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Quantitative Analysis of Optimal Investment Scale and Timing for Flood Control Measures by Multi-Regional Economic Growth Model: Case Studies in Viet Nam

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Abstract: *This study aims to develop and utilise a multi-regional economic growth model that can take into account flood damage and investment in disaster risk reduction, and, through case studies in Viet Nam, quantitatively analyse the long-term effects of investment in disaster risk reduction on the national and local economy, as well as the optimal scale and timing of investments in flood protection, to gain a better overview of these factors. The results indicate that additional investment in disaster risk reduction could stimulate economic growth, and that the optimal range of the disaster risk reduction budget rate was around 0.3% to 0.5% of GDP, assuming a constant budget rate throughout the total 25-year calculation period. In the case of a variable disaster risk reduction budget rate, we observed that a variable budget rate that gradually reduces the disaster risk reduction budget rate from a higher level than the current rate could further promote economic growth than if the budget rate were fixed. In both cases, we verified that with excessive investment in disaster risk reduction, the high tax burden had the risk of reducing investment in production capital and lead to stagnating economic growth. By region, the long-term effects of investment in disaster risk reduction were most seen in the Central region, where the rate of flood damage is the highest.*

Keywords: disaster risk reduction investment, extensive flood risk, multi-regional economic growth model, Viet Nam

JEL Classification: C68; E17; H21; H54; O11; O41; O53; R12

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1. Introduction

Since the adoption of the Sendai Framework for Disaster Risk Reduction 2015–2030 at the Third UN World Conference on Disaster Risk Reduction in 2015, countries have accelerated their efforts for disaster risk reduction – yet disasters continue to cause much human suffering and economic damage. Of these, the risk of flooding is increasing in particular due to a combination of factors such as climate change and increasing urbanisation.

Since the Sendai Framework for Disaster Risk Reduction 2015–2030 will reach the midpoint of its objective timeframe in 2023, countries are conducting interim assessments of priority actions and progress on global targets. Against this backdrop, Sendai City, the namesake the framework was adopted in, became the first local government in the world to conduct a medium-term assessment of that framework (Sendai City and Tohoku University, 2023), and outlined at the Third World BOSAI Forum (March 2023) and the UN General Assembly (May 2023) the importance of collecting and collating disaster-related data – not only at the national level but also at the regional level – to quantitatively monitor the occurrence of disasters, and analyse and assess the effects of disaster mitigation efforts. Meanwhile, following the Third UN World Conference on Disaster Risk Reduction, some developing countries have moved to develop databases on disaster statistics (like DIBI/ InaRisk in Indonesia) that include disaster-related data at the regional level. Collecting and organising disaster-related data at the regional level would make it possible to quantitatively identify impacts and other factors that are hard to ignore at the regional level, but which cannot be ascertained at the national level.

In addition to the concept of Build Back Better through the recovery and reconstruction process, advance investment in disaster risk reduction is important to build a disaster-resilient society (UNISDR, 2015b). The latter is said to be particularly cost-effective (UNISDR, 2015a), but advance investment into disaster risk reduction is not always sufficient. One of the reasons for this is that, unlike road construction, it is difficult to visualise the benefits of advance investment for disaster risk reduction, and furthermore, it could take a long period of time before the benefits of investment come to fruition. This results in a priority on investments into other projects guaranteed to deliver effects over the short term, rather than advance investments in disaster risk reduction. An example of another reason is that the optimal scale and timing of advance investments in disaster risk reduction remains unclear, meaning it is difficult to make policy decisions for accelerating advance investments in disaster risk reduction. A closer look at the ratio of flood control budgets to gross domestic product (GDP) in Asian countries as summarised by Ishiwatari (2019) reveals that Japan, which in the past suffered from countless floods and focused efforts on flood control, had a budget of around 1% in 1980 and around 0.4% in 2014. This indicates that the budget for flood control accounted for a relatively large percentage of the total budget until the risk of flooding had reduced to a certain degree, after which the ratio of the budget was gradually decreased. In contrast, the scale and timing of investment in flood control measures varies depending on the various circumstances present in each country. In the Philippines, for example, the ratio of the budget for flood control measures has increased with economic growth, from about 0.1% in 1990 to about 0.4% in 2015, whereas in Pakistan, the budget ratio for flood control measures remains approximately the same regardless of the level of economic growth (See Figure 1 in Ishiwatari (2019)). With the lack of any clear standards to draw on, the use of economic models can be one of effective methods for each country's policymakers and those in charge of financial affairs for making the appropriate decisions, as a policy support tool for quantitatively analysing the long-term effects, optimal scale and timing of advance investments for disaster risk reduction.

There are some existing studies of economic models for advance investment for disaster risk reduction and disaster risk financing. For example, such models include the analytical framework for the design, pricing, and applications of index-based risk transfer products as a means to handle insurance market imperfections under disaster risks in developing Asian countries (Chantarat et al., 2013); the regression model to show that ex-ante cash transfer programs play a crucial role in encouraging poor households under the threat of disaster in Cambodia to invest in business rather than in food (Vathana et al., 2013); the input–output (I–O) model to examine economic losses and damages caused by natural disasters at the local, national, and the regional levels in the ASEAN region (Shiomi, Ono, and Fukushima, 2019); the catastrophe simulation (CATSIM) model that made it possible to analyse from the standpoint of financial strategies the vulnerabilities of a nation's finances when faced with natural disasters (e.g. Mechler et al., 2006); the endogenous business cycle model that made it possible to analyse the long-term impacts of natural disasters on asset formation and production volume (e.g. Hallegatte, Hourcade, and Dumas, 2007; Hallegatte and Ghil, 2008); the dynamic stochastic macroeconomic model making qualitative analysis on long-term disaster risk reduction investment policies possible through examination of production capital and disaster risk reduction capital (Segi, Ishikura, and Yokomatsu, 2012); the multi-sector multi-region economic growth model that quantitatively analyses the long-term impact of drought by focusing on the leaf area index (LAI) (Yokomatsu et al., 2019); the composite methodology model to quantify and visualise disaster risks and infrastructure investment priorities at the regional level for building resilient regional infrastructure systems in developing countries against climate change and natural disasters (UNDP, 2021); the integrated macroeconomic framework to provide an economy-wide assessment of the social and economic effects of climate impacts (Espagne et al., 2021); the CatDSGE model capable of simulating the economic impacts of a host of catastrophes, including floods, droughts, earthquakes, and pandemics (e.g. Yuasa and Rielaender, 2023); and the multiple regression model estimating that the ratio of flood protection budgets to GDP in nine Asian developing countries would increase from 0.21% in 2015 to an average of 0.36% from 2016 to 2030 (Ishiwatari and Sasaki, 2020). In addition, the dynamic stochastic macroeconomic models exist to quantitatively analyse the long-term impacts and effects of flood risk and investment in disaster risk reduction, and to quantify the optimal level of investment in disaster risk reduction at the national level (e.g. Ishiwata and Yokomatsu, 2018; Ishiwata et al., 2020). On the other hand, while flood damage at the national level may have only a marginal economic impact, flood damage at the regional level may have a significant economic impact, and this model, which applies to the economy of a single country, is unable to analyse the impact of flood damage on regional economies. In addition, as the budget ratio of disaster risk reduction investment is assumed to be constant as a percentage of GDP, the optimal patterns of budget ratio by year when the same ratio is varied over time cannot be shown.

As a quantitative analysis method, this study will develop and utilise a multi-regional economic growth model capable of taking into account flood damage and investment in disaster risk reduction, and apply it to case studies in Viet Nam. The objective is then to quantitatively analyse the long-term effects of investment in disaster risk reduction on the national and local economy, in addition to the optimal scale and timing of investment in flood countermeasures, to gain an overview of these effects. A formula for this model is shown in Chapter 2 below, then applied to the case studies in Viet Nam in Chapter 3. Chapter 4 then presents the conclusions of this study.

