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Original paper

The Role of a Macro-Economic Model for Disaster Risk Reduction Policy in Developing Countries

Hiroyuki Wada[1], Katsumi Wakigawa[2], Muneta Yokomatsu[3], Kimio Takeya[4]

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Abstract: It has been noted that in recent years disaster risk reduction (hereafter DRR) investment, in particular such investment prior to a disaster, is important in dealing with increasingly large-scale natural disasters that have serious socio-economic impacts. Especially, developing countries are in a vulnerable position vis-à-vis natural disasters, as the scale of economies in these countries is small and they do not foster a culture of reducing disaster risks. As a result, disasters directly harm their economic underpinnings, inhibiting their economic growth and sending them back into the poverty trap. DRR investment prior to a disastrous event is an extremely effective measure of preventing or ameliorating such conditions. However, no definitive method for evaluating the quantitative effects of DRR investment as a decision making tool has been established. Given this situation, we develop a model in this study that allows the quantitative evaluation of DRR investment focused on developing countries. Moreover, we use data from Pakistan to confirm the efficacy of the model, as well as to confirm that DRR investment contributes to economic growth and the alleviation of poverty in developing countries.

Key Words: Natural disaster risk reduction, Development economics, Gini coefficient, DCGE model

1. THE BACKGROUND AND THE AIM OF THIS STUDY

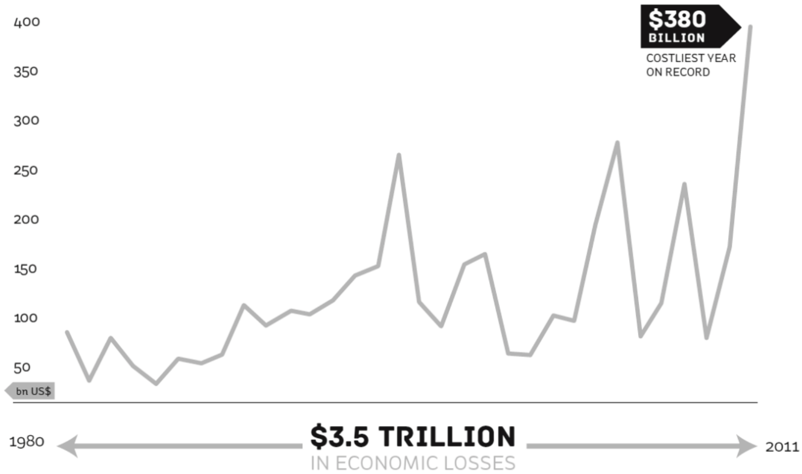
1.1 The Occurrence of Large-scale Natural Disasters

In recent years large-scale natural disasters that cause significant socio-economic impacts have frequently occurred throughout the world. The damage caused by such disasters has serious impacts on society, the economy, and the global environment. The damage has been increasing considerably over time.

[1] Pacific Consultants Co., LTD., Tokyo, Japan. Mail: hiroyuki.wada@tk.pacific.co.jp

[2] Japan Institute of Country-ology and Engineering, Tokyo, Japan.
[3] Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan.

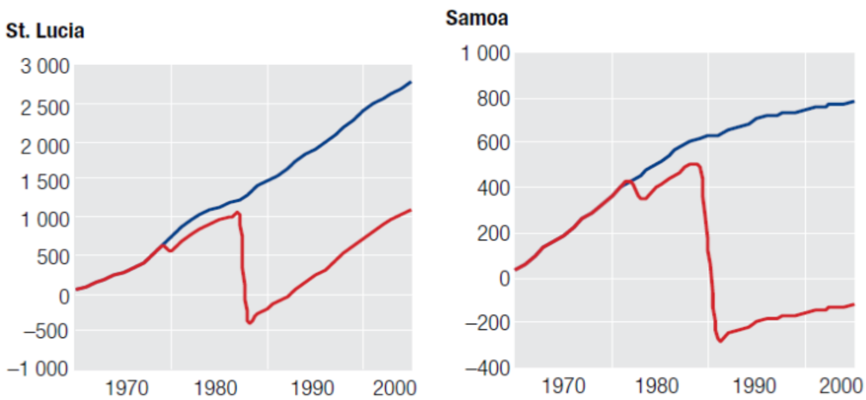
[4] Japan International Cooperation Agency, Tokyo, Japan.



*Source: GFDRR (2012)

Fig.1. Trends in Economic Losses Arising from Natural Disasters

Especially, the economic losses incurred by developing countries as a result of natural disasters are increasing and this has a profound impact on national economies. For example, we can express the magnitude of the damage caused by natural disasters as a proportion of GDP. As in the case of the storm in St. Lucia that occurred in 1988, the damages accounted for about 365% of the country's GDP. And in the case of the storm in Samoa that occurred in 1990 and 1991, the damages accounted for about 178% and 248% of the country's GDP, respectively. Such natural disasters that have a significant impact on GDP and cause major hurdle to sustainable development are shown in Figure 2.



*1970-2006 Cumulative Net Capital Formation (Unit: $ million, 2000 base year)
Blue Line: Not including impact of economic losses due to disasters
Red Line: Including impact of economic losses due to disasters

*Source: Baritto (2008)

Fig.2. The Impact on Economic Losses Caused by Disasters in St. Lucia and Samoa in terms of Cumulative Net Capital Formation

Natural disasters have strong negative impacts on economic development, national stability and the lives of the lower income population in developing countries. According to McMahon (2007), as the lower income population live in places that are especially vulnerable to damages caused by disasters with weak infrastructure, it is difficult for them to get out of the poverty trap. This is confirmed by UNISDR (2009), which states that the long term effects of frequently occurring disasters is that it suppresses income and consumption, which adversely affects the welfare and educational environment and further delays the alleviation of poverty.

