MEASURING MULTIPLE BENEFITS OF DISASTER RISK REDUCTION INVESTMENT AND GROWTH OF DEVELOPING COUNTRIES

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This study develops a model that aims at quantitatively evaluating disaster fiscal policy in developing countries. Specifically, we formulate a dynamic stochastic macroeconomic model that incorporates multiple hazards such as flood and drought and multiple disaster mitigation measures such as dikes, dams, and insurance. In addition to foci on the allocation of limited resource among plural stocks and between pre-disaster prevention and post-disaster reconstruction, we also focus on “co-benefit” whereby disaster prevention facilities bring benefits beyond mere disaster mitigation toproduction. The study includes case studies targeting African countries.

Key Words : *disaster risk reduction policy, economic growth, developing country*

1. TITLE PAGE

We formulate a dynamic macroeconomic model that contributes to disaster fiscal policy. The model captures a forward-looking rational expectation of a representative household and firm, whose perception of future earnings and losses will be affected by the prevailing levels of multiple types of disaster risk and disaster risk reduction (DRR) investment. The changes in expected utility of households and expected profit of production sectors will then affect other aspects of economic activities such as the optimal levels of savings and investment, demands for labor and capital, shares of import/export, and ultimately a country’s GDP growth trajectory.

Within stochastic dynamic optimization framework, the society in recovery process from one disaster is simultaneously exposed to risk of the next disaster. Therefore, the best allocation of resource between productive investment, which includes reconstruction of production infrastructure, and mitigation is analyzed.

The model is capable of quantifying the macroeconomic costs and benefits of investment in DRR, including how the provision of safer environments fosters productive investments and private savings and how multi-purpose DRR investments bring co-benefits such as the improvement in public services provision and other socioeconomic gains.

2. THEORETICAL FOUNDATION

(1) DRR investment in macroeconomic modeling

Economic evaluation of disaster and DRR investment is a part of the risk assessment process that is composed by transdisciplinary integration of models in multiple areas (Hoffmann, 2011). Among economic models that explicitly deal with market transactions, the most commonly used approaches are input–output (I-O) (e.g., Hallegatte, 2014; Koks et al., 2015) and Computational General Equilibrium (CGE) (e.g., Giesecke et al., 2012; Rose and Shu-Yi, 2005) modelings. As for dynamic frameworks, agent-based models (e.g., Hochrainer-Stigler and Poledna, 2016) that are associated with market disequilibrium have been recently used.

Applications of dynamic macroeconomic models to natural disaster issues are being developed. Some studies pay exclusive focus to the behavior of financial markets (e.g., Barro, 2006, 2009; Gourio, 2008; Rietz, 1988; Wachter, 2013). Other studies include the impacts of disasters on real assets and production in dynamic models, such as the Dynamic Stochastic General Equilibrium (DSGE) model (e.g., Keen and Pakko, 2007; Posch and Trimborn, 2011; Segi et al., 2012) and the endogenous business cycle model (Hallegatte and Ghil, 2008; Hallegatte et al., 2007). Recent studies used dynamic macroeconomic models to evaluate the macroeconomic impacts of disasters in disaster-prone countries (Cantelmo et al., 2019; Yokomatsu et al., 2019) and in small developing states (Marto et al., 2019). Among them, Ishiwata and Yokomatsu (2018) propose the accounting framework of decomposing DRR policy effect into the ex-post damage mitigation effect (PDME) and the ex-ante risk reduction effect (ARRE).

(2) Co-benefits of DRR investment

The latest literature on the economics of DRR investment increasingly emphasizes that DRR investment protects productive assets and lives and, when implemented wisely, yields multiple additional benefits. Such benefits are increasingly referred to as "multiple dividends" (Tanner et al. 2015), namely:

- The 1st dividend – reducing disaster impact. DRR investments reduce immediate disaster impacts (human and direct economic losses);
- The 2nd dividend – fostering economic potential. DRR investments foster a safer environment for investment and enhanced economic activities (e.g., increasing business and capital investments, increasing fiscal stability and access to credit);
- The 3rd dividend – producing co-benefits. DRR investments produce additional co-benefits (e.g., environmental and societal benefits).

The model of this study is designed to account for the multiple benefits associated with DRR investment. These benefits can be estimated with regards to both the growth effects of DRR investment on disaster risk reduction and also to its co-benefits. These growth effects of DRR investment may further be considered as Ex Post Damage Mitigation Effect (PDME), Ex Ante Risk Reduction Effect (ARRE), and Co-benefit Production Expansion Effect (CPEE). We extend the accounting framework of Ishiwata and Yokomatsu (2018) by incorporating CPEE that describes the additional co-benefits that could be produced as a result of DRR investment.

Fig. 1 illustrates the multiple benefits that could be provided by DRR investment. The blue solid line and the green solid line represent GDP paths without and with a DRR investment policy, respectively. Disaster occurs and GDP drops at time t_1. On the other hand, the blue and the green dashed lines represent their

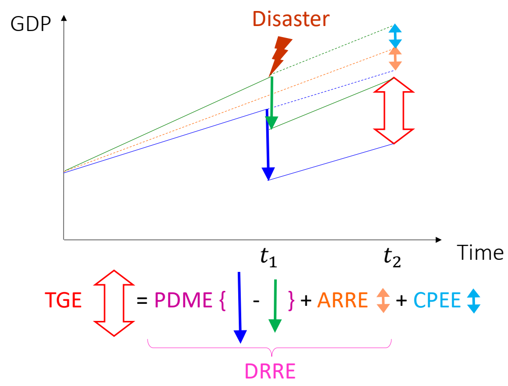

Fig.1 Decomposition of Total growth effect (TGE)

paths in the hypothetical case in which the disaster did not occur at time t_1. Now, we evaluate the effect of DRR investment at the end of the planning period, t_2. Total Growth Effect (TGE) of the policy in terms of GDP is decomposed into Disaster Risk Reduction Effect (DRRE) and Co-benefit Production Expansion Effect (CPEE), where DRRE is composed of PDME and ARRE. Since CPEE is obtained in non-disaster times, the sum of ARRE and CPEE is a benefit that is obtained even without an actual arrival of disaster. The model provides such an accounting of DRR investment effects.

3. MODEL

(1) Markets

Economic space consists of one country that is composed of two spatial areas, two business sectors, and an open economy. All markets are perfectly competitive under symmetric and perfect information. Two sectors are identified by Agricultural and Composite good sectors. The two types of goods are used for intermediate inputs of production, consumed by households in the country, and exported to foreign countries. They are different in two features; first, Agricultural good is different from Foreign agricultural good, therefore they are exchanged with each other in international trade (Hereafter, for notational convenience, “Agricultural good” means “Domestic agricultural good”.), while Composite good is perfectly substitutable with one in international market. Second, Agricultural good is perishable, meaning that they cannot be stocked to be consumed in a next period, while Composite good is unperishable, hence it is used for investment to become a physical capital for production.