2. Model

2.1. Basic Setup

2.1.1. Economic Environment

The economic space is assumed to be a small closed economy made up of three regions $i \in I = \{1,2,3\}$, comprising three categories of economic agents (government, households, and firms). It is assumed that each economic agent is aware of the risk of flooding and engages in economic activities that are deemed to be fully rational. Each region has two sectors $j \in$

$J = \{a, x\}$ – agricultural and non-agricultural (e.g. manufacturing and service) – and both sectors have production technologies of constant returns to scale. Assuming that the final goods in each sector are fully substitutable within each sector and traded across regions without transportation costs, the price p_{ji} of final goods produced in sector j in region i would be $p_{a1} = p_{a2} = p_{a3} =: p_a$ in the agricultural sector and $p_{x1} = p_{x2} = p_{x3} =: p_x$ in the non-agricultural sector. It is also assumed that agricultural goods are consumed as non-durable goods, while non-agricultural goods are consumed as non-durable goods or used as durable goods to generate production capital or disaster risk reduction capital.

Assuming that the markets for production factors (labour and production capital markets) are fully competitive and open across regions but closed within a country, the wage rate and capital rents are endogenously determined through each market. A representative household supplies labour, production capital, and land to a representative firm, and in return receives labour incomes, capital incomes, and shares of firm profits. Assuming that a representative household supplies one unit of labour inelastically every period, the total labour force L equals the total population N. It is also assumed that household savings accumulate as production capital via banks. A representative firm produces agricultural or non-agricultural goods using production factors that remain after a flooding event. The government utilises its available budget acquired with tax collection from households to invest in disaster risk reduction to reduce the risk of flooding. It is assumed that there will be no rapid technological growth caused by changes in the socioeconomic structure.

2.1.2. Event Flow

The following flow of events is assumed for each period.

i) At the start of the period, a representative household acknowledges the expected risk of flooding and determines the amount of labour and production capital supplied to each sector in each region to increase income, for the purpose of utility maximisation. Meanwhile, a representative firm determines the amount of labour and production capital demand to increase production, for the purpose of profit maximisation.

ii) Flooding causes expected damage to each production factor. The extent of damage is reduced according to the amount of disaster risk reduction capital accumulated by the government.

iii) A representative firm produces agricultural or non-agricultural goods using the labour and production capital remaining after the flood event. On the other hand, a representative household uses disposable incomes to consume final goods or for savings.

Yet a portion of household incomes is taxed for investments in disaster risk reduction by the government.

iv) In processes i) to iii) above, the wage rate of labour, the rent of production capital, and the price of final goods are adjusted through the markets of production factors (labour and production capital) and goods markets (agricultural and non-agricultural goods) until an equilibrium is reached.

v) At the end of the period, production capital is generated up to what a representative household has saved, and disaster risk reduction capital is generated up to the extent that the government invests in disaster risk reduction. The cycle is then repeated again from i) when transitioning from t period to $t + 1$ period.

2.2. Government Behaviour

2.2.1. Disaster Risk Reduction Investment

The government collects taxes from each household and invests in disaster risk reduction T_i to reduce the risk of floods. Assuming that the budget collected in region i is used to fund disaster risk reduction investment T_i in region i, budget constraints for the disaster risk reduction investment T_i is as follows.

$$T_i(t) = \tau_i(t) \cdot N_i(t), \tag{1}$$

where $T_i, \tau_i \geq 0$. Here, τ_i represents the per capita tax collections for region i and N_i represents the population of region i.

2.2.2. Disaster Risk Reduction Capital

Disaster risk reduction capital G are assets (levees, floodwalls, etc.) that serve to reduce the risk of flooding, and the following accumulation builds up with investment in disaster risk reduction T_i.

$$G(t) \coloneqq \sum_i G_i(t), \tag{2}$$

$$G_i(t+1) = (1 - \delta_G) \cdot G_i(t) + T_i(t) \tag{3}$$

for all i, where δ_G indicates the depreciation rate of disaster risk reduction capital and G_i indicates the amount of disaster risk reduction capital accumulated in region i.

2.2.3. Flood Risk and Mitigation

Floods are assumed to occur in each period, and two rates of flood damage have been considered: the rate of reduction in working hours ω_i (indirect damage), and the rate of damage to production capital ψ_i (direct damage). It is assumed that production capital K is lost due to flooding and that recovery requires reinvestment (permanent damage), while human losses due to flooding do not occur and labour hours are reduced due to flood damage (temporary damage). Each flood damage rate is assumed to decrease with accumulation of disaster risk reduction capital G in line with the following flood damage mitigation function $\zeta_{\iota i}$.

$$\omega_i\big(G_i(t)\big) := \omega_i^0 \cdot \zeta_{\omega i}\big(G_i(t)\big), \tag{4}$$

$$\psi_i\big(G_i(t)\big) := \psi_i^0 \cdot \zeta_{\psi i}\big(G_i(t)\big) \tag{5}$$

for all i, where

$$\zeta_{\iota i}\big(G_i(t)\big) := \left[\frac{G_i(t)}{G_i^0}\right]^{-\theta_{\iota i}} \tag{6}$$

for all $\iota \in \{\omega, \psi\}$. Here, G_i^0 denotes the accumulation of disaster risk reduction capital in region i during the base period t_0, ω_i^0 and ψ_i^0 refer to the rate of reduction in working hours and the rate of damage to production capital in region i if the same scale of disaster risk reduction capital is maintained as during base period t_0, and $\theta_{\iota i}$ refers to the effective parameter of the flood damage mitigation function in region i.

2.3. Household Behaviour

2.3.1. Income

A representative household supplies labour, production capital, and land to a representative firm, and in return for each, receives labour incomes, capital incomes, and shares of firm profits. The household income f is as follows.

$$f(t) := \sum_i f_i(t), \tag{7}$$

$$f_i(t) := \sum_{j \in \{a,x\}} \left[w(t) \cdot \hat{l}_{ji}(t) + r(t) \cdot \hat{k}_{ji}(t) + \pi_{ji}(t)\right] \tag{8}$$

for all i, where

$$\hat{l}_{ji}(t) := \left[1 - \omega_i\big(G_i(t)\big)\right] \cdot l_{ji}(t), \qquad \sum_{j,i} l_{ji}(t) = 1, \tag{9}$$

$$\hat{k}_{ji}(t) \coloneqq \left[1 - \psi_i\big(G_i(t)\big)\right] \cdot k_{ji}(t), \qquad \sum_{j,i} k_{ji}(t) = k(t), \tag{10}$$

$$\pi_{ji}(t) = \frac{\Pi_{ji}(t)}{N(t)}. \tag{11}$$

Here, f_i refers to income earned in region i; l_{ji} and k_{ji} refer to per capita inputs of labour and production capital in sector j in region i; $\hat{l}_{ji}$ and $\hat{k}_{ji}$ refer to per capita inputs of labour and production capital remaining after flooding in sector j in region i; π_{ji} and Π_{ji} refer to per capita profit and total profit of a representative firm in sector j in region i; and k refers to per capita production capital.

2.3.2. Tax Payment

A disaster risk reduction tax τ is assumed to be σ% of GDP (GRP) per capita and collected from each household by the government as follows.

$$\tau(t) \coloneqq \sum_i \tau_i(t), \tag{12}$$

$$\tau_i(t) \coloneqq \sigma(t) \cdot \left[f_i(t) + \delta_k \sum_{j \in \{a,x\}} \hat{k}_{ji}(t) \right] \tag{13}$$

for all i, where τ_i is the per capita taxes paid in region i and δ_k is the depreciation rate of production capital. The disaster risk reduction budget rate σ is a policy variable that allows the government to secure a disaster risk reduction budget, and the ratio can be changed from period to period.