1.2 The Gap between the Awareness on Disaster Prevention and its Implementation

Since the late 1980s the international society has made continuous efforts to strengthen international initiatives on disaster risk reduction (hereafter DRR). In 1994 the United Nations (hereafter UN) World Conference on Disaster Reduction was held, and in 2000 the United Nations Office for Disaster Risk Reduction (hereafter UNISDR) was established. In addition, the Hyogo Framework of Action (hereafter HFA) was set up as an action plan under the 2nd Session of the UN World Conference on Disaster Reduction. The strategic goals of HFA are to incorporate DRR into sustainable development, and to develop and improve the capacity of DRR systems. By 2015 it hopes to achieve "The substantial reduction of disaster losses, in human lives and in the social, economic and environmental assets of communities and countries (UNISDR 2005). As an international cooperation for development, the Millennium Development Goals (hereafter MDGs) for developing countries were established in the late 1980s to find solutions to the issue of poverty. Through international initiatives such as the 1992 United Nations Conference on Environment and Development, the "Johannesburg Plan of Implementation" was adopted in 2002 under the theme of sustainable development. In addition to development, the Plan called for DRR:

> *"Use low-cost and sustainable materials and appropriate technologies for the construction of adequate and secure housing for the poor, [etc] taking into account their culture, climate, specific social conditions and vulnerability to natural disasters; implement speedily, effectively and comprehensively the enhanced heavily indebted poor countries (HIPC) initiative, ...taking into consideration measures to address any fundamental changes in the economic circumstances of those developing countries with unsustainable debt burden caused by natural catastrophes ."*

As seen, awareness of disaster prevention is growing. However there seems to be a gap between the heightening of awareness in the international society and the implementation of DRR investment. Although 91.2 billion US dollars out of the total international aid given during 1980-2009 was used for disaster related activities, only 3.3 billion US dollars, which is just 3.6 % of the budget, was used for investment in disaster risk prevention. (GFDRR 2012)

1.3 The Importance and Promotion of Disaster Risk Reduction Investment in Developing Countries

DRR investment differs from social infrastructure such as lifelines and transport facilities, in that benefits from DRR investment, even if substantial, may be less visible as its effects are felt after a longer span of time. It is quite likely that, although the provision of social capital and organization of systems related to DRR are generally agreed upon, in developing countries where transportation infrastructure development is behind along with budget restrictions for investment, the reality is that DRR investment ends up being low in priority.

Regarding the preparation for a large-scale natural disaster, its occurrence frequency is low and it may take several decades in order to benefit from the preparation. If it were for small-scale disasters that occur every year, the effects of prevention can be well recognized, however if such disasters become normalized, then the fact that negative impacts are being restrained will become forgotten. As seen, for the people who benefit disaster risk prevention, such preparation has the characteristic that the recognition of its effects becomes gradually forgotten after several years. As a result, the recognition towards the risks of natural disasters becomes inadequate and approaches to disaster risk prevention strategies become delayed/reduced, which causes the repetition of damages when large-scale disasters of

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low frequency occur. As a fact, Fuente (2010) has compared the investment in disaster risk prevention and the amount of investment after the disaster in low and middle income countries with high degrees of exposure to multiple disasters (more specifically Mexico, Colombia, Nepal and Indonesia), and it can be understood that on average the amount invested after disasters is greater than the amount invested before disasters, therefore in developing countries the investment in prevention is still relatively small.

The UN Development Programme (hereafter UNDP) states "every dollar invested prior to the disaster for the purpose of alleviating damages, mitigates seven dollars― worth of economic loss at the time of the disaster" (UNDP 2012). However, the grounds for such estimation are not shown. Such issues were featured in the "Natural Hazards, Unnatural Disasters: The Economics of Effective Prevention" which was published in 2010 by UNISDR and the World Bank. It states that the investment in disaster risk prevention is much more economical compared to investment in restoration after the disaster. This has led to the active promotion of investment in disaster risk prevention.

1.4 The Importance of a Disaster Risk Reduction Investment Evaluation Model

It is important to develop decision-making supporting tools to measure quantitatively the impact on the direct and indirect long-term investment in disaster risk prevention.

The follows are the examples of project evaluations. In Japan, the reduction of damages caused by floods with improved flood controlling facilities is evaluated by using flood simulations. However, the analysis focuses on reduction of damage to physical assets; the improvements in the assets or economic growth after a disaster are not measured. Looking at the evaluation for developing countries, Kerjan *et al.* (2013) applied Cost Benefit Analysis (hereafter CBA) to examine DRR investment, using catastrophe modeling, and to estimate the benefits of DRR measures for houses in St. Lucia in the Caribbean, due to hurricane risks, and in Istanbul, Turkey, due to earthquake risks. Kull et.al (2013) applied the CBA within the Disaster Risk Management (DRM) decision-making process in developing countries and points out the fact that in order to evaluate the magnitude of the indirect damages (impact on life and income) that affected the direct damages is desirable, but it is difficult in reality.