Foreign bond is transacted in the international market and functions as a financial vehicle for lending and borrowing. It is issued also for financing investments in infrastructure for production and for disaster risk reduction (DRR stock).

The number of Households (hereafter refer to as domestic households) grows with a constant growth rate. Labor market is closed within the country, where households inelastically supply their labor. Households are assumed to have an infinite time horizon, to be identical, forward looking, and rational, with perfect perception of disaster risks and schedules of policies, and to maximize expected lifetime utility.

Under these assumptions, the model economy achieves the Pareto-optimal allocation. Therefore, it can be solved by dealing with "the planning problem," in which one representative agent allocates all the resources over an infinite time horizon to maximize household lifetime expected utility, describing the equivalent allocation in a competitive equilibrium (Stokey, Lucas, & Prescott, 1989). Moreover, although government does not appear explicitly in the model, allocation is equivalent to one with fiscal policies based on lump-sum tax and the household's expected lifetime utility as an objective function of government. Following most of Real Business Cycle (RBC) models, we deal with the equivalent first-best problem.

(2) Technology and population growth

The model economy grows both by endogenous capital deepening and exogenous technical progress. Although one of our main concerns is on how the former is affected by disaster risk reduction (DRR) policies, we recognize that the latter is also quantitatively non-negligible when we think about progress in an area of information system, for example, where most of new ideas have developed overseas or in international society.

We assume the Harrod-neutral technical progress which increases the efficiency of labor. Let $A(t)$ be the Harrod-neutral technology level, and $L(t)$ be the total amount of labor, that is, the total number of households. Now the labor force in efficiency units is given by the product $A(t)L(t)$, and increases faster than the number of workers, $L(t)$. Thus, technical progress of this form is characterized by labor-saving.

We assume that $A(t)$ and $L(t)$ develop with the constant growth rates, ζ_A and ζ_L, respectively, as follows:

$$A(t+1) = A(t) \cdot (1+\zeta_A), \quad A(0) = 1 \tag{1a}$$

$$L(t+1) = L(t) \cdot (1+\zeta_L) \tag{1b}$$

$$L(0) = L_0 = 1 \text{ (standardized)} \tag{1c}$$

We will transform the model into the one composed of the effective labor unit so that we detrend the model with an intention of preventing variables from diverging to infinity. Variables of the effective labor unit are obtained by dividing their (original) totalized values by $A(t)L(t)$.

(3) Hazards

Let $t = 0,1,\cdots$ be a period of time whose unit is given by a year. We assume two kinds of hazards: flood and drought. The scale of flood in Period t is represented by a random variable ϕ_t that can take one value out of a set $\{0, 1, \cdots, \phi_{\max}\}$ where $\phi_t = 0$ represents a case of no flood damage in Period t. Note that, precisely, ϕ_t represents the sum of damage in one period especially in cases that the probability that floods occur more than twice is not negligible. $P_F(\phi)$ represents the probability of flood of the scale ϕ. Thus, $\sum_\phi P_F(\phi) = 1$ holds.

Drought is identified as the smallest scale of yearly precipitation represented by $\psi_t = 1,2,\cdots,\psi_{\max}$. Larger precipitation ψ_t results in larger production. $P_P(\psi)$ represents the probability of precipitation of the scale ψ, which meets $\sum_\psi P_P(\psi) = 1$. For the both hazard, we assume the stable stochastic processes meaning that the probabilities, $\{P_F(\phi)|\phi = 0,1,\cdots,\phi_{\max}\}$ and $\{P_P(\psi)|\psi = 0,1,\cdots,\psi_{\max}\}$, do not change throughout.

Against the both hazards, multiple DRR measures are considered in the model: construction of dams and dikes, flood and drought insurance, exposure management, and application of drought resistant crop. Details are explained subsequently.

(4) Physical stock formation

The model incorporates multiple economic stocks, levels of which change over time. Letting J_ι be stock $J\,(= K, H, G_P)$ at place $\iota\,(= S, V)$, where K represents firms' production capital, and H household asset, G_P infrastructure for production, S Safer place, and V Vulnerable place. Formation process is given as follows:

$$J_S{}^-(t+1) = (1-\delta)\cdot J_S(t) + L(t)\{\eta_{JS}(t) + \eta_{JR}(t)\} \tag{2a}$$

$$J_V{}^-(t+1) = (1-\delta)\cdot J_V(t) + L(t)\{\eta_{JV}(t) - \eta_{JR}(t)\} \tag{2b}$$

$$J_\iota(t+1;\phi_{t+1}) = \left(1-\omega_{J\iota\phi}\right)J_\iota^-(t+1) \tag{2c}$$

where $J_\iota^-(t+1)$ represents the stock level at the beginning of Period $t+1$ and before a flood arrives, while $J_\iota(t+1;\phi_{t+1})$ represents its level after flood of the scale ϕ_{t+1} arrives. δ is the depreciation rate, and $L(t)$ the total number of households, and $\eta_{J\iota}(t)$ $(\iota = S, V)$ the per-household investment, $\eta_{JR}(t)$ the stock relocated from Place V to Place S in stock J_ι in

Period t. $\omega_{J\iota\phi}$ is the damage rate caused by flood of the scale ϕ_{t+1}, and depends on the levels of other stock variables such as dam and dike. On the other hand, we assume for computational convenience that dam $D_M(t)$ and dike $D_K(t)$ are not damaged by flood, and moreover, construction is completely scheduled at the initial period of time.

The total amount of labor $L(t)$, and land T_{aj} $(j = I, R), T_c$ can also be regarded as a part of stocks in society, where T_{aI} and T_{aR} are irrigable land and rainfed land for agriculture respectively, and T_c is land for Composite-good production. We assume that they are reduced to be $(1-\omega_{L\phi})L(t)$, $(1-\omega_{aT\phi})T_{aj}$ $(j = I, R)$, and $(1-\omega_{cT\phi})T_c$, respectively, in the period of disaster of the scale ϕ, but will recover itself without cost by the end of each period. Moreover, the technology level $A(t)$ is assumed not to be affected by disaster.