2.3.3. Savings

A household savings (production capital investments) η is assumed to be a portion of disposable incomes and a supplement of depleted production capital (production facilities and equipment).

$$\eta(t) \coloneqq s \cdot [f(t) - \tau(t)] + \delta_k \sum_{j,i} \hat{k}_{ji}(t), \tag{14}$$

where s refers to the savings rate (rate of investment in production capital) and is assumed to be constant.

2.3.4. Consumption

A household consumption is assumed to come from the residual income after tax payments and savings (production capital investment) are subtracted. If the consumption of final goods j produced in region i is q_{ji}, the per capita consumption of final goods j is $q_j := \sum_i q_{ji}$, based on the assumption that final goods j produced in each region are perfect substitutes for each other within each sector. The consumption budget constraint for a representative household is as follows.

$$\sum_{j\in\{a,x\}} p_j(t) \cdot q_j(t) = (1-s) \cdot [f(t) - \tau(t)]. \tag{15}$$

2.3.5. Utility Maximisation

The utility function u of a representative household is assumed to be of the Cobb–Douglas type, and determines the consumption q_j of each good to maximise utility u under the budget constraint on consumption. The utility maximisation problem of a representative household is as follows.

$$\max_{q_a, q_x} u\big(q_a(t), q_x(t)\big) := \sum_{j\in\{a,x\}} \gamma_j \cdot \ln q_j(t), \tag{16}$$

subject to Eq. (15), where

$$\sum_{j\in\{a,x\}} \gamma_j = 1, \qquad \gamma_j \in (0,1), \tag{17}$$

where γ_j refers to the share parameter of consumptions. Solving the utility maximisation problem above allows the Marshallian demand function for a representative household to be calculated as follows.

$$q_j(t) = \frac{\gamma_j \cdot (1-s) \cdot [f(t) - \tau(t)]}{p_j(t)} \qquad \text{for all } j. \tag{18}$$

2.4. Firm Behaviour

2.4.1. Technological Progress

The total factor productivity (TFP) of a representative firm B_{ji}, which represents technological progress and production efficiency, grows at a constant rate for each period as follows.

$$B_{ji}(t) := B_{ji}^0 \cdot \left(1 + \beta_{ji}\right)^{t-t_0} \tag{19}$$

for all i and j, where B_{ji}^{0} refers to TFP in sector j in region i for the base period t_0, and β_{ji} refers to the TFP growth rate in sector j in region i.

2.4.2. Production Technology

The production function Y_{ji} of a representative firm is assumed to be of the Leontief type, the value-added function F_{ji} is assumed to be of the Cobb–Douglas type. Then, the production of goods requires labour $\hat{L}_{ji}$ and production capital $\hat{K}_{ji}$ that remain after the flood event, land A_{ji}, and intermediate goods $y_{j'ji}$ in each sector. Namely,

$$Y_{ji}(t) \coloneqq \min\left[F_{ji}\big(B_{ji}(t), \hat{L}_{ji}(t), \hat{K}_{ji}(t), A_{ji}\big), \frac{y_{aji}(t)}{\varphi_{aji}}, \frac{y_{xji}(t)}{\varphi_{xji}}\right], \tag{20}$$

$$F_{ji}\big(B_{ji}(t), \hat{L}_{ji}(t), \hat{K}_{ji}(t), A_{ji}\big) \coloneqq B_{ji}(t) \cdot \hat{L}_{ji}(t)^{\alpha_{Lji}} \cdot \hat{K}_{ji}(t)^{\alpha_{Kji}} \cdot A_{ji}{}^{\alpha_{Aji}} \tag{21}$$

for all i and j, where $\hat{L}_{ji} = \hat{l}_{ji} \cdot N$, $\hat{K}_{ji} = \hat{k}_{ji} \cdot N$, and

$$\sum_{\iota' \in \{L,K,A\}} \alpha_{\iota' ji} = 1, \qquad \alpha_{\iota' ji} \in (0,1), \tag{22}$$

where $\varphi_{j'ji}$ refers to the input coefficients for intermediate goods j' that are input to sector j in region i, and $\alpha_{\iota' ji}$ refers to the share parameters of production factors in sector j in region i.

2.4.3. Value-Added Price

The value-added price of goods produced by a representative firm p_{ji}^{v} is given by taking the difference between the final goods price and the intermediate goods price as follows.

$$p_{ji}^{v}(t) \coloneqq p_j(t) - \sum_{j' \in \{a,x\}} \varphi_{j'ji} \cdot p_{j'}(t) \qquad \text{for all } i \text{ and } j. \tag{23}$$

2.4.4. Profit Maximisation

A representative firm produces goods using the labour $\hat{L}_{ji}$ and production capital $\hat{K}_{ji}$ remaining after the flood event to maximise profit Π_{ji} based on the production technology it possesses and the land available to it. The profit maximisation problem for a representative firm is as follows.

$$\max_{L_{ji},K_{ji}} \Pi_{ji}\left(L_{ji}(t), K_{ji}(t)\right) := p_{ji}^{v}(t) \cdot F_{ji}\big(B_{ji}(t), \hat{L}_{ji}(t), \widehat{K}_{ji}(t), A_{ji}\big) \\ -w(t) \cdot \hat{L}_{ji}(t) - [r(t) + \delta_k] \cdot \widehat{K}_{ji}(t) \tag{24}$$

for all i and j. Solving the above profit maximisation problem allows the factor demand function for a representative firm to be calculated as follows.

$$L_{ji}(t) = \frac{1}{1 - \omega_i\big(G_i(t)\big)} \left[\frac{\bar{\alpha}_{Lji} \cdot p_{ji}^{v}(t) \cdot B_{ji}(t)}{w(t)^{1-\alpha_{Kji}} \cdot \{r(t) + \delta_k\}^{\alpha_{Kji}}}\right]^{\frac{1}{\alpha_{Aji}}}, \tag{25}$$

$$K_{ji}(t) = \frac{1}{1 - \psi_i\big(G_i(t)\big)} \left[\frac{\bar{\alpha}_{Kji} \cdot p_{ji}^{v}(t) \cdot B_{ji}(t)}{w(t)^{\alpha_{Lji}} \cdot \{r(t) + \delta_k\}^{1-\alpha_{Lji}}}\right]^{\frac{1}{\alpha_{Aji}}} \tag{26}$$

for all i and j, where

$$\bar{\alpha}_{Lji} := {\alpha_{Lji}}^{1-\alpha_{Kji}} \cdot {\alpha_{Kji}}^{\alpha_{Kji}} \cdot {A_{ji}}^{\alpha_{Aji}}, \tag{27}$$

$$\bar{\alpha}_{Kji} := {\alpha_{Lji}}^{\alpha_{Lji}} \cdot {\alpha_{Kji}}^{1-\alpha_{Lji}} \cdot {A_{ji}}^{\alpha_{Aji}}. \tag{28}$$

2.5. Market Equilibrium

2.5.1. Production Factor Market

Supply and demand for labour and production capital are balanced through the production factor markets, and the equilibrium condition of the labour market and the production capital market is determined by the following equation, respectively.

$$\sum_{j,i} L_{ji}(t) = L(t), \tag{29}$$

$$\sum_{j,i} K_{ji}(t) = K(t), \tag{30}$$

where $L_{ji} = l_{ji} \cdot N$, $K_{ji} = k_{ji} \cdot N$. Here, the left side of the above equation refers to the total demand for the production factors, and the right side refers to the total supply of the production factors. The total supply of labour and production capital varies over time with population growth and production capital investment η as follows.

$$L(t) = N(t) := N^0 \cdot (1 + n)^{t - t_0}, \tag{31}$$

$$K(t+1) = (1 - \delta_k) \sum_{j,i} \widehat{K}_{ji}(t) + \eta(t) \cdot N(t), \tag{32}$$

where N^0 refers to the total population during base period t_0 and n refers to the population growth rate.

