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Economic Assessment of Flood Control Facilities under Climate Uncertainty: A Case of Nakdong River, South Korea

Kyeongseok Kim [1,*] and Ji-Sung Kim [2]

[1] School of Civil & Environmental Engineering, Yonsei University, Seoul 03277, Korea
[2] Hydro Science and Engineering Research Institute, Korea Institute of Civil Engineering and Building Technology, Goyang-Si 10223, Korea; jisungk@kict.re.kr
* Correspondence: kim.ks@yonsei.ac.kr; Tel.: +82-2123-7940

Received: 6 November 2017; Accepted: 24 January 2018; Published: 25 January 2018

Abstract: Climate change contributes to enhanced flood damage that has been increasing for the last several decades. Understanding climate uncertainties improves adaptation strategies used for investment in flood control facilities. This paper proposes an investment decision framework for one flood zone to cope with future severe climate impacts. This framework can help policy-makers investigate the cost of future damage and conduct an economic assessment using real options under future climate change scenarios. The proposed methodology provides local municipalities with an adaptation strategy for flood control facilities in a flood zone. Using the proposed framework, the flood prevention facilities in the Nakdong River Basin of South Korea was selected as a case study site to analyze the economic assessment of the investments for flood control facilities. Using representative concentration pathway (RCP) climate scenarios, the cost of future flood damage to 23 local municipalities was calculated, and investment strategies for adaptation were analyzed. The project option value was determined by executing an option to invest in an expansion that would adapt to floods under climate change. The results of the case study showed that the proposed flood facilities are economically feasible under both scenarios used. The framework is anticipated to present guidance for establishing investment strategies for flood control facilities of a flood zone in multiple municipalities' settings.

Keywords: climate change; flood control; real options analysis; economic assessment; adaptation

1. Introduction

Climate change (CC) contributes to severe environmental risks to the world [1]. Because CC alters current precipitation patterns, heavier precipitation events have occurred in a number of regions throughout the last 60 years [2]. The risks caused by changes in precipitation include increased flooding and drought. The impact of CC arises over both short-term and long-term periods [3], and losses and costs related to global and local flood damage have been increasing for the last several decades [2]. The destruction and insufficient capacity of flood control facilities (FCFs) due to flooding events require not only urgent recovery, but also adaptation. However, conducting economic feasibility studies of adaptation for FCFs is not easy because uncertainties are associated with future CC and economic growth [4]. Thus, planning adaptation related to FCF should take into account changes in future climate patterns and economic uncertainty.

There have been numerous attempts to develop economic assessment techniques for adaptation investment to CC. Arnbjerg-Nielsen and Fleischer [5] used the net present value (NPV) method to assess the feasibility of urban drainage facilities considering adaptation to long-term sea-level rise, using an analysis of flood damage costs. Zhou et al. [6] proposed a framework that provided an economic assessment of pluvial flood risk, considering CC, and calculated the expected annual damage from future extreme precipitation, using a cost-benefit analysis with NPV. Olsen et al. [7] compared methods of calculating expected annual damage in urban pluvial flood risk assessments in Denmark and showed that estimating the expected annual damage correlated with degrees of flood risk. Ha et al. [8] proposed a reliability-based economic assessment of adapting infrastructure to CC to estimate the damage costs from climate-related risks. From this, decision-makers can apply a cost and benefit estimation of an adaptation project using CC scenario analysis.

Traditional economic assessment methods, such as discount cash flow (DCF) estimate investments using NPV, which is the most widely-used decision-making tool for various investment projects, but not for highly volatile investments [9]. In the case of an investment with options, real option analysis (ROA) is a novel method in investment decision-making that more precisely evaluates projects, as compared to traditional methods, such as DCF [