The evaluation of DRR investments in prevention at a national scale has been studied by the International Institute for Applied Systems Analysis (IIASA) using their CATSIM (CATastrophe SIMulation) model. This is used as a DRM tool. It can calculate the optimum combination of financial strategies by predicting a disaster occurrence and estimating the "financial gap," that is, the government's ability to finance the recovery process in the event of a predicted disaster in the future. While we share the view that models are built for practical use, our study, unlike theirs, considers investment in human capital as an important factor in economic growth. Narayan(2003) analyzed the impact of natural disasters on the short-term macro economy of Fiji by using the computable general equilibrium model (CGE model). The study found that cyclone disasters have negative impact on private income, consumption, savings, real GDP and real national welfare. However, their study analyzed short-term impacts; the long-term effects of disaster mitigation or DRR investments remain unanswered.

1.5 The Aim of this Study

As viewed above, in order to develop a method to show the effects of DRR investment in developing countries and to prompt its implementation are definitively useful as a decision-making supporting tool. It is also considered effective to show the effects that DRR investment has on the economic development of developing countries, as well as on the alleviation of poverty.

This study aims to develop a DRR investment evaluation model capable of measuring the effect that risk reduction investment in developing countries prior to a disaster has on the countries' economic growth and on poverty alleviation. Therefore, this study analyzes the factors underlying economic growth in developing countries, and also considers how the model would be used in the future as a decision making supporting tool. First, we identify the factors to be considered in creating our model; we then attempt to develop a basic model structure. Furthermore, after formulating a simple model, a case study is performed with Pakistan as a target country.

2. AN ANALYSIS OF THE COMPONENTS OF ECONOMIC GROWTH IN DEVELOPING COUNTRIES

In order to show the impact of DRR investments on economic growth, it is necessary to understand what types of factors are related to the economic growth in developing countries. In section 2, we review previous studies concerning factors that influence or determine economic growth in developing countries. Furthermore, we examine the relation between GDP and growth factors shown in previous studies.

2.1 Factors Determining Economic Growth in Developing Countries

The general relationship between disasters and economic growth in developing countries was discussed in the previous section. This section discusses specific factors that influence economic growth found in existing studies. On the subject of poverty and economic growth, Nurkse (1953) showed that the poverty of the developing countries would continue for a long time as a vicious cycle of poverty. Kraay and Raddatz (2007) formulated the structure of a poverty trap that is caused by the subsistence constraint. Barro and Martin (1995) explained the mechanism that gives rise to the poverty trap using the dynamic, neoclassical growth model. These and other theories show that the elimination of poverty leads to economic growth.

With regards to the relationship between education and economic growth, there is a stable positive correlation between economic growth and the accumulation of human capital (Barro and Lee 1993). Furthermore, according to Shirai (2004) the accumulation of human capital is important for achieving economic growth. In developing countries, where investment funds are limited, it is important to prioritize the investment considering the level of education, healthcare and other factors of production such as physical capital with its national conditions. Baez et al. (2010) showed that natural disasters could have an important yet detrimental effect on the education stock of a country by affecting complementary infrastructure such as school buildings and access roads. Jacoby et al. (1997) showed that increasing child work participation rates results in the removal of children from schools. Moreover, Alderman et al. (2009) showed that nutritional deficiencies might occur, causing a negative effect on education.

2.2 A Structural Analysis of Economies in Developing Countries

In this section, the relationship between the factors such as poverty and education shown in the previous section and economic growth is verified statistically using macroeconomic data. In order to confirm this relationship macroscopically, we performed a multiple regression analysis of 107 countries, using the related indicators from the World Bank's database "World Development Indicators." A multiple regression analysis is performed in order to clarify what (statistical) indicators are related to GDP (In the analysis, GDP per capita is used as an indicator of economic growth). Equation (1) is used to estimate the results of our analysis, (R^2=0.5), shown as an adequate relational expression to explain GDP. Although the determination coefficient is relatively small, significant results are obtained for the explanatory variables t and p, and for the signs, as shown in Table 1. It is confirmed that disaster damage rates, poverty and education (literacy rate, primary education rate) all have a significant impact on economic growth in developing countries.

$$\text{GDP per capita (current US\$)} = -364\,x_1 - 43.9\,x_2 + 71.2\,x_3 + 26.8\,x_4 - 1640 \quad (1)$$

Table 1. Results of Multiple Regression Analysis

Variable		t-value	p-value	Significance level
x_1	Droughts, floods, extreme temperatures (% of population, average 1990-2009) *This variable is measured by "affected people / total population."	-2.3531	0.0213	*
x_2	Poverty headcount ratio at national poverty line (% of population)	-2.3888	0.0195	*
x_3	Literacy rate, youth total (% of people ages 15-24)	3.2227	0.0019	**
x_4	School enrollment, preprimary (% gross)	2.7197	0.0082	**
Constants		-0.7628	0.4480	

* : 5% significance, ** : 1% significance

3. CONSTRUCTION OF A DYNAMIC MODEL

3.1 Fundamental Objectives of the Model

The objective of analyzing the model is (i) to determine the differences in the degree of direct damages caused by natural disasters depending on the type of reduction measures and the presence or absence of DRR investment; and (ii) to understand the impact of such differences on mid-long term economic growth such as GDP (Figure 3), as well as to measure poverty rates which demonstrate the structural changes of society (Figure 4). Then, simulations on economic growth based on the scenario with DRR investment and the scenario without such investment are carried out. By comparing the anticipated results, we shall be able to evaluate the effects of DRR investment.