(5) Production technologies

The economy´s domestic production activities are expressed in a series of equations known as the nested production function structure. Production technologies of Agricultural sector $(i = a)$, and Composite good sector $(i = c)$ are given by the following equations:

$$Y_i = \min\left[F_i(\cdot),\ \frac{Y_{ai}}{\kappa_{ai}}, \frac{Y_{ci}}{\kappa_{ci}}\right], \tag{3a}$$

$$F_i(\cdot) = \alpha_i(1+\sigma_i\varepsilon_t){G_P}^{\alpha_{GPi}} \cdot \\ \{(1-\omega_{L\phi})AL_i\}^{\alpha_{Li}}{K_i}^{\alpha_{Ki}}(ALZ_i)^{\alpha_{Zi}}(ALX_{i\phi\psi})^{\alpha_{Xi}} \tag{3b}$$

where $F_i(\cdot)$ is the value added function. Y_{ai} and Y_{ci} are intermediate inputs of Agricultural good and Composite good (We will often call "Ag-good" and "Cm-good", respectively, for notational convenience.), respectively, while κ_{ai} and κ_{ci} are their input-output coefficients. We assume that the total factor productivity (TFP) of the value added function includes a random shock, ε_t, as a white noise. $L_i(t)$ and $K_i(t)$ are labor and capital rented by Sector i, respectively. $X_{i\phi\psi}(t)$ represents the functional level of the land-water (LW) composite under the flood scale ϕ and the precipitation scale ψ, whose structure is assumed by Eqs. (4a) and (4b) below. α_i and σ_i are scale parameters, and $\alpha_{GPi}, \alpha_{Li}, \alpha_{Ki}, \alpha_{Zi}$ and α_{Xi} are share parameters of Cobb-Douglas technology whose sum is unity. $A(t)L(t)$ are applied as multipliers for technical reason that we deal with the per-effective-labor unit in calculation process. It is emphasized that the level of LW composite is stochastic because land and water are exposed to the risks every period of time. $X_{a\phi\psi}(t)$ is assumed to be composed as follows:

$$X_{a\phi\psi}(t) = X_{aI\phi\psi}(t)^{\alpha_{XaI}}X_{aR\phi\psi}(t)^{\alpha_{XaR}} \tag{4a}$$

$$X_{aj\phi\psi}(t) = X_{aj0}\{(1-\omega_{aT\phi})T_{aj}\}^{\alpha_{aTj}} \cdot \\ W_{Eaj\psi}(t)^{\alpha_{aWj}}\ (j = I, R) \tag{4b}$$

$X_{aI\phi\psi}(t)$ and $X_{aR\phi\psi}(t)$ are the LW composite of irrigable land $(j = I)$ and rainfed land $(j = R)$, respectively. $W_{Eaj\psi}(t)$ is the effective amount of water. α_{XaI}, α_{XaR}, α_{aTj}, and α_{aWj} $(j = I, R)$ are share parameters that meet $\alpha_{XaI} + \alpha_{XaR} = 1$ and $\alpha_{aTj} + \alpha_{aWj} = 1$ for $j = I, R$. X_{aj0} $(j = I, R)$ is a scale parameter. Availability of water is assumed as follows:

$$W_{Eaj\psi}(t) = \{\mu_{Wa}(\psi)\rho + (1-\rho)\} \cdot W_{aj\psi}(t) \\ (j = I, R) \tag{5a}$$

$$W_{aI\psi}(t) = \zeta_\psi T_{aI} + W^I_{a\psi}(t) + W^G_{a\psi} \tag{5b}$$

$$W_{aR\psi}(t) = \zeta_\psi T_{aR} \tag{5c}$$

ρ is the percentage of drought resistant crop that is introduced in agricultural production. $\mu_{Wa}(\psi)$ (≥ 1) represents the effect of drought resistant crop. $W_{aI\psi}(t)$ and $W_{aR\psi}(t)$ are the volumes of water input to irrigated and rainfed agriculture, respectively, where the former is given by the sum of rainfall $\zeta_\psi T_{aI}$, irrigation river water $W^I_{a\psi}(t)$, and irrigation ground water $W^G_{a\psi}$, and the latter, only by rainfall $\zeta_\psi T_{aR}$.

Likewise, LW composite and the available water of Cm-sector are given in the following way:

$$X_{c\phi\psi}(t) = X_{c0}\{(1-\omega_{cT\phi})T_c\}^{\alpha_{cT}}W_{c\psi}(t)^{\alpha_{cW}} \tag{6a}$$

$$W_{c\psi}(t) = W^S_{c\psi}(t) + W^G_{c\psi} \tag{6b}$$

where α_{cT} and α_{cW} are share parameters whose sum is unity, and X_{c0} is a scale parameter. $W_{c\psi}(t)$ represents the available water of Cm-sector, composed of water drawn by water system, $W^S_{c\psi}(t)$, and ground water $W^G_{c\psi}$.

(6) DRR measures and co-benefit

We examine effects of combinations of multiple DRR measures that include dam, dike, flood and drought insurance, exposure management, and drought resistant crop. Stocks of dam $D_M(t)$ and dike $D_K(t)$ mitigate the flood damages, namely, the flood damage rates of stocks are given by decreasing functions both of $D_M(t)$ and $D_K(t)$ like

$$\omega_{J\iota\phi} = \Omega_{J\iota\phi}(D_M(t), D_K(t), J_\iota^-(0)) \tag{7}$$

for all (J, ι) that are exposed to the flood, and the flood scale ϕ, where parameters of each function are estimated with data.

Households prepare against flood damage by making insurance contracts on production capital $K_\iota(t)$, household asset $H_\iota(t)$, and infrastructure for production $G_{P\iota}(t)$ with an insurance company in international market. Insurance is defined by the following set:

(insurance premium, {Insurance money for the scale-ϕ-flood})
$=\left(\xi_{J\iota F}(t)\Xi_{J\iota F}(t)J_\iota(t), \{\omega_{J\iota\phi}(t)\Xi_{J\iota F}(t)J_\iota(t) \mid \phi = 0,1,\cdots,\phi_{\max}\}\right)$

(for $J = K, H, G_P$ and $\iota = S, V$), (8)

where $\Xi_{J\iota F}(t)$ $\left(0 \leq \Xi_{J\iota F}(t) \leq 1\right)$ is the insurance coverage that households determine every period to have $\Xi_{J\iota F}(t)J_\iota(t)$ insured. Therefore, if the stock is damaged by the rate $\omega_{J\iota\phi}(t)$, insurance money $\omega_{J\iota\phi}(t)\Xi_{J\iota}(t)J_\iota(t)$ is paid to households. $\xi_{J\iota F}(t)$ is the premium rate that is determined by:

$$\xi_{J\iota F} = \xi_{0J\iota F} \sum_{\phi} P_F(\phi)\omega_{J\iota\phi}(t) \tag{9}$$

where $\xi_{0J\iota F}$ (≥ 1) is a parameter that represents “the risk premium” or the mark-up rate in the flood insurance market. If $\xi_{0J\iota F} = 1$, the flood insurance system would be fair insurance. However, due to a peculiar feature of disaster insurance market, that is, coincidence of large-scale insurance claims that could drive insurers to insolvency, insurers request the large risk premium to prepare for that risk. Thus, $\xi_{0J\iota F}$ is usually not set at one but larger.