2.5.2. Goods Market

Supply and demand for agricultural and non-agricultural goods are balanced through the goods markets, and the equilibrium condition of the agricultural goods market and the non-agricultural goods market is determined by the following equation, respectively.

$$q_a(t) \cdot N(t) + \sum_{j,i} y_{aji}(t) = \sum_i Y_{ai}(t), \tag{33}$$

$$[q_x(t) + \eta(t) + \tau(t)] \cdot N(t) + \sum_{j,i} y_{xji}(t) = \sum_i Y_{xi}(t). \tag{34}$$

The left side of the above equation is the sum of aggregate demand for final goods by households (including investment in production capital and disaster risk reduction capital in the case of non-agricultural goods) and aggregate demand for intermediate goods by firms, while the right side refers to the aggregate supply of goods.

2.6. Economic Indicator

Gross domestic product GDP and gross regional product GRP_i can be expressed as aggregate value-added amounts for the country as a whole and for the region as a whole using the following equation.

$$\mathrm{GDP}(t) \coloneqq \sum_i \mathrm{GRP}_i(t), \tag{35}$$

$$\mathrm{GRP}_i(t) \coloneqq \sum_{j \in \{a,x\}} p_{ji}^v(t) \cdot Y_{ji}(t) = \left[f_i(t) + \delta_k \sum_{j \in \{a,x\}} \hat{k}_{ji}(t) \right] \cdot N_i(t) \quad \text{for all } i. \tag{36}$$

3. Case Study

3.1. Target Area

A case study was conducted for Viet Nam to quantitatively analyse the long-term effects of investment in disaster risk reduction on the national and local economy (e.g. GDP), in addition to the optimal scale and timing of investment for disaster risk reduction. The three regions covered were the Northern region that includes the capital city, Hanoi, the Central region that includes the commercial city of Da Nang, and the Southern region that includes the largest city, Ho Chi Minh. Details of the regional classification were organised in Table 1. Each region is characterised by a GRP share (as of 2015) of 41% in the Northern region, 22% in the Central region, and 37% in the Southern region (General Statistics Office of Viet Nam, 2020). The Northern and Southern regions have relatively large economies, while the Central region has relatively small economy in comparison. Furthermore, about 70% of the total population lives along coastal regions and low delta areas, making them vulnerable to flooding (Huong et al., 2022; Tukker and Ngo, 2014; Davis, 2014), with the Central region tending to be the most flood-prone, especially during flood season (Huong et al. 2022; Manh et al., 2013; Hung et al., 2014).

Table 1: Regional Classification

Region	Subregion	Provinces and Cities
Northern Viet Nam	Red River Delta	Bac Ninh, Ha Nam, Ha Noi, Hai Duong, Hai Phong, Hung Yen, Nam Dinh, Ninh Binh, Quang Ninh, Thai Binh, Vinh Phuc
	Northern Midlands and Mountain Areas	Bac Giang, Bac Kan, Cao Bang, Dien Bien, Ha Giang, Hoa Binh, Lai Chau, Lang Son, Lao Cai, Phu Tho, Son La, Thai Nguyen, Tuyen Quang, Yen Bai
Central Viet Nam	North Central and Central Coastal Areas	Binh Dinh, Binh Thuan, Da Nang, Ha Tinh, Khanh Hoa, Nghe An, Ninh Thuan, Phu Yen, Quang Binh, Quang Nam, Quang Ngai, Quang Tri, Thanh Hoa, Thua Thien Hue
	Central Highlands	Dak Lak, Dak Nong, Gia Lai, Kon Tum, Lam Dong
Southern Viet Nam	Southeast	Ba Ria Vung Tau, Binh Duong, Binh Phuoc, Dong Nai, Ho Chi Minh City, Tay Ninh
	Mekong River Delta	An Giang, Bac Lieu, Ben Tre, Ca Mau, Can Tho, Dong Thap, Hau Giang, Kien Giang, Long An, Soc Trang, Tien Giang, Tra Vinh, Vinh Long

Source: regional classification used for the statistical data of General Statistics Office of Viet Nam.

3.2. Input Data

The base year for this case study was 2015, when most of the necessary input data was collected, and the calculation period was for a total of 25 years, with a unit period of one year. The values of each parameter set are listed in the Appendix at the end of this paper. Due to data limitations in the target countries, some parameters have been defined with alternative values. For example, due to limitations in obtaining past data on disaster risk reduction budgets, the effective parameter $\theta_{\iota i}$ of the flood damage mitigation function $\zeta_{\iota i}$ was applied alternatively to estimates from past data (from the immediate postwar year of 1953 to 2014) such as flood damage and social capital stock statistics of Japan. These alternative values would ideally be replaced in the future after collecting more data for the target country.

Socio-economic data was mainly from the input–output tables of the ADB Data Library, the social accounting matrix from previous studies (Thurlow, 2021; Thanh, 2006; Tapp et al., 2002), World Development Indicators (statistical database) from the World Bank, and various statistics from the General Statistics Office of Viet Nam. This socio-economic data was used to set initial values for each variable of the base period and to calibrate each parameter of functions.

Disaster-related data was primarily obtained from DesInventar of the UNDRR, which includes disaster damage data by region in Viet Nam. The type of disaster selected was flooding, which has caused much damage in Viet Nam and for which data on the budget spent on disaster risk reduction investments is relatively well organised. Note that in DesInventar, the amount of rainfall and flood waters were not recorded, but human and physical damage were. The period of flood damage data used to establish flood damage rates covered a total 21-year span from 1990 to 2010, for which a sufficient amount of information is available. Flood damage rates were set to the average of the 21-year total, namely, assumed to be an extensive risk (low severity, high-frequency events) situation, which is said to account for more than 42% of economic losses due to disasters in low- and middle-income countries (UNISDR, 2015). For flood damage rates by region, the rate of reduction in working hours was alternatively set by dividing the total number of deaths, injured, missing and affected people in each region by the population of each region, while the rate of damage to production capital was alternatively set by dividing the number of houses totally destroyed or damaged in each region by the number of households in each region. The budget for disaster risk reduction investments covered national and local expenditures obtained through taxes, while support from the domestic private sector and international assistance were not covered.

3.3. Result and Discussion

3.3.1. Economic Growth with Constant Disaster Risk Reduction Budget Rate

First, a case study was conducted where the disaster risk reduction budget rate σ was held constant. The disaster risk reduction budget rate σ was set for a total of seven cases ranging from 0.05% to 3% of GDP, as shown in Table 2. Here, Case 1 ($\sigma = 0.05\%$) is the current level of disaster risk reduction budget rate σ set based on Ishiwatari (2019). The main results of the case studies are shown in Figure 1. The horizontal axis in each figure is time, and the vertical axis is the ratio of the results with investment in disaster risk reduction ($\sigma > 0$) divided by the results without investment in disaster risk reduction ($\sigma = 0$), indicating the percentage difference in growth that occurred with and without investment in disaster risk reduction.