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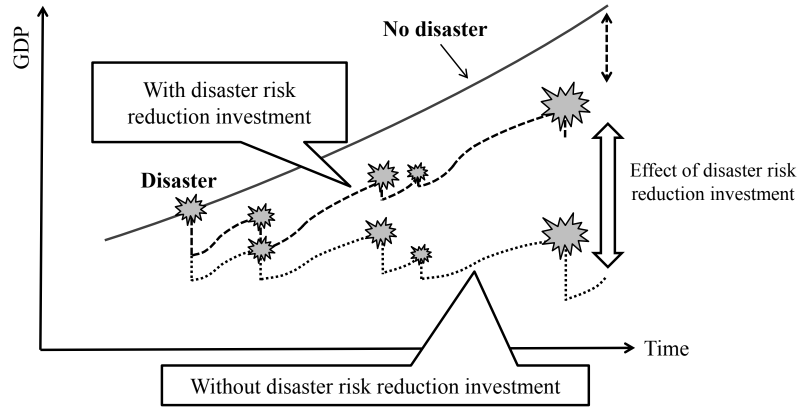

Fig.3. Evaluating the differences in economic growth, with and without DRR investment

Poverty rate is expressed using the Gini coefficient. The cumulative relative frequency of the poor's income is low due to the existence of the poverty trap, resulting in a large Gini coefficient (the area surrounded by the Lorenz curve is large). As the relative income of the poor increases, the Gini coefficient declines (the area surrounded by the Lorenz Curve is small).

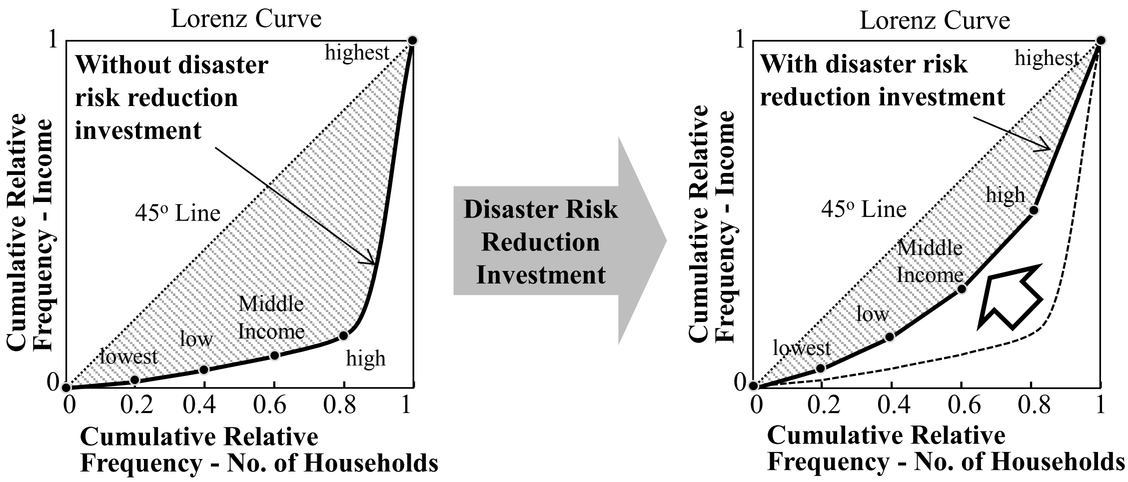

Fig.4. Evaluation of poverty conditions with and without DRR investment

In addition to expressing the economic growth cycle to properly illustrate the characteristics of developing countries, we also include the factors identified in the analysis in Chapter 2 that are closely related to economic growth (namely disasters, poverty and education) and organize our modeling concepts for each element as shown in Table 2.

Taking into account the factors mentioned above and reflecting on the model's objectives, we now build a model focusing on household behavior. The reasons are as follows. (i)Household consumption behavior determines the investment in education. Higher education level leads to higher income. (ii) Disaster damage has large impact on the household's consumption and investment levels in education. (iii) the impact of natural disasters on poorer households are greater than that incurred by firms. This means that for any of these factors, we are able to develop our model by focusing on household behavior.

It is assumed to be important to construct a model that focuses on household consumption patterns, as household labor capital forms the basis of the nation's power. This is due to the fact that, in developing countries, they highly depend on primary industry and the provision of labor capital is necessary to attract foreign capital. On the other hand, although we have focused on households, the model also needs to reflect corporate behavior, as overall GDP is expressed by domestic production.

Table 2. Concepts for Factors Used in Constructing the Model

Factor	Modelling Concept
<Economy> a) Factors expressing economic growth	To express the discrepancies in mid-long term economic growth that results from the variations in direct damage caused by the scale and presence/absence of a disaster.
<Disaster> b) To take account of the damage rates of disasters	To consider different types of disasters such as floods, earthquakes etc. And to also take into account various disaster damage rates that harm human capital such as the rate of human suffering (e.g. inability to attend school); mortality rates; physical asset damage rates for household goods etc.; and rates of financial damage that are a drain on corporate capital.
<Poverty> c) To take the poverty situation into account	To classify the population by social strata and take into account the effect of social strata (the poor and the rich etc.) as regards the disaster.
<Education> d) To take educational factors into account	To express human growth resulting from investment in education, in order to illustrate the difference that levels of education make to income.

3.2 Evaluation Method

Next we consider the framework of a model that satisfies the modeling concepts of each factor outlined in Table 3. We choose a dynamic computable general equilibrium (DCGE) model as the framework for our basic model rather than a static model, which does no more than forecast conditions at a single point in time. The DCGE model is capable of dealing with variations in the accumulation of human capital, <factor d)>, that result from differences in the degree and the presence/absence of disaster, or <factor b)>; and expressing the variations in capital accumulation of GDP, <factor a)>, etc., in each social stratum such as the poverty-stricken, etc., or <factor c)>.