Drought insurance is formulated in the same manner. Insurance premium and insurance money are defined as follows:

(insurance premium, {Insurance money for the scale-ψ-flood})
$=\left(\xi_D\Xi_D(t)I_D(t), \{\pi(\psi)\Xi_D(t)I_D(t) \mid \psi = 0,1,\cdots,\psi_{\max}\}\right)$ (10a)

$\xi_D = \xi_{0D} \sum_\psi P_P(\psi)\pi(\psi),$ (10b)

where ξ_D denotes the premium rate, $\Xi_D(t)$ $(0 \leq \Xi_D(t) \leq 1)$, the insurance coverage, $I_D(t)$, the full scale of insurance, and ξ_{0D} (≥ 1), the risk premium in the market.

Moreover, exposure management is defined by relocation of production capitals and infrastructure, and household assets from Vulnerable place to Safer place, and represented by $\eta_{JR}(t)$ $(J = K, H, G_P)$ in Eq.(2a) and (2b). It is associated by adjustment cost, $L(t) \cdot \Gamma_{JR0} \cdot \eta_{JR}(t)^2/j_S(t)$, where $j_S(t) = J_S(t)/L(t)$ and Γ_{JR0} is a parameter.

Drought resistant crop achieves higher efficiency in water intake for growth as is represented by $\mu_{Wa}(\psi)$ in Eq.(5a). Its seeds are supplied in international market, and annual expenditure for purchasing them is equal to $\Theta_{\mathrm{DRC}} \cdot \rho \cdot A(t)L(t) \cdot (T_{aI} + T_{aR})$ where Θ_{DRC} is a parameter.

Furthermore, we focus on multiple functions of dam; in addition to the flood damage mitigation as represented by Eq.(7), the available amounts of the river irrigation water $W^I_{a\psi}(t)$, the water withdrawn by water system and used by Cm-sector $W^S_{c\psi}(t)$, residential water $W_{r\psi}(t)$, and electric power $Z_i(t)$ $(i = a, c)$ are increasing with the number of dam;

$$W^I_{a\psi}(t) = W^I_{a\psi}\left(D_M(t)\right), \quad W^S_{c\psi}(t) = W^S_{c\psi}\left(D_M(t)\right),$$
$$W_{r\psi}(t) = W_{r\psi}(D_M(t)), \quad Z_i(t) = Z_i(D_M(t)) \ \ (i = a, c) \tag{11}$$

Parameters of these functions are estimated by data. The co-benefits of dam will be evaluated in terms of GDP.

(7) Financial stock formation

Households can make deposit and withdrawal to manage timings of expenditure. They can go into debt within a certain range. Such an intertemporal value management is implemented by transacting foreign bonds in the international market where an interest rate is given exogenously and assumed to be constant throughout. This management through bond transaction is mathematically equivalent to one on a bank account. Moreover, by aggregating over all the nations, the position of the aggregated foreign bond stock is equivalent to the level of households’ net foreign asset. Let $B(t)$ be the position of the total foreign bond stocked in Period t, and its sign be consistent with asset accumulation. Formation process is represented as follows:

$$\begin{aligned}B^-(t+1) &= (1+r)B(t) + \mathrm{GDP}(t) - p_a(t)Q_a(t) \\ &-Q_c(t) - p_{af}Q_{af}(t) - \Theta_{\mathrm{DRC}} \cdot \rho AL \cdot (T_{aI} + T_{aR}) \\ &-L(t) \sum_{J=K,H,G_P} \left[\sum_{\iota=S,V} \eta_{J\iota}(t)\left\{1 + \Gamma_{J\iota 0} \cdot \frac{\eta_{J\iota}(t)}{j_\iota(t)}\right\} + \Gamma_{JR0} \cdot \frac{\eta_{JR}(t)^2}{j_S(t)}\right] \\ &-L(t) \sum_{J=D_M,D_K} \Theta_J \cdot \eta_J(t)\left\{1 + \Gamma_{J0} \cdot \frac{\eta_J(t)}{j(t)}\right\} \\ &- \sum_{J=K,H,G_P} \sum_{\iota=S,V} \xi_{J\iota F}\Xi_{J\iota F}(t)J_\iota(t) - \xi_D\Xi_D(t)I_D\end{aligned} \tag{12a}$$

$$\begin{aligned}B(t+1;\phi_{t+1},\psi_{t+1}) &= B^-(t+1) \\ &+ \sum_{J=K,H,G_P} \sum_{\iota=S,V} \omega_{J\iota\phi}\Xi_{J\iota F}(t)J_\iota(t) + \pi(\psi_{t+1})\Xi_D(t)I_D\end{aligned} \tag{12b}$$

$$\lim_{t\to\infty} E\left[\tilde{b}(t)\beta^t\right] \geq 0 \tag{12c}$$

As with the notation of physical stocks J_ι, $B^-(t+1)$ and $B(t+1;\phi_{t+1},\psi_{t+1})$ represent the stock level at the beginning of Period $t+1$, and the level after the-ϕ_{t+1}-scale flood and the-ψ_{t+1}-scale precipitation arrive, respectively. r is the interest rate. $\mathrm{GDP}(t)$ is the gross domestic product. $Q_a(t), Q_c(t)$, and $Q_{af}(t)$ represent domestic households’ consumption of Ag-goods, Cm-goods, and foreign Ag-goods, respectively. The second term of the second line of Eq.(12a) represents payment for seeds of drought resistant crop. $\eta_{J\iota}(t)$ is the per-household level of investment in stock $J\iota$. $j\iota(t)$ is the per-household level of stock $J\iota(t)$. The third and fourth lines identify costs of investment in the physical stocks, where the second terms in the curly brackets represent the adjustment cost of investment, meaning that the second term does not result in increase in stocks as is checked on Eq.(2a) and (2b). The fifth line represents payment for the insurance premium.

Equation (12b) indicates that insurance money is obtained after occurrence of flood and drought, amount of which is determined by the flood and precipitation scales ϕ and ψ. Inequality (12c) represents No-Ponzi-Game (NPG) condition that is defined on the variable of the effective labor unit: $\tilde{b}(t) = B(t)/\{A(t)L(t)\}$. NPG condition means that debt will not grow too fast so that its growth rate must be smaller than the discount rate (interest rate) in the infinite future.