Table 2: Setting of Fixed Budget Rate for DRR Investment

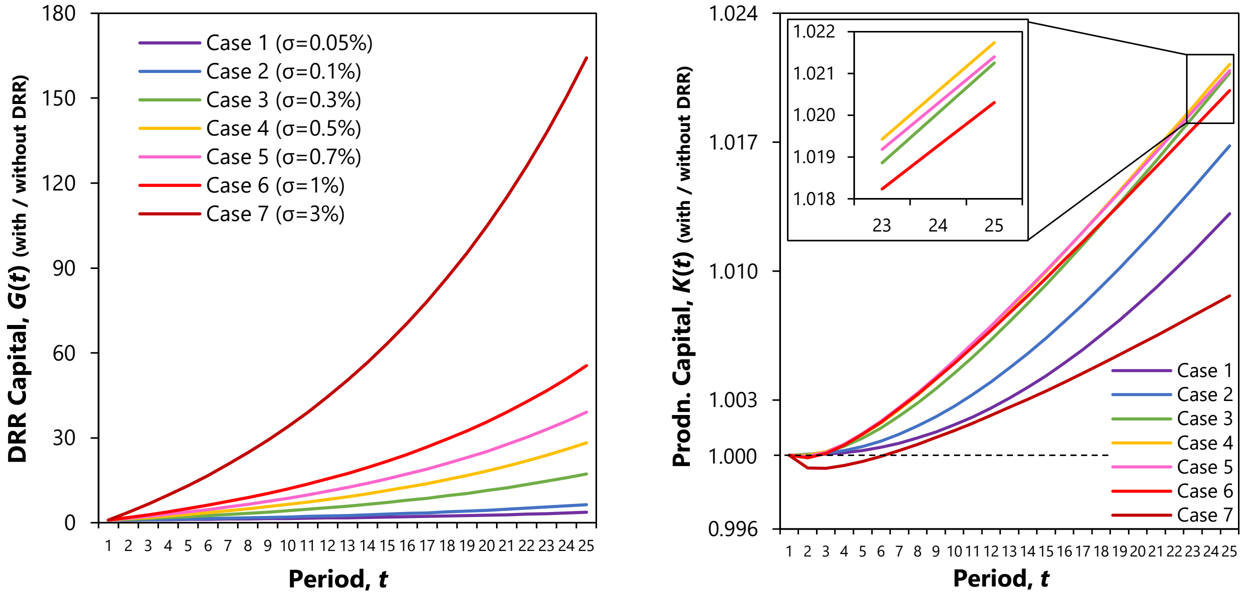
Fixed Budget Rate for DRR Investment by Case, σ (% of GDP)						
Case 1 (Current Level)	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**
0.05%	0.1%	0.3%	0.5%	0.7%	1%	3%

DRR = disaster risk reduction, GDP = gross domestic product.

Figure 1 (A) shows the accumulation process of disaster risk reduction capital G. The higher the disaster risk reduction budget rate σ, the more disaster risk reduction capital G is accumulated, verifying the trend of growing differences between cases year by year.

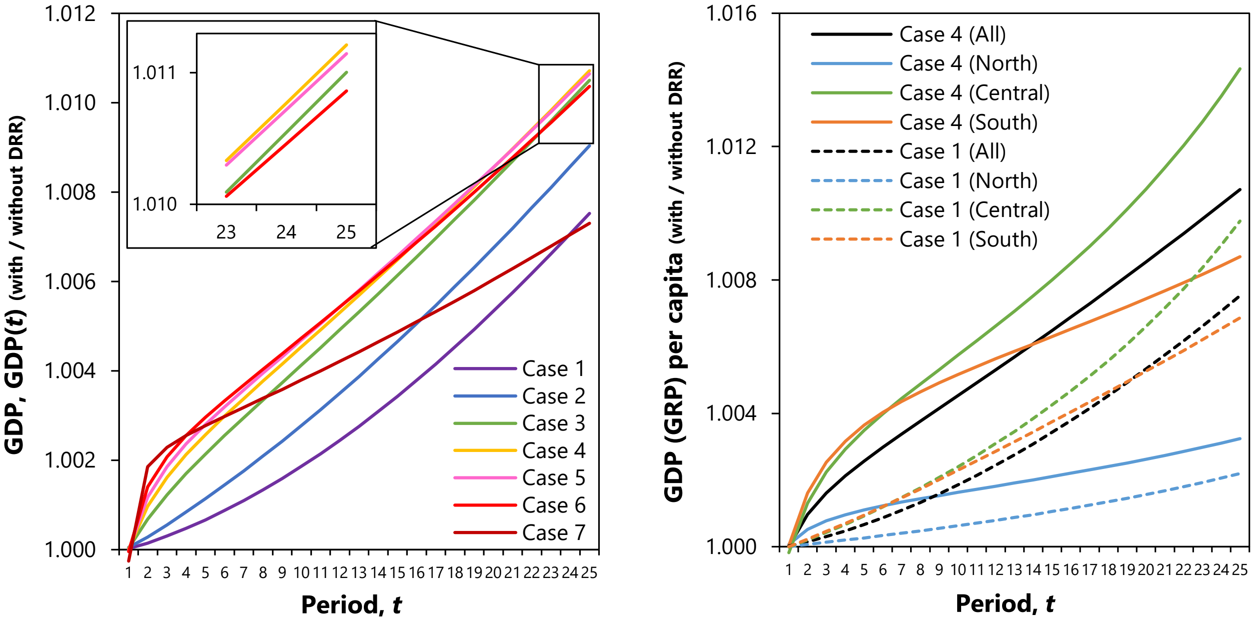
Figure 1 (B) shows the accumulation process of production capital K. From the final calculation period (25th period), the accumulation of production capital K was greatest in Case 4 ($\sigma = 0.5\%$). In Case 1 ($\sigma = 0.05\%$), the accumulation of disaster risk reduction capital G is more gradual than other cases, so the loss of production capital K after the flood event is relatively large until a sufficient level of disaster risk reduction capital G is accumulated, which may have caused a delay in the accumulation of production capital K. In contrast, the accumulation of disaster risk reduction capital G in Case 7 ($\sigma = 3\%$) is faster than other cases, so the loss of production capital K after the flood event is relatively small, but the higher tax burden stifles investment in production capital K, which may have led to a delay in the accumulation of production capital K.

Figure 1: Long-Term Effects and Optimal Level of DRR (Fixed Budget Rate)



(A) DRR Capital, $G(t)$

(B) Production Capital, $K(t)$



(C) GDP, $\mathrm{GDP}(t)$

(D) GDP (GRP) per capita

DRR = disaster risk reduction, GDP = gross domestic product, GRP = gross regional product.
Source: from the case study results of the model in this paper (see Appendix for detailed input data).

Figure 1 (C) shows the growth process of GDP, and Table 3 summarises the calculated values for the final calculation period (25th period) for each case. In the final calculation period (25th period), GDP grew by +1.07% compared to no investment in disaster risk reduction ($\sigma = 0\%$), and grew by +0.32% compared to the current level indicative in Case 1 ($\sigma = 0.05\%$). Maximum growth in GDP was with Case 4 ($\sigma = 0.5\%$), in line with production capital K. Approximately the same level of growth was observed in Case 3 ($\sigma = 0.3\%$), which has a lower disaster risk reduction budget rate σ than Case 4 ($\sigma = 0.5\%$).

Table 3: Ratio of GDP With DRR to that Without DRR (Fixed Budget Rate)

Name	DRR Budget Rate (% of GDP)	25-Period Ratio of GDP with / without DRR ($\sigma = 0\%$)	25-Period Additional Growth from Current Level (Case 1)
Case 1	$\sigma = 0.05\%$ (Current Level)	$+0.75\%$	—
Case 2	$\sigma = 0.1\%$	$+0.90\%$	$+0.15\%$
Case 3	$\sigma = 0.3\%$	$+1.05\%$	$+0.30\%$
Case 4	$\sigma = 0.5\%$	$+1.07\%$	$+0.32\%$
Case 5	$\sigma = 0.7\%$	$+1.06\%$	$+0.31\%$
Case 6	$\sigma = 1\%$	$+1.04\%$	$+0.28\%$
Case 7	$\sigma = 3\%$	$+0.73\%$	-0.02%

DRR = disaster risk reduction, GDP = gross domestic product.
Source: from the case study results of the model in this paper (see Appendix for detailed input data).

Figure 1(D) shows the growth process of GDP (GRP) per capita. Table 4 summarises the difference in GDP (GRP) per capita in the final calculation period (25th period), using the current level Case 1 ($\sigma = 0.05\%$) and Case 4 ($\sigma = 0.5\%$), which had larger growth in GDP. By increasing the budget rate on disaster risk reduction σ from the current level, GDP per capita grew by +0.32% and GRP per capita grew by +0.10% in the Northern region, +0.46% in the Central region, and +0.18% in the Southern region. This indicated that the long-term effects of investments in disaster risk reduction are particularly evident in the Central region, where there is a high rate of flood damage.