Table 3. Characteristics of Evaluation Method

Evaluation Method	**Summary**	**Characteristics**	
		Merit	**Demerit**
Consumer Surplus Estimation Method	A common technique used in CBA of individual projects.	Evaluation is simple.	It cannot measure the benefit of non-market items.
Macro Econometric Model	Statistically analyzes the cross-relationships between consumption, investment, trade etc. and allows an understanding of their impact on the economy.	Provides an accurate reproduction of the current status and can be used for future projections.	It is difficult to understand the magnitude of each of the multiple effects of a policy; the interrelationships between the variables.
Static Equilibrium Model (CGE etc.)	Able to predict consumption and investment equilibrium at a given, single point in time.	Easier to analyze economic structure and social disparity for a given, single point in time than using dynamic models.	Unable to take into account the effects of time.
Dynamic Computable General Equilibrium （DCGE Model）	Able to take into account supply and demand dynamically.	Capable of making forecasts that take into account factors dynamically (accumulation of human capital etc.) .	**Simulation is difficult.**

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3.3 Structure of the Model

3.3.1 The overall structure of the model

Figure 5 shows (1) the basic concepts; and (2) the overall structure of the model constructed on the basis of the model framework. The model can calculate GDP and the Gini coefficient by creating formulas for household behavior by social strata and corporate behavior. The model predicts the state of equilibrium when variations in damage rates with/without DRR investment are introduced, and is then able to express the effect of DRR investment by calculating the difference between the with/without scenarios. In addition, as we expect the impact of disaster damage to differ for each income level, it expresses household behavior for each of these levels.

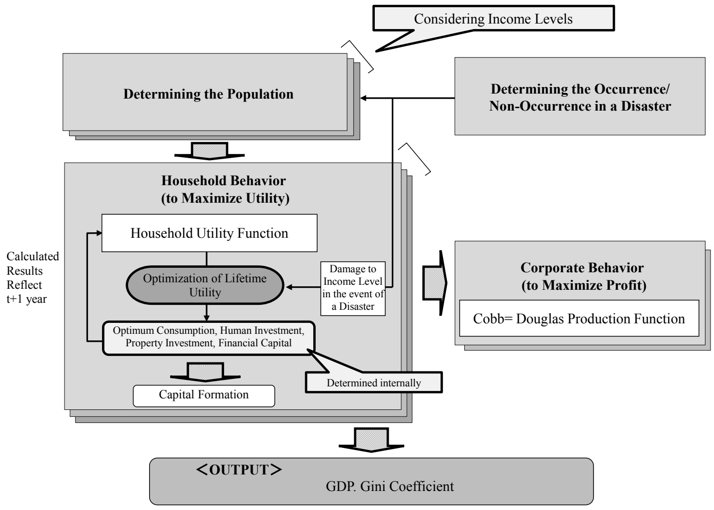

Fig.5. Overall Structure of the Model

3.3.2 Households

a) Preference

Under the condition that all households are aware of the risk of a disaster occurring, we hypothesize a reasonable income distribution for the purpose of maximizing lifetime utility, as shown in Equation (2). Under this scenario, for each period, households allocate their income from labor and interest for consumption; the investment on physical assets; savings; and human investment. When making predictions on the effects caused by the occurrence of a natural disaster, it is desirable to make predictions using the expected value, which is based on the probability of disaster occurrence; however this model does not deal with the probability of disaster occurrence. Therefore in order to compensate for this, we apply the Monte Carlo simulation. Note that, in order to allow the consideration of differences in income levels, we looked at the behavior of 5 social strata (The lowest income, low income, middle income, high income and the highest income households).

$$\max E\left[\sum_{t}^{\infty} u\left(c_j(t), z_j(t)\right)\left(\frac{1}{1+\rho_j}\right)^{t}\right], \tag{2}$$

where

c_j: goods for consumption (non-durable), ρ_j: discount rate, $u(c_j(t), z_j(t))$:utility function,

$z_j(t)$: physical assets, E: expectation operation, t:time period, j:social stratum.

The utility function represents household consumption behavior as shown in Equation (3) and it assumes a popular Stone-Geary type function wherein utility can be obtained from physical assets, as well as from the consumption of composite goods. In this case, if we set $\bar{c}$ as the minimum consumption levels of composite goods, and incorporate them into the utility function, then the marginal utility increases when the respective levels approach $\bar{c}$. This represents a situation where people fall into a poverty trap, as priority is given to consumption and the formation of physical assets, and other investments are ignored.

$$u\left(c_j(t), z_j(t)\right) = \frac{\{(c_j(t)-\bar{c})^{\gamma}\cdot z_j(t)^{1-\gamma}\}^{1-\theta}-1}{1-\theta}\ , \tag{3}$$

where

$\bar{c}$: subsistence level consumption, γ: consumption share parameters, θ: relative risk aversion.