(8) Household's utility

We formulate the dynamic optimization problem of the representative household (hereafter refer to as Household) in order to directly derive the aggregate demand functions. One-period utility function of the representative household of the effective labor unit is represented as follows:

$$U\left(\tilde{q}_{aa}(t), \tilde{q}_c(t), \tilde{h}(t), \tilde{w}_{r\psi}(t), \tilde{b}(t)\right)$$
$$= \frac{A}{1-\theta}\{(\tilde{q}_{aa}(t)^{\gamma_{aa}}\tilde{q}_c(t)^{\gamma_c})^{1-\theta} + \chi_h \tilde{h}(t)^{1-\theta}$$
$$+\chi_{wr}\left(\tilde{w}_{r\psi}(t)\right)^{1-\theta} + \chi_b\left(\tilde{b}(t) - \tilde{b}_B\right)^{1-\theta}\} \tag{13}$$

where $\tilde{q}_{aa}(t) = Q_{aa}(t)/\{A(t)L(t)\}$ is Ag-good composite that is composed of domestic and foreign Ag-goods as will be formulated below by Eq.(14). $\tilde{q}_c(t) = Q_c(t)/\{A(t)L(t)\}$, and $\tilde{h}(t) = H(t)/\{A(t)L(t)\}$. $\tilde{w}_{r\psi}(t)$ is the amount of residential water per effective labor. Household obtains utility by consuming Ag-good composite, Cm-good, and household asset. A term of $\tilde{b}_B$ is tentatively introduced as the penalty term so that it prevents too large debts represented by the negative positions of the bond, $\tilde{b}$. χ_b is a weight, and $\tilde{b}_B$ is the allowable limit. Household is assumed to be risk averse. θ is a parameter that represents the degree of relative risk aversion. γ_{aa} and γ_c are share parameters of the sub-utility of Ag and Cm goods, represented by the first term of the right-hand-side of Eq.(13). χ_h is a weight, representing relative strength of preference for household asset over the sub-utility of Ag and Cm goods. Ag-good composite is composed in the following way:

$$\tilde{q}_{aa}(t) = \left\{\gamma_a \tilde{q}_a(t)^{\gamma_{aa0}} + \gamma_{af}\tilde{q}_{af}(t)^{\gamma_{aa0}}\right\}^{\frac{1}{\gamma_{aa0}}} \tag{14}$$

where $\tilde{q}_a(t) = Q_a(t)/\{A(t)L(t)\}$ represents domestic Ag-goods, and $\tilde{q}_{af}(t) = Q_{af}(t)/\{A(t)L(t)\}$, foreign Ag-goods purchased by Household. $\gamma_a, \gamma_{af}, \gamma_{aa0}$ are parameters that form the constant-elasticity-of-substitution (CES) function applied to compose Ag-good composite.

Household takes the market prices as given, and determines the optimal combination of $\tilde{q}_a(t)$ and $\tilde{q}_{af}(t)$, so that it minimizes expenditure of having $\tilde{q}_{aa}(t)$ every period in the following problem:

$$\min_{\tilde{q}_a(t),\tilde{q}_{af}(t)} p_a(t)\tilde{q}_a(t) + p_{af}\tilde{q}_{af}(t) \tag{15a}$$

subject to

$$\left\{\gamma_a \tilde{q}_a(t)^{\gamma_{aa0}} + \gamma_{af}\tilde{q}_{af}(t)^{\gamma_{aa0}}\right\}^{\frac{1}{\gamma_{aa0}}} = \tilde{q}_{aa}(t), \tag{15b}$$

The optimal $\tilde{q}_a(t)$ and $\tilde{q}_{af}(t)$ are introduced as functions of $\tilde{q}_{aa}(t)$ as well as $p_a(t)$ and p_{af} like the followings:

$$\tilde{q}_a(t) = \lambda_a(t)\tilde{q}_{aa}(t) \tag{16a}$$

$$\tilde{q}_{af}(t) = \lambda_{af}(t)\tilde{q}_{aa}(t) \tag{16b}$$

$$\text{where } \lambda_a(t) = \left(\frac{\gamma_a}{p_a(t)}\lambda_{aa}(t)\right)^{\frac{1}{1-\gamma_{aa0}}} \tag{16c}$$

$$\lambda_{af}(t) := \left(\frac{\gamma_{af}}{p_{af}}\lambda_{aa}(t)\right)^{\frac{1}{1-\gamma_{aa0}}} \tag{16d}$$

$$\lambda_{aa}(t) = \left\{\left(\frac{\gamma_a}{p_a(t)^{\gamma_{aa0}}}\right)^{\frac{1}{1-\gamma_{aa0}}} + \left(\frac{\gamma_{af}}{p_{af}^{\gamma_{aa0}}}\right)^{\frac{1}{1-\gamma_{aa0}}}\right\}^{-\frac{1-\gamma_{aa0}}{\gamma_{aa0}}} \tag{16e}$$

The level of $\tilde{q}_{aa}(t)$ is determined in the dynamic stochastic optimization problem; Household finally maximizes the following expected lifetime utility:

$$E\left[\sum_{t=0}^{\infty} U(\cdot)\left(\frac{1+\zeta_L}{1+r}\right)^t\right] \tag{17}$$

where $E[\cdot]$ is the expectation operator with respect to $(\phi, \psi, \varepsilon)$. It is the main problem of the model where we introduce the optimal controls for the stock formations under risks of disaster and environmental change. Framework of the main problem will be shown later.

(9) Market clearing conditions, GDP, and trade

balance

Market clearing conditions of domestic Ag-good and Cm-good are given respectively by the following equations:

$$Y_a(t) = \kappa_{aa} Y_a(t) + \kappa_{ac} Y_c(t) + Q_a(t) + D_a^F\big(p_a(t)\big) \tag{18a}$$

$$\begin{aligned} Y_c(t) &= \kappa_{ca} Y_a(t) + \kappa_{cc} Y_c(t) + Q_c(t) + N_c^E \\ &+ L(t) \sum_{J=K,H,G_P} \left[\sum_{\iota=S,V} \eta_{J\iota}(t) \left\{ 1 + \Gamma_{J\iota 0} \cdot \frac{\eta_{J\iota}(t)}{j_\iota(t)} \right\} + \Gamma_{JR0} \cdot \frac{\eta_{JR}(t)^2}{j_S(t)} \right] \\ &+ L(t) \sum_{J=D_M,D_K} \Theta_J \cdot \eta_J(t) \left\{ 1 + \Gamma_{J0} \cdot \frac{\eta_J(t)}{j(t)} \right\} \end{aligned} \tag{18b}$$

where $D_a^F\big(p_a(t)\big)$ represents the export of domestic Ag-goods, that is, a demand function for domestic Ag-goods outside of the country, form of which is assumed to be as follows:

$$D_a^F\big(p_a(t)\big) = A(t)L(t)d_{aF0} \cdot \exp\{-d_{aF1} \cdot p_a(t)\} \tag{19}$$

where d_{aF0} and d_{aF1} are parameters of positive values. The left-hand-sides of Eqs. (18a) and (18b) represent supplies of Ag-good and Cm-good, respectively, while the right-hand-sides represent demands. The first and second terms of the right-hand-sides of Eqs. (18a) and (18b) are intermediate demands. The other terms on the right-hand-sides of the first lines are consumption. The terms on the second and third lines of Eq. (18b) are demands for investments.