Table 4: Ratio of GDP (GRP) per Capita With to Without DRR (Fixed Budget Rate)

Name	DRR Budget Rate (% of GDP)	25-Period Ratio of GDP (GRP) per capita with/without DRR			
		All Country	Northern Region	Central Region	Southern Region
Case 1	$\sigma = 0.05\%$ (Current Level)	$+0.75\%$	$+0.22\%$	$+0.98\%$	$+0.69\%$
Case 4	$\sigma = 0.5\%$	$+1.07\%$	$+0.32\%$	$+1.43\%$	$+0.87\%$
Additional Growth (= Case 4 − Case 1)		$+0.32\%$	$+0.10\%$	$+0.46\%$	$+0.18\%$

DRR = disaster risk reduction, GDP = gross domestic product, GRP = gross regional product.
Source: from the case study results of the model in this paper (see Appendix for detailed input data).

In summary, if the disaster risk reduction budget rate σ is held constant throughout the calculation period, additional investment in disaster risk reduction above the current level has the potential to trigger economic growth, with the optimal range of disaster risk reduction budget rate σ being around 0.3% to 0.5%. Conversely, it was also verified that excessive investments in disaster risk reduction (such as $\sigma = 3\%$) presents a large tax burden that could reduce investment in production capital K and lead to stagnation of economic growth. By region, the long-term effects of investment in disaster risk reduction were most seen in the Central region, where the rate of flood damage is the highest. It should be noted, however, that these results indicate the optimal level of the disaster risk reduction budget rate σ may change depending on the number of years covered in the calculation period.

3.3.2. Economic Growth with Variable Disaster Risk Reduction Budget Rates

A case study was then conducted where the disaster risk reduction budget rate σ was varied over time. To analyse the pattern of change over time with the disaster risk reduction budget rate σ that led to more growth than Case 4 ($\sigma = 0.5\%$), which was the optimal case when the disaster risk reduction budget rate σ was held constant, a total of six cases were defined, including a pattern of raising or lowering the disaster risk reduction budget rate σ over time, as shown in Table 5. The main results of the case studies are shown in Figure 2. The horizontal axis in each figure is time, and the vertical axis is the ratio of the results with investment in disaster risk reduction ($\sigma > 0$) divided by the results without investment in disaster risk reduction ($\sigma = 0$), indicating the percentage difference in growth that occurred with and without investment in disaster risk reduction.

Table 1: Setting of Variable Budget Rate for DRR Investment

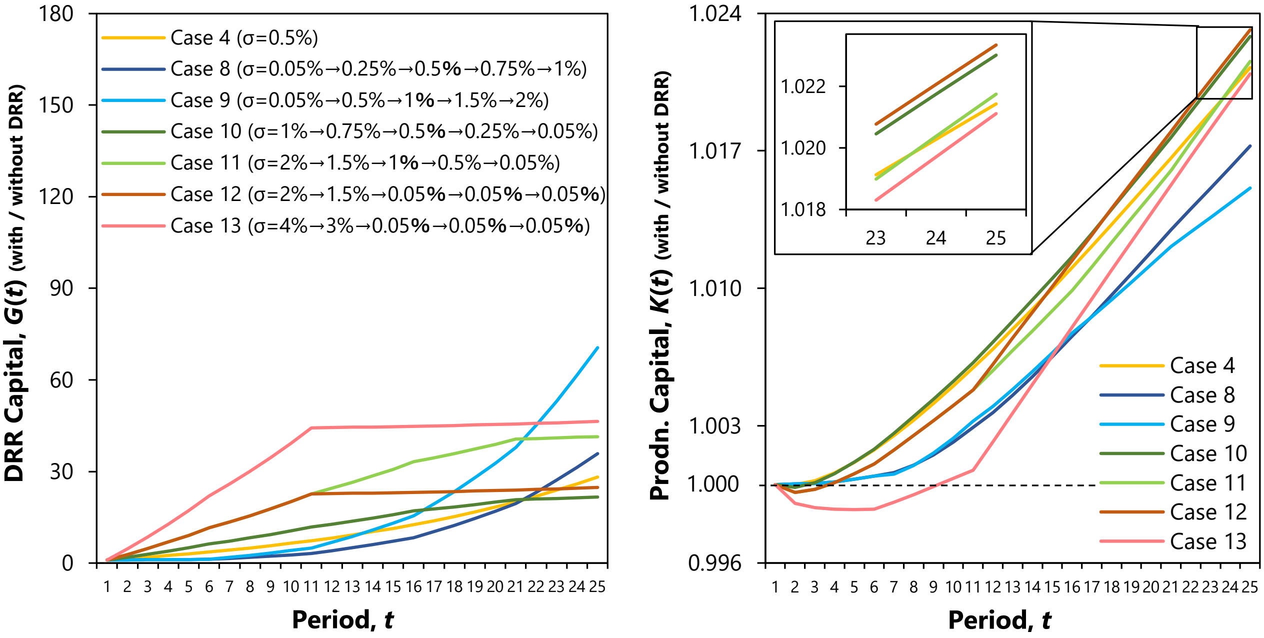
Name	**Explanation of DRR Budget Rate (% of GDP) Patterns**	**DRR Budget Rate by Period, σ (% of GDP)**				
		1 to 5	**6 to 10**	**11 to 15**	**16 to 20**	**21 to 25**
Case 8	Raise from the current level to 1% in 21 years	0.05%	0.25%	0.5%	0.75%	1%
Case 9	Raise from the current level to 2% in 21 years	0.05%	0.5%	1%	1.5%	2%
Case 10	Lower from 1% to the current level to in 21 years	1%	0.75%	0.5%	0.25%	0.05%
Case 11	Lower from 2% to the current level to in 21 years	2%	1.5%	1%	0.5%	0.05%
Case 12	Lower from 2% to the current level to in 11 years	2%	1.5%	0.05%	0.05%	0.05%
Case 13	Lower from 4% to the current level to in 11 years	4%	3%	0.05%	0.05%	0.05%

DRR = disaster risk reduction, GDP = gross domestic product.