Note that financial assets made up of savings, pass through financial institutions, to become production capital for corporations; consequently, household financial assets contributes to the improvement in productivity in the form of corporate production capital. Meanwhile, human investment improves productivity in the form of human capital in the future. Thus savings and investment in human capital are behaviors that aim to promote increased future consumption. In doing so, as a general rule we set liquidity constraints so that the total sum of consumption and investment for any given period shall never exceed the income from labor and interest for that period; this is done to represent the fact that borrowing becomes difficult, including for the poor, when a disaster strikes.

b) Human Capital

Regarding the production in developing countries, since we consider that not only labor rates but human factors such as education attainment rates also affect productivity, here we set human capital stock. We consider education factors based on the assumption that the process of human capital formation vis-à-vis human investment for income level j is as described below.

$$\Delta h_j = \{\eta(m_j) - \delta_h h_j\}\Delta t, \tag{4}$$

where

δ_h: depreciation rate of human capital , h_j: human capital,

m_j: investment in human capital (education costs etc.), $\eta'(m_j) > 0, \eta''(m_j) \leq 0$.

c) Physical Assets

The process of physical asset formation, such as housing and household goods, for income level j is as below. In addition, this model assumes a format that provides constant wage rates and interest rates, and determines the income uniformly for the current period in line with the size of financial assets and human capital, in order to simplify calculations. In order to account for the damage that disasters cause to physical capital, we determine a term for the physical damage rate.

$$\Delta z_j = (\xi_j - \delta_z z_j)\Delta t - \varphi z_j \varepsilon, \tag{5}$$

where

z_j: physical assets, ξ_j: physical asset formation, δ_z: physical asset depreciation rate,
φ: physical damage rate, ε: dummy variable.

d) Financial Assets

The process of financial asset formation for income level j is as below. In order to account for the damages caused on assets, we determine a term for the capital damage rate.

$$\Delta b_j = (rb_j + wh_j - c_j - \xi_j - m_j)\Delta t - \psi b_j \varepsilon, \tag{6}$$

where

b_j: financial assets, r: interest rate, w: wage rate (per unit of human capital), ψ: financial loss rate

e) Total Assets

The total assets of income level j are defined as the sum of its financial assets and physical assets. The change in total assets is given by the sum of the process of change in financial assets and the change in physical assets.

$$\Delta a_j = \Delta b_j + \Delta z_j$$
$$= \left(ra_j + wh_j - c_j - rz_j - m_j - \delta_z z_j\right)\Delta t - \{\psi a_j + (\varphi - \psi)z_j\}\varepsilon, \tag{7}$$

where a_j: total assets.

3.3.3 Firms

Firms produce goods through the use of human capital and production capital. In this model, we consider one industry and set the production function (GDP function) for the representative industry using a Cobb-Douglas (Douglas 1976) style production function.

$$Y(t) = F(H(t),K(t)) = B(t)H(t)^{\alpha}K(t)^{1-\alpha}, \tag{8}$$

where

B(t): external technological advances, H(t): human capital stock,
K(t): production capital stock, α: share parameter of production function.

3.4 Construction of the model

We check the adequacy and applicability of the model that we have developed. There seems to be various points of view on how to validate a model's adequacy and applicability. Our primary means of validating our model was to focus on its ability to reproduce results similar to those of other published models, using estimated UNISDR statistics for scenarios with or without a disaster (The Asia-Pacific Disaster Report 2012). We confirm the model's adequacy by comparing the reproduction of past results. In addition, we conduct future estimates for the next 30 years to check whether it is possible to express economic growth and poverty alleviation in terms of the presence or absence of investment in DRR.

3.4.1 Procedure

We construct the model with the procedures listed in a)～d) below (Figure 6).

a) We calibrate the parameters of the production function so that the estimated values in the model match the actual GDP results for the year 2004 (the year prior to the disaster.).

b) By applying a damage rate to each disaster, we confirmed whether the model could reproduce the real GDP figures for the years 2005, 2007 and 2010, when disasters actually did occur (Table 4).

c) We compare the forecasted values calculated through the use of the model with GDP estimates formulated by UNISDR on the basis of no disaster occurring, and confirm whether we are able to reproduce the current status. At this time, how the decade of the predicted value is matched is a criterion of reproducibility.

d) We carry out future projections for a scenario with DRR investment, and a scenario without investment.

Table 4. Disaster damage data in Pakistan

	2005.10	2007.8	2010.7
Disaster	Earthquake	Flood	Flood
No. of death	73,338	44	1985
No Total Affected	5,128,309	20	20,359,496
Cost of economic damage (000 US$)	5,200,000	327,118	9,500,000

Source: EM-DAT database (http://www.emdat.be/result-country-profile)

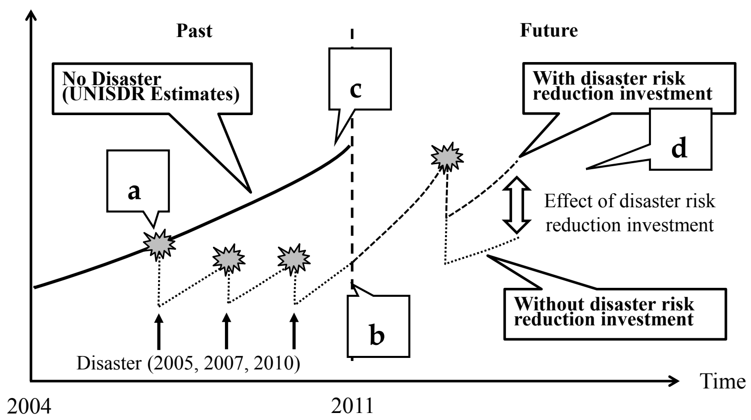

Fig.6. Model Verification Procedures

3.4.2 Input data

In order to check the adequacy and applicability of the model, we used data from Pakistan in 2004. Tables 5-7 show the categories of input data and their initial values. The data presented in Table 6 correspond to the initial values. Therefore, these data will be updated each period of the calculation.