Market clearing conditions of labor and capital are given respectively by the following equations:

$$L_a(t) + L_c(t) = L(t) \tag{20a}$$

$$K_a(t) + K_c(t) = K(t) = K_S(t) + K_V(t) \tag{20b}$$

The left-hand-sides of the both equations above represent demands by domestic Ag-good and Cm-good sectors. $K_S(t)$ and $K_V(t)$ on the right-hand-side of Eq.(20b) show spatial distribution of capital $K(t)$.

Gross domestic product (GDP) is represented as follows:

$$\mathrm{GDP}(t) = p_{va}(t)Y_a(t) + p_{vc}(t)Y_c(t) \tag{21a}$$

$$\text{where } p_{va}(t) = p_a(t) - \kappa_{aa} \cdot p_a(t) - \kappa_{ca} \tag{21b}$$

$$p_{vc}(t) = 1 - \kappa_{ac} \cdot p_a(t) - \kappa_{cc} \tag{21c}$$

(13)

$p_{va}(t)$ and $p_{vc}(t)$ are the value-added prices of Ag-good and Cm-good sectors, respectively. The trade balance condition of macroeconomy is derived by Eqs. (12b), (18a), (18b).

(10) Dynamic optimization

a) State and control variables

We "detrend" the above equations in order to formulate the dynamic optimization problem, so that state variables do not diverge to infinity. "Detrending" is executed by dividing equations either by $\{A(t)L(t)\}$ or $A(t)$ or $L(t)$. As a result, most endogenous variables are turned into ones of the effective labor unit, which are denoted by $\tilde{x}(t)$. Now, with the framework with detrended variables $\tilde{x}(t)$, even if $\tilde{x}(t)$ reaches to steady state $\tilde{x}^{SS}$ where its value does not further increase, its original-unit variable, $X(t)$, will keep on growing by $X(t) = A(t)L(t)\tilde{x}^{SS}$ because $A(t)$ and $L(t)$ continuously grow. Because it would be a tiresome process for readers to see the detrending works for all equations, we skip that process in this draft, and deal with the detrended framework hereafter.

As a dynamic optimization model, variables are categorized into state variables $\boldsymbol{s}$ (vector), decision (control) variables $\boldsymbol{d}$ (vector), and parameters. We further categorize state variables into the exogenous state variables $\boldsymbol{s}^X$ and the endogenous state variables $\boldsymbol{s}^N$, namely $\boldsymbol{s} = (\boldsymbol{s}^X, \boldsymbol{s}^N)$; the former variables change over time but are not affected by choices of decision variables, while the latter variables are controlled by decision variables as well as affected by other factors including random variables. Moreover, we make the price of domestic Ag-good $p_a(t)$ independent of state variable although, in one sense, it may be interpreted as "intra-temporal state variable".

The exogenous state variables, $\boldsymbol{s}^X$, and the endogenous state variables, $\boldsymbol{s}^N$, are given respectively by:

$$\boldsymbol{s}^X = (t, \phi, \psi, \varepsilon), \tag{22a}$$

$$\boldsymbol{s}^N = (\tilde{b}, \tilde{k}_S, \tilde{k}_V, \tilde{h}_S, \tilde{h}_V, \tilde{g}_{PS}, \tilde{g}_{PV}). \tag{22b}$$

The decision-variable vector $\boldsymbol{d}$ is composed of:

$$\boldsymbol{d} = (\tilde{q}_{aa}, \tilde{q}_a, \tilde{q}_{af}, \tilde{q}_c, l_a, l_c, \tilde{k}_a, \tilde{k}_c, \tilde{\eta}_{KS}, \tilde{\eta}_{HS}, \tilde{\eta}_{GPS}, \tilde{n}_c^E). \tag{23}$$

b) Event sequence

It is crucially important to identify an order of events in dynamic stochastic optimization problems because such an order determines availability of information for each decision making. For example, decisions on the investment level differ between a situation where disaster may occur probabilistically and one where disaster has just occurred.

As mentioned above, decision rules on a part of variables are determined at the beginning; namely, we have the scheduled (pre-determined) controls/developments for those variables. Other decisions are made every period t in the following sequence:

0) At the beginning of Period t, the levels of stock variables before the occurrence of the shocks, $\boldsymbol{s}^{N-}(t)$, are confirmed.
1) The shocks arrive; values of the random variables such as the flood scale ϕ_t, the precipitation scale ψ_t, the technological shock ε_t, are determined. Accordingly, payments of claims of insurance are implemented, resulting in determination of the post-shock state variables in Period t, $\boldsymbol{s}^N(t)$.
2) Having a set of the state variables $\boldsymbol{s}(t) = (\boldsymbol{s}^X(t), \boldsymbol{s}^N(t))$, the Bellman equation of Period t is identified; namely, the optimization problem is set.
3) Decisions are made. The levels of production, consumption, investment, etc., are determined as well as the market price of domestic Ag-good. The set of the optimal controls, $\boldsymbol{d}^*\big(\boldsymbol{s}(t)\big)$, is derived. The level of the one-period utility, $u(t)$, is obtained.
4) At the end of Period t, some stocks get depreciated, while others are recovered from disaster damage without cost. The stock variables are updated to $\boldsymbol{s}'^{N-}(\boldsymbol{s}(t), \boldsymbol{d}^*(\boldsymbol{s}(t))) = \boldsymbol{s}^{N-}(t+1)$. Time moves to the next period $t+1$, and the same cycle is repeated.