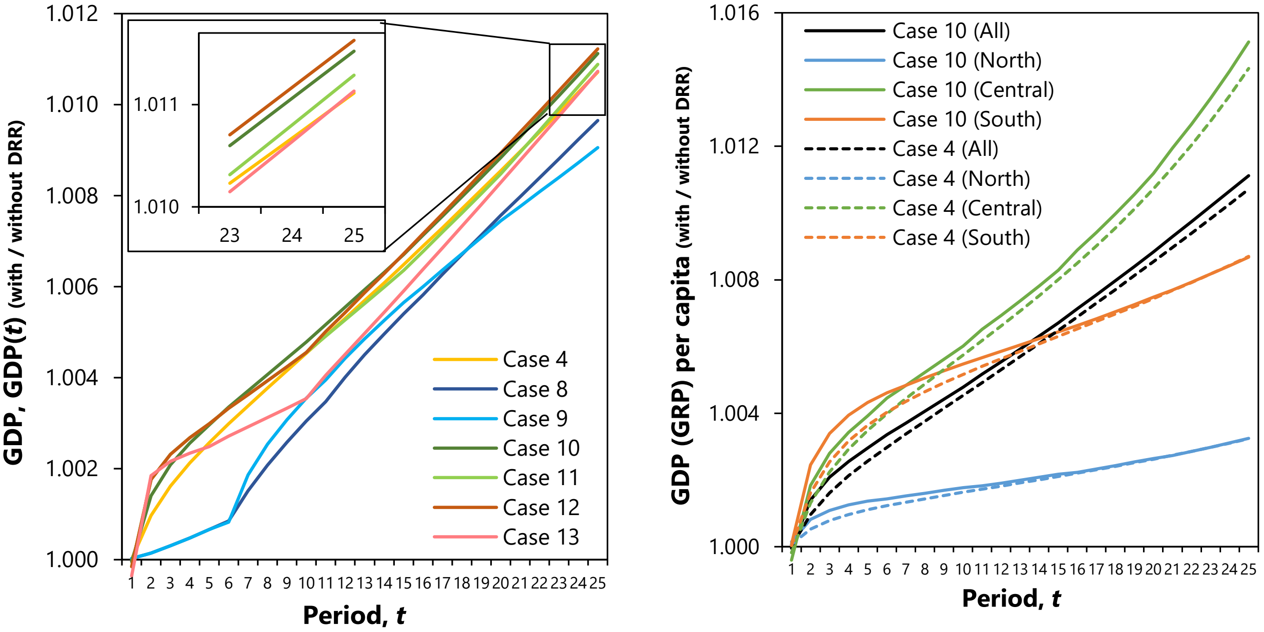
Figure 2 (A) shows the accumulation process of disaster risk reduction capital G. Compared to disaster risk reduction capital G in Case 4, where the disaster risk reduction budget rate σ was held constant, the disaster risk reduction capital G in Cases 8 and 9 – where the disaster risk reduction budget rate σ was gradually increased from a lower level than the current level – was smaller than Case 4 in the first half of the calculation period, but larger than Case 4 in the second half. Conversely, Case 10, which gradually reduces the disaster risk reduction budget rate σ from a higher level than the current rate, and Case 12, which reduces it earlier, have disaster risk reduction capital G larger than Case 4 in the first half of the calculation period, but smaller than Case 4 in the second half. The disaster risk reduction capital G of Case 11 and Case 13 – which had higher disaster risk reduction budget rates σ than those of Case 10 and Case 12 – was larger than that of Case 4 throughout the entire period.

Figure 2: Long-Term Effects and Optimal Level of DRR (Variable Budget Rate)

(A) DRR Capital, $G(t)$　　**(B) Production Capital, $K(t)$**



(C) GDP, GDP(t)　　**(D) GDP (GRP) per capita**



DRR = disaster risk reduction, GDP = gross domestic product, GRP = gross regional product.
Source: from the case study results of the model in this paper (see Appendix for detailed input data).

Figure 2 (B) shows the accumulation process of production capital K. A closer look at the final calculation period (25th period) reveals a low rate of growth in production capital K for Case 8 and Case 9, where the disaster risk reduction budget rate σ was gradually increased from the current level, compared to the production capital K of Case 4, where the disaster risk reduction budget rate σ was kept constant. This may be because accumulation of disaster risk reduction capital G is more gradual than in other cases, resulting in a relatively large loss of production capital K after the flood event until sufficient accumulation of disaster risk reduction capital G, and a delay in the accumulation of production capital K. In contrast, the production capital K of Case 10, where the disaster risk reduction budget rate σ is gradually reduced from a level higher than the current rate, led to higher growth than Case 4. This can be attributed to the accumulation of disaster risk reduction capital G in the first half of the calculation period, which allowed the loss of production capital K after the flood event to be controlled, while investment in production capital K increased in the second half of the calculation period because the disaster risk reduction budget rate σ was lowered. Additionally, production capital K for Case 12, which the disaster risk reduction budget rate σ was reduced earlier from a level that was higher than the current rate, led to slightly higher growth than Case 10. Therefore, it is assumed that lowering flood damage earlier by accelerating investment in disaster risk reduction as early as possible will be effective for accumulating production capital K. Yet when the disaster risk reduction budget rate σ is larger than necessary, as in Case 11 and Case 13, the loss of production capital K after a flood event is relatively smaller along with the rapid accumulation of disaster risk reduction capital G, but the large tax burden stifles investment in production capital K, resulting in slower accumulation of production capital K than in Case 10 and Case 12.

Figure 2 (C) shows the growth process of GDP, and Table 6 summarises the calculated values for the final calculation period (25th period) for each case. In the final calculation period (25th period), GDP grew at the same high rates in Case 10 and Case 12 similarly to production capital K, and was over +1.1% compared to no investment in disaster risk reduction ($\sigma = 0\%$) and over +0.04% compared to Case 4, which was the optimal case when disaster risk reduction budget rate σ was held constant.

Table 2: Ratio of GDP With DRR to that Without DRR (Variable Budget Rate)

Name	DRR Budget Rate (% of GDP) *See Table 5 for details on the pattern of budget rates.	25-Period Ratio of GDP with / without DRR ($\sigma = 0\%$)	25-Period Additional Growth from Fixed Budget Rate (Case 4)
Case 4	$\sigma = 0.5$ (%) (Fixed Budget Rate)	$+1.07\%$	—
Case 8	$\sigma = 0.05 \rightarrow 0.25 \rightarrow 0.5 \rightarrow 0.75 \rightarrow 1$ (%)	$+0.97\%$	-0.11%
Case 9	$\sigma = 0.05 \rightarrow 0.5 \rightarrow 1 \rightarrow 1.5 \rightarrow 2$ (%)	$+0.91\%$	-0.17%
Case 10	$\sigma = 1 \rightarrow 0.75 \rightarrow 0.5 \rightarrow 0.25 \rightarrow 0.05$ (%)	$+1.11\%$	$+0.04\%$
Case 11	$\sigma = 2 \rightarrow 1.5 \rightarrow 1 \rightarrow 0.5 \rightarrow 0.05$ (%)	$+1.09\%$	$+0.02\%$
Case 12	$\sigma = 2 \rightarrow 1.5 \rightarrow 0.05 \rightarrow 0.05 \rightarrow 0.05$ (%)	$+1.12\%$	$+0.05\%$
Case 13	$\sigma = 4 \rightarrow 3 \rightarrow 0.05 \rightarrow 0.05 \rightarrow 0.05$ (%)	$+1.07\%$	0.00%

DRR = disaster risk reduction, GDP = gross domestic product.
Source: from the case study results of the model in this paper (see Appendix for detailed input data).

Figure 2 (D) shows the growth process of GDP (GRP) per capita, and Table 7 summarises the difference in GDP (GRP) per capita in the final calculation period (25th period), using the examples of Case 4 with fixed budget rates and Case 10 with variable budget rates, where the size of GDP growth was large. The change in the disaster risk reduction budget rate σ from the fixed rate in Case 4 to a variable rate in Case 10 resulted in +0.04% growth in GDP per capita and +0.08% growth in GRP per capita in the Central region, while there was almost no change observed in the Northern and Southern regions. One possible reason for the effective results of early investment in disaster risk reduction in the Central region is due to the higher flood damage rate than in other regions of the country.

Table 7: Ratio of GDP (GRP) Per Capita With to Without DRR (Variable Budget Rate)

Name	DRR Budget Rate (% of GDP) *See Table 5 for details on the pattern of Case 10	25-Period Ratio of GDP (GRP) per capita with/without DRR			
		All Country	Northern Region	Central Region	Southern Region
Case 4	$\sigma = 0.5\%$ (Fixed Budget Rate)	$+1.07\%$	$+0.32\%$	$+1.43\%$	$+0.87\%$
Case 10	$\sigma = 1 \rightarrow 0.75 \rightarrow 0.5 \rightarrow 0.25 \rightarrow 0.05$ (%)	$+1.11\%$	$+0.32\%$	$+1.51\%$	$+0.87\%$
Additional Growth (= Case 10 − Case 4)		$+0.04\%$	0.00%	$+0.08\%$	0.00%

DRR = disaster risk reduction, GDP = gross domestic product, GRP = gross regional product.
Source: from the case study results of the model in this paper (see Appendix for detailed input data).