Table 5. Socio-economic Parameters

Macroeconomic data	Initial value
Population(household) nj	1st(lowest income) : 3,599,540 2nd(low income) : 4,090,815 3rd(middle income) : 4,465,904 4th(high income) : 4,940,097 5th(highest income) : 5,994,618
Population change rate σ	2.9% (average between 1975-2003)
Discount rate ρ	0.12 (F/S in Pakistan apply 12% or 15%)
Depreciation rate of financial capital stock δ	0.2 (depreciation rates by asset use 10-30%)
Rental rate r	0.15 (reference discount rate)
Growth rate of exogenous technological change B	0%
Labor relative share α	0.63 (Input Output table of Pakistan(1955))

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Table 6. Household data

Household data	Initial value
Consumption(nondurable) c_j	Determined endogenously
Physical assets z_j	1st(lowest income) : 84\$ 2nd(low income) : 151\$ 3rd(middle income) : 181\$ 4th(high income) : 197\$ 5th(highest income) : 313\$ (source: Household Integrated economic survey in Pakistan)
Relative risk aversion θ	2.0
Minimum subsistence consumption amount $\bar{c}$	\$400
Financial savings (financial investment) bj	1st(lowest income) : 302\$ 2nd(low income) : 392\$ 3rd(middle income) : 451\$ 4th(high income) : 568\$ 5th(highest income) : 1,126\$ (source: Finance Division, Government of Pakistan)
Investment for physical assets ξj	z_j is given, determined endogenously
Human capital hj	1st(lowest income) : 41% 2nd(low income) : 50% 3rd(middle income) : 54% 4th(high income)) : 56% 5th(highest income) : 71% (Set by Enrollment rate in primary education from Pakistan MDGs report)
Human capital investment per house hold mj	1st(lowest income) : 16\$/household 2nd(low income) : 52\$/ household 3rd(middle income) : 68\$/ household 4th(high income) : 76\$/ household 5th(highest income) : 135\$/ household (source: MDGs report)
Depreciation rate of human capital δh	0%

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Wage rate w	73.7 Set by income and enrollment rate by social strata
Human capital formation ηj	Set by investment for education by social strata and enrollment rate y = 14.16ln(x) + 1.541 y: enrollment x: investment for education
Share parameter of consumption γ	0.6 (source: Household integrated economic survey)

Table 7. Disaster data

Disaster data	Initial value
Occurrence of disaster at T q(t)	Depends on the result of the simulation
Physical damage rate φ	same as the financial loss rate
Financial loss rate Ψ	Earthquake : 0%～22.9% Flood : 0%～40.8% Storm : 0%～6.5% (source: EM-DAT, World Bank)

3.4.3 Damage rate function

In making future projections, we determine the necessary scale and the occurrence of disasters as below. We use EM-DAT and the World Bank database for the disaster damage rates and estimate the damage rate functions for physical damage and financial loss, using historical data on disasters (classified as earthquakes, floods and storms) that have occurred in Pakistan over the past 36 years. Concretely, we estimate the damage rate function by regression analysis between the disaster damage rate and the cumulative relative frequency of its rate which is obtained by ascending to the disaster damage rates in the past 36 years (refer to Figure 7). Note that we assume the damage rates of production capital and households' physical assets to be equal constraints of the available data.

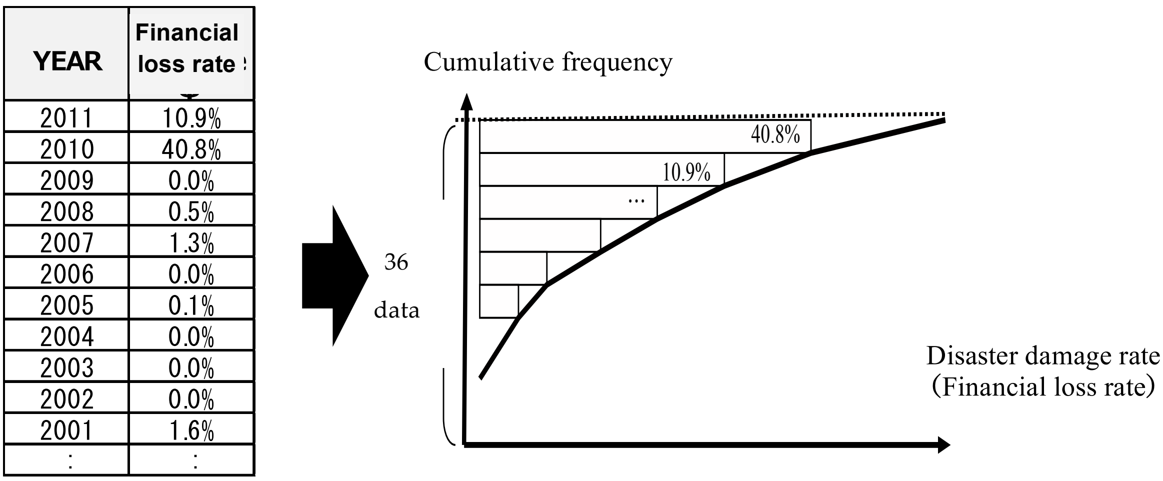

Fig.7. An illustration of how historical data on damages is used to determine the damage rate function

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In order to verify the effectiveness of DRR measures, having grasped the relationship of damage rates from the specifics of the essential DRR measures, we need to run a simulation of the growth process with such measures and compare it to the growth process without such measures. However, due to the constraints of the data, we were limited to the assumption that DRR measures could reduce the maximum disaster damage rates incurred in the past by half.