c) Value function and Bellman equation

The objective function of the dynamic stochastic optimization problem is transformed as follows:

$$E\left[\sum_{t=0}^{\infty} U(\cdot)\left(\frac{1+\zeta_L}{1+r}\right)^t\right] = E\left[\sum_{t=0}^{\infty} \beta^t u(\cdot)\right], \tag{24a}$$

$$\text{where } u(\cdot) = \frac{U(\cdot)}{(1+\zeta_A)^t}, \tag{24b}$$

$$\beta = \frac{(1+\zeta_A)(1+\zeta_L)}{1+r}. \tag{24c}$$

$u(\cdot)$ is the one-period utility, and β $(0 < \beta < 1)$ is the discount factor in the detrended framework. The value function, $V(\boldsymbol{s})$, is defined by the maximized objective function, and meets the recursive structure called Bellman equation as follows:

$$V(\boldsymbol{s}) = \max_{\boldsymbol{d}} E\left[\sum_{t=0}^{\infty} \beta^t u(\cdot)\right]$$
$$= \max_{\boldsymbol{d}} \left[u(\cdot) + \beta E\left[V\big(\boldsymbol{s}'(\boldsymbol{s}, \boldsymbol{d})\big)\right]\right] \tag{25}$$

where $\boldsymbol{s}'$ represents a state in the next period, that is dependent on the current state, $\boldsymbol{s}$, and the control, $\boldsymbol{d}$. To repeat the above mentioned logic, the value function, $V(\boldsymbol{s})$, is the maximum expected lifetime utility achievable by the optimal decision under the state $\boldsymbol{s}$, $\boldsymbol{d}^*(\boldsymbol{s})$, which derives the optimal state in the next period $\boldsymbol{s}'^* = \boldsymbol{s}'\big(\boldsymbol{s},\ \boldsymbol{d}^*(\boldsymbol{s})\big)$. Hence our dynamic stochastic optimization is specified so that we solve the Bellman equation (25) with the constraint conditions, the transition equations, and the equilibrium conditions.

(11) Policy indicators

We solve the Bellman equation numerically for the purpose of obtaining the decision rule under each state $\boldsymbol{s}$, $\boldsymbol{d}^*(\boldsymbol{s})$. In the next step, we carry out Monte-Carlo simulation to investigate the effects of policies on the expected growth of the country.

The policy parameters, represented by a vector $\boldsymbol{g}$, are categorized into two groups: $\boldsymbol{g} = (\boldsymbol{g}_{MI}, \boldsymbol{g}_{PR})$ where $\boldsymbol{g}_{MI}$ includes policy parameters for disaster mitigation, and $\boldsymbol{g}_{PR}$, those for production.

The effect of a target policy, $\boldsymbol{g}$, is measured by increase of the expected GDP from the level under the reference policy, $\boldsymbol{g}_0 = (\boldsymbol{g}_{MI0}, \boldsymbol{g}_{PR0})$; namely by Total growth effect (TGE) defined by:

$$\mathrm{TGE}(\boldsymbol{g}, t) = \mathrm{MP}(\boldsymbol{g}, t) - \mathrm{MP}(\boldsymbol{g}_0, t) \tag{26}$$

Where $\mathrm{MP}(\boldsymbol{g}, t)$ represents the mean path of Monte-Carlo simulation obtained by:

$$\mathrm{MP}(\boldsymbol{g}, t) = E_\chi[\mathrm{SP}^\chi(\boldsymbol{g}, t)], \tag{27a}$$

$$\text{where } \mathrm{SP}^\chi(\boldsymbol{g}, t)$$
$$\approx \mathrm{NDP}(\boldsymbol{g}, t) - \sum_{t' \le t} \widehat{\mathrm{D}}^\chi(t', \phi_{t'}, \psi_{t'}, \varepsilon_{t'}, \boldsymbol{g}). \tag{27b}$$

$\mathrm{SP}^\chi(\boldsymbol{g}, t)$ represents the GDP path of the χ-th run of the simulation, that is approximately equal to No-disaster path, $\mathrm{NDP}(\boldsymbol{g}, t)$, minus the sum of decreases of GDP at disaster times t', $\widehat{\mathrm{D}}^\chi(t', \phi_{t'}, \psi_{t'}, \varepsilon_{t'}, \boldsymbol{g})$, up to t. Note that $\mathrm{NDP}(\boldsymbol{g}, t)$ is define by the GDP path where $(\phi_{t'}, \psi_{t'}, \varepsilon_{t'}) = (0, \psi_{\max}, 0)$ for all t.

Total Growth Effect (TGE) is composed of Disaster Disk Reduction Effect (DRRE) and Co-benefit Production Expansion Effect (CPEE), where we find two cases of decomposition that depend on the order of changing $\boldsymbol{g}_{MI}$ and $\boldsymbol{g}_{PR}$. The first case is given by:

$$\mathrm{TGE}(\boldsymbol{g}, t) = \mathrm{MP}(\boldsymbol{g}_{MI}, \boldsymbol{g}_{PR}, t) - \mathrm{MP}(\boldsymbol{g}_{MI0}, \boldsymbol{g}_{PR0}, t)$$
$$= \{\mathrm{MP}(\boldsymbol{g}_{MI}, \boldsymbol{g}_{PR}, t) - \mathrm{MP}(\boldsymbol{g}_{MI0}, \boldsymbol{g}_{PR}, t)\}$$
$$+\{\mathrm{MP}(\boldsymbol{g}_{MI0}, \boldsymbol{g}_{PR}, t) - \mathrm{MP}(\boldsymbol{g}_{MI0}, \boldsymbol{g}_{PR0}, t)\}$$
$$= \mathrm{DRRE}_1(\boldsymbol{g}, t) + \mathrm{CPEE}_1(\boldsymbol{g}, t), \tag{28a}$$

$$\text{where } \mathrm{DRRE}_1(\boldsymbol{g}, t)$$
$$= \mathrm{MP}(\boldsymbol{g}_{MI}, \boldsymbol{g}_{PR}, t) - \mathrm{MP}(\boldsymbol{g}_{MI0}, \boldsymbol{g}_{PR}, t) \tag{28b}$$

$$\mathrm{CPEE}_1(\boldsymbol{g},t) = \mathrm{MP}(\boldsymbol{g}_{MI0},\boldsymbol{g}_{PR},t) - \mathrm{MP}(\boldsymbol{g}_{MI0},\boldsymbol{g}_{PR0},t). \tag{28c}$$