In summary, we verified that a variable budget rate (e.g. $\sigma = 1\% \rightarrow 0.75\% \rightarrow 0.5\% \rightarrow 0.25\% \rightarrow 0.05\%$), which gradually lowers the disaster risk reduction budget rate σ from a higher level than the current rate, could possibly trigger economic growth further than a fixed budget rate. Yet just as the analysis results of the fixed budget rate, we were able to verify that a variable budget rate could potentially present a large tax burden that would reduce investment in production capital K and lead to stagnation of economic growth if the investment in disaster risk reduction is excessive. By region, the long-term effects of investment in disaster risk reduction were most seen in the Central region, where the rate of flood damage is the highest. It should be noted, however, that these results indicate the optimal level of the disaster risk reduction budget rate σ may change depending on the number of years covered in the calculation period.

4. Conclusion

4.1. General Conclusion

In this study, a multi-regional economic growth model capable of taking into account flood damage and investment in disaster risk reduction was developed and utilised in case studies conducted in Viet Nam. A quantitative analysis was then conducted to provide an overview of the long-term effects of investment in disaster risk reduction on the national and local economy (e.g. GDP), in addition to the optimal scale and timing of investment in flood control. The results indicate that additional investment in disaster risk reduction could stimulate economic growth, and that the optimal range of the disaster risk reduction budget rate was around 0.3% to 0.5% of GDP, assuming a constant budget rate throughout the total 25-year calculation period. For variable disaster risk reduction budget rates, we verified that a variable budget rate (e.g. $1\% \rightarrow 0.75\% \rightarrow 0.5\% \rightarrow 0.25\% \rightarrow 0.05\%$) where the disaster risk reduction budget rate is gradually lowered from a higher level than the current rate could further stimulate economic growth, compared to a fixed budget rate. In both cases, we verified that with excessive investment in disaster risk reduction, the high tax burden had the risk of reducing investment in production capital and lead to stagnating economic growth. By region, the long-term effects of investment in disaster risk reduction were most seen in the Central region, where the rate of flood damage is the highest. It should be noted, however, that the optimal level of the disaster risk reduction budget rate could change depending on the number of years covered in the calculation period.

4.2. Recommendations

Several tasks remain that need to be addressed to expand the scope and improve the accuracy of effectiveness analysis. The first is to quantify the normative solution regarding the scale and timing of investment in disaster risk reduction measures. Doing so would require the optimisation problem to be addressed with the disaster risk reduction budget rate as an endogenous variable, rather than attributing it exogenously as a policy variable. Secondly, the risk of occurrence of low-frequency and large-scale disasters should be considered. To achieve this, it would be effective to extend the model to a stochastic one that takes into account not only high-frequency small-scale disasters (extensive risk) but also low-frequency large-scale disasters (intensive risk). Thirdly, the input data needs to be refined further. In this paper, case studies were conducted using data available online and alternative data to obtain the overview of results. Updating parameters such as flood damage rates and flood damage mitigation function parameters, particularly after data on flood damage and disaster risk reduction budgets over time have been sufficiently collected, would be effective in improving accuracy. Finally, case studies should be conducted in developing countries other than Viet Nam to confirm differences in the optimal level of disaster risk reduction investment by country and to verify the applicability of the model. As an example of a target country in developing countries, Indonesia would be assumed to be relatively easy to conduct a case study due to its well-developed socio-economic and disaster-related data.

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Appendix: List of Data Used

Table A1: Socio-Economic Data

Symbol	Definition	Value	Note
N^0	Total population in the initial period	92.2 (million people)	From the statistical data (World Bank)
N_i^0	Regional population in the initial period	$\{N_1^0, N_2^0, N_3^0\}$ $= \{32.9, 25.4, 33.9\}$ (million people)	From the statistical data (World Bank; General Statistics Office of Viet Nam)
n	Population growth rate	0.93 (%)	Average of 2015-2021 from the statistical data (World Bank)
γ_j	Share parameter of consumptions	$\{\gamma_a, \gamma_x\} = \{0.19, 0.81\}$	By the calibration (Asian Development Bank; Thurlow, 2021; Thanh, 2006; Tapp et al., 2002; World Bank; Federal Reserve Bank of St. Louis; General Statistics Office of Viet Nam)
s	Saving rate (production capital investment rate)	15.3 (%)	
$\alpha_{i'ji}$	Share parameter of production factors	$\{\alpha_{La1}, \alpha_{Ka1}, \alpha_{Aa1}\}$ $= \{0.63, 0.10, 0.26\}$ $\{\alpha_{Lx1}, \alpha_{Kx1}, \alpha_{Ax1}\}$ $= \{0.60, 0.39, 0.01\}$ $\{\alpha_{La2}, \alpha_{Ka2}, \alpha_{Aa2}\}$ $= \{0.56, 0.09, 0.34\}$ $\{\alpha_{Lx2}, \alpha_{Kx2}, \alpha_{Ax2}\}$ $= \{0.98, 0.00, 0.02\}$ $\{\alpha_{La3}, \alpha_{Ka3}, \alpha_{Aa3}\}$ $= \{0.66, 0.11, 0.23\}$ $\{\alpha_{Lx3}, \alpha_{Kx3}, \alpha_{Ax3}\}$ $= \{0.69, 0.30, 0.01\}$	
B_{ji}^0	Total factor productivity (TFP) in the initial period	$\{B_{a1}^0, B_{a2}^0, B_{a3}^0\}$ $= \{1.93, 7.70, 1.00\} \times 10^5$ $\{B_{x1}^0, B_{x2}^0, B_{x3}^0\}$ $= \{0.19, 7.44, 0.46\} \times 10^7$	
β_{ji}	TFP growth rate	$\{\beta_{a1}, \beta_{a2}, \beta_{a3}\}$ $= \{2.9, 3.2, 3.8\}$ (%) $\{\beta_{x1}, \beta_{x2}, \beta_{x3}\}$ $= \{3.3, 4.1, 3.5\}$ (%)	
$\varphi_{j'ji}$	Intermediate input co-efficient	$\{\varphi_{\mathrm{aa}i}, \varphi_{\mathrm{xa}i}\} = \{0.13, 0.40\}$ (for all i) $\{\varphi_{\mathrm{ax}i}, \varphi_{\mathrm{xx}i}\} = \{0.08, 0.58\}$ (for all i)	
A_{ji}	Land share amongst regions	$\{A_{a1}, A_{a2}, A_{a3}\}$ $= \{0.25, 0.40, 0.35\}$ (%) $\{A_{x1}, A_{x2}, A_{x3}\}$ $= \{0.35, 0.40, 0.25\}$ (%)	From the statistical data (General Statistics Office of Viet Nam)
δ_K	Depreciation rate of production capital	0.02	From the previous research (Uemura et al., 2018)
$K(t_0)$	Total production capital in the initial period	1.32 (trillion US$)	From the statistical data (World Bank; Federal Reserve Bank of St. Louis)

Source: Authors.

Table A2: Disaster-Related Data

Symbol	Definition	Value	Note
ω_i^0	Initial labour damage rate	$\{\omega_1^0, \omega_2^0, \omega_3^0\} = \{0.16, 0.53, 0.49\}$ (%)	By the assumption and the estimation (UNDRR; World Bank; General Statistics Office of Viet Nam)
ψ_i^0	Initial production capital damage rate	$\{\psi_1^0, \psi_2^0, \psi_3^0\} = \{0.04, 0.41, 0.20\}$ (%)	
$\theta_{\iota i}$	Effective parameter of flood damage mitigation function	$\{\theta_{\omega i}, \theta_{\psi i}\} = \{1.07, 0.85\}$ (for all i)	By the assumption and the estimation (Cabinet Office, Government of Japan; Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan; World Bank)
δ_G	Depreciation rate of disaster risk reduction capital	0.02	By the assumption that $\delta_G = \delta_K$
$G(t_0)$	Total disaster risk reduction capital in the initial period	2.67 (billion US$)	By the assumption and the estimation (World Bank; Federal Reserve Bank of St. Louis)

Source:Authors.

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