3.4.4 Predictions

a) Reproducing Current Conditions

Figure 8 shows the results produced by our model. When comparing the values from the model with actual results obtained when a disaster occurred and UNISDR estimated values when there was no disaster, we were able to broadly reproduce the current conditions in a similar order. Consequently, we were able to confirm the validity of applying this model as a method to describe the differences in economic growth, i.e. differences that stem from the presence or absence of DRR.

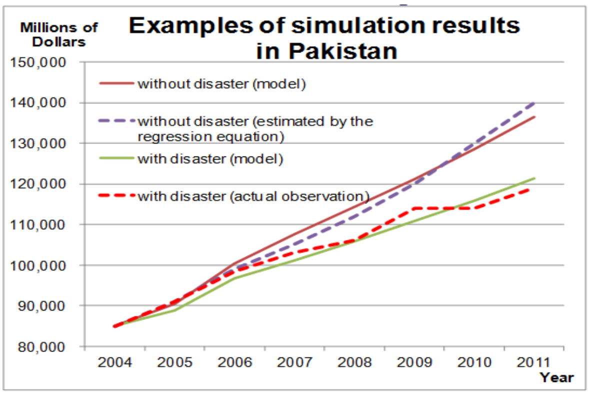

Fig.8. Comparison between the Estimates of our Model and the Estimates of UNISDR.

b) Predictions

When making predictions, we need to establish the effects of DRR measures. Once we understand the relationship between damage rates and how they depend on the content of primary DRR measures, we then need to simulate a growth scenario with risk reduction measures in place and compare it to one without such measures in place. The graph below is an estimation of the future growth in GDP and Gini Coefficient after performing the Monte Carlo simulations 100 times, under consideration of both cases with and without DRR investment. In this estimation, apart from with and without DDR, there are notations of the mean, ±1σ and ±2σ (σ: standard deviations). As a result, the scenario with DRR measures in place predict that by 2042 economic growth would be around 25% higher, with an improvement of approximately 0.5% in the Gini coefficient when compared to the scenario with no such measures. This confirms that the model could be used for making predictions.

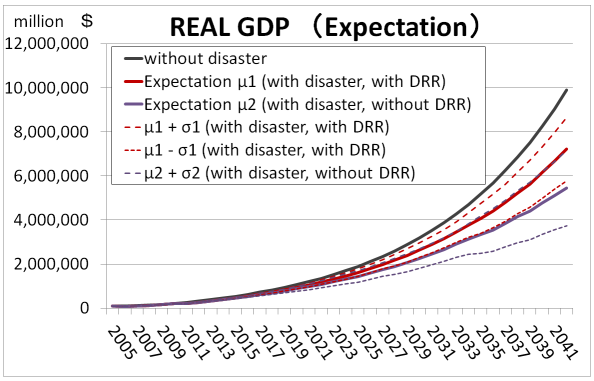

Fig.9. GDP Growth Process

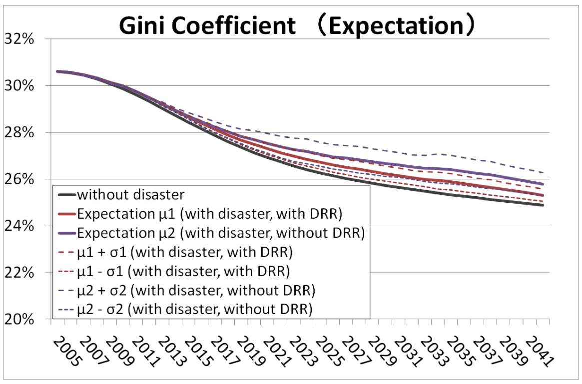

Fig.10. Trends in the Gini Coefficient

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4. CONCLUSION

4.1 Outcome

This study identifies the requirements needed to create a model for evaluating DRR investment at a national or a regional macro level, and has developed the basic framework for such a model. Having made some simplifications based on the basic framework, we created a straightforward dynamic model capable of measuring the effects of investment in DRR measures. As a result of applying the model to Pakistan, we were able to confirm its adequacy; we were able to reproduce the current circumstances of that country and notice that even if Pakistan is hit by a disaster in the future, investing in risk reduction measures is expected to allow economic growth to continue and help alleviate poverty. Despite remaining issues such as the need for refinements to our model, given the above result, it can be said that we have constructed a framework for a basic model for evaluating investment in DRR measures based on the specific characteristics of the economy and the disasters faced by a country or region.

4.2 Future works

It was our intention to attempt the creation of a simple model to measure the effects of DRR investment. Consequently, there are still issues due to the fact that we have been unable to deal with the probability of disaster occurrence, and reach strict equilibrium. Therefore, in the future we need to address the following issues.

a) Dealing with the Probability of a Disaster Occurrence

This model is based on the premise that households behave rationally in recognizing that a disaster will take place at some time in future. However, strictly speaking it is optimal to deal with values that indicate when disasters are anticipated.

b) Considering Firm Behavior

The dynamic model that we construct is structured simply so that household behavior determines production itself. However, incorporating the general equilibrium theory in the strictest sense requires us to create a model that also takes into account the profit optimizing behavior of firms.

c) Establishing Disaster Damage Rates

There are also issues on how to account for the impact of a disaster and establish damage rates by industry, income levels, etc., according to the specific characteristics of the disaster and the region where it occurs. Furthermore, we need to know the extent by which damage rates are reduced depending on the various structural and non-structural risk reduction measures, so that we may determine the investment efficiencies of individual measures.

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