Moreover, DRRE is further decomposed into Ex-post Damage Mitigation Effect (PDME) and Ex-ante Risk Reduction Effect (ARRE) such like:

$$\begin{aligned}\mathrm{DRRE}_1(\boldsymbol{g},t) &= \mathrm{MP}(\boldsymbol{g}_{MI},\boldsymbol{g}_{PR},t) - \mathrm{MP}(\boldsymbol{g}_{MI0},\boldsymbol{g}_{PR},t)\\ &= \mathrm{NDP}(\boldsymbol{g}_{MI},\boldsymbol{g}_{PR},t) - \mathrm{NDP}(\boldsymbol{g}_{MI0},\boldsymbol{g}_{PR},t)\\ &+E_\chi\left[\sum_{t'\le t}\{\widehat{\mathrm{D}}^\chi(t',\phi_{t'},\psi_{t'},\varepsilon_{t'},\boldsymbol{g}_{MI0},\boldsymbol{g}_{PR}) - \widehat{\mathrm{D}}^\chi(t',\phi_{t'},\psi_{t'},\varepsilon_{t'},\boldsymbol{g}_{MI},\boldsymbol{g}_{PR})\}\right]\\ &= \mathrm{ARRE}_1(\boldsymbol{g},t) + \mathrm{PDME}_1(\boldsymbol{g},t),\end{aligned} \tag{29a}$$

where $\mathrm{ARRE}_1(\boldsymbol{g},t)$

$$= \mathrm{NDP}(\boldsymbol{g}_{MI},\boldsymbol{g}_{PR},t) - \mathrm{NDP}(\boldsymbol{g}_{MI0},\boldsymbol{g}_{PR},t) \tag{29b}$$

$$\mathrm{PDME}_1(\boldsymbol{g},t) = E_\chi\left[\sum_{t'\le t}\{\widehat{\mathrm{D}}^\chi(t',\phi_{t'},\psi_{t'},\varepsilon_{t'},\boldsymbol{g}_{MI0},\boldsymbol{g}_{PR}) - \widehat{\mathrm{D}}^\chi(t',\phi_{t'},\psi_{t'},\varepsilon_{t'},\boldsymbol{g}_{MI},\boldsymbol{g}_{PR})\}\right]. \tag{29c}$$

In other words, PDME is measured by the mean of actual loss reduction obtained at disaster times, while ARRE is given by the gap of No-disaster paths. Likewise, the second case of the decomposition is obtained by exchanging the order of changing $\boldsymbol{g}_{MI}$ and $\boldsymbol{g}_{PR}$. Finally, because of no reason of choosing one of the two cases, the decomposed effects are identified by the means of the two cases like

$$\mathrm{DRRE}(\boldsymbol{g},t) = \frac{1}{2}\{\mathrm{DRRE}_1(\boldsymbol{g},t) + \mathrm{DRRE}_2(\boldsymbol{g},t)\}. \tag{30}$$

$\mathrm{CPEE}(\boldsymbol{g},t)$, $\mathrm{ARRE}(\boldsymbol{g},t)$, and $\mathrm{PDME}(\boldsymbol{g},t)$ are obtained in the same manner. Furthermore, Ex-ante Effect (EE) is obtained by changes both of the parameters for mitigation and production:

$$\begin{aligned}\mathrm{EE}(\boldsymbol{g},t) &= \mathrm{NDP}(\boldsymbol{g},t) - \mathrm{NDP}(\boldsymbol{g}_0,t)\\ &= \mathrm{NDP}(\boldsymbol{g}_{MI},\boldsymbol{g}_{PR},t) - \mathrm{NDP}(\boldsymbol{g}_{MI0},\boldsymbol{g}_{PR0},t).\end{aligned} \tag{31}$$

4. CASE STUDY

The model parameters are identified with data from Tanzania withsome parameters given hypothetical values due to the lack of data. The average annual growth rate of the mean path based on Monte-Carlo simulation is found at 4.32% over 30 periods (30 years) under the reference policy scenario where no additional dam provision is planned.

Under the target policy scenario in which a new dam of a fixed capacity is built every ten years, namely three dams are constructed in 30 years,, the average annual growth rate of GDP is increased relative to thereference policy by 0.47%. The expected agricultural and composite good productions in Period 30 are increased by 14% and 13% relative to thereeference policy scenario, respectively.

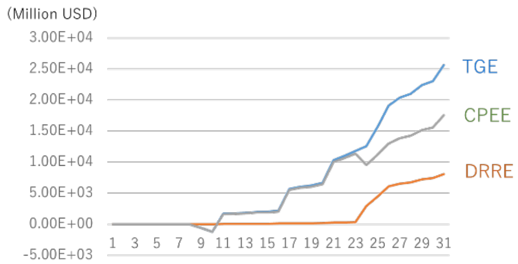

Fig.2 TGE, DRRE, and CPEE (case study)

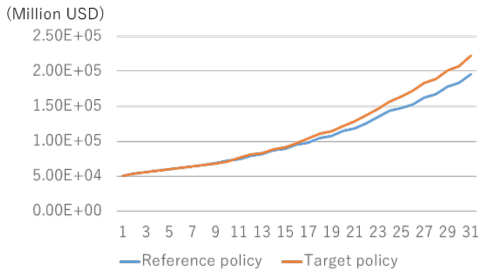

Fig.3 No-disaster paths of GDP (case study)

Fig. 2 shows that TGE of the target policy is increasing in trend and reaches 23.1 billion USD in Period 30. Moreover, TGE is decomposed into DRRE and CPEE, which accounts for 32% and 68% of TGE, respectively.

Fig. 3 illustrates two No-disaster paths of GDP: $\mathrm{NDP}(\boldsymbol{g},t)$ and $\mathrm{NDP}(\boldsymbol{g}_0,t)$. The gap of the two paths in Period 30, $\mathrm{EE}(\boldsymbol{g},30)$, is equivalent to 13% of $\mathrm{NDP}(\boldsymbol{g}_0,30)$. Additional results will be showcased at the conference.

5. DISCUSSION AND CONCLUSION

Evaluation of Ex-ante effect, as demonstrated in our modeling framework has the potential to serve in decision making process of DRR policy. On some sample paths, "Ex-post effect" (given by actual decreases of disaster damages) might not be obtained because disasters did not occur as frequently as expected. In such cases, "Ex-post evaluation" may judge that "DRR investment was not beneficial". Because ofsuch criticism, it may be the case that DRR investment can not be implemented especially in developing coutries.

Demonstration of DRR benefits via simulation overcomes such biases since the "Ex-ante effect" can certainly be obtained, regardless of whether disasters actually occur. This guaranteed long-term effect could make DRR policies more economically attractive.

Disaster policies in developing countries need to allocate limited resources appropriately to various disaster prevention facilities and measures, taking into account the multiple hazards that a society is faced with. Hence, without evaluating co-benefit and ex-ante effects, policies could largely underestimate DRR investment benefits and socially desirable investments may be forgone.

Our study shows that disaster risk reduction investment may be followed by economic growth. In other words, (short-term) balanced budget policy – that forgo DRR investment - could impede the growth of economy in the longer-term. It is a role of our dynamic macroeconomic framework to explore both annual budget and allocation among multiple investments with a focus on dynamic optimization or improvement of long-term social welfare.

Important tasks are left to be tackled. First, effects of other DRR measures and combinations of multiple DRR measures need to be evaluated. Second, computation algorithm should be improved to mitigate "Curse of dimensionality" so that we can use finer grids of the state spaces, which will result in more smooth paths of variables. Third, it is important to further validate the model by statistical verification.

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