><td>28.1</td><td>51.1</td></tr><tr><td>5th</td><td>3.30</td><td>13.3</td><td>28.3</td><td>51.3</td></tr></table>⇒By calibration and assumption
⇒The higher the education level, the larger the education cost.
*Source 1: UNDP (website) *Source 2: World Bank (website)
*Source 3: Household Integrated Economic Survey 2004–2005, Pakistan</td></tr>
<tr><td>$\bar{T}$</td><td>1.0 ⇒By normalization</td></tr>
<tr><td>$\tilde{T}$</td><td><table><tr><td>Group</td><td>1st</td><td>2nd</td><td>3rd</td><td>4th</td><td>5th</td></tr><tr><td>Share (%)</td><td>9.5</td><td>13.2</td><td>16.4</td><td>21.4</td><td>39.4</td></tr></table>⇒Assumed to be relative to be each $b(0)$</td></tr>
<tr><td colspan="2">■ Disaster Data</td></tr>
<tr><td>μ^l</td><td><table><tr><td>Scale</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td></tr><tr><td>Rate</td><td>0.36</td><td>0.29</td><td>0.22</td><td>0.11</td><td>0.02</td></tr></table>⇒In the numerical example, a scale-0-disaster includes relatively frequent and small flood. *Source : Ota (2014)</td></tr>
<tr><td>ω^l</td><td><table><tr><td>Scale</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td></tr><tr><td>Rate</td><td>1.73×10^{-6}</td><td>2.94×10^{-6}</td><td>3.51×10^{-6}</td><td>4.38×10^{-6}</td><td>12.2×10^{-6}</td></tr></table>⇒Due to data limitations, the labor damage rates are assumed to be identical among all the groups. *Source : Ota (2014)</td></tr>
<tr><td>φ^l</td><td><table><tr><td>Group \ Scale</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td></tr><tr><td>1st</td><td>0.010</td><td>0.023</td><td>0.037</td><td>0.036</td><td>0.054</td></tr><tr><td>2nd</td><td>0.007</td><td>0.032</td><td>0.034</td><td>0.029</td><td>0.084</td></tr><tr><td>3rd</td><td>0.055</td><td>0.072</td><td>0.061</td><td>0.081</td><td>0.220</td></tr><tr><td>4th</td><td>0.019</td><td>0.050</td><td>0.053</td><td>0.147</td><td>0.082</td></tr><tr><td>5th</td><td>0.020</td><td>0.061</td><td>0.140</td><td>0.219</td><td>0.220</td></tr></table>*Source : Ota (2014)</td></tr>
<tr><td>ψ^l</td><td><table><tr><td>Scale</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td></tr><tr><td>Rate</td><td>0.079</td><td>0.140</td><td>0.148</td><td>0.277</td><td>0.548</td></tr></table>*Source : Ota (2014)</td></tr>
<tr><td>τ^l</td><td><table><tr><td>Scale</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td></tr><tr><td>Rate</td><td>0.021</td><td>0.049</td><td>0.060</td><td>0.090</td><td>0.150</td></tr></table>⇒Due to data limitations, the land damage rates are assumed to be identical among all the groups. *Source : Ota (2014)</td></tr>
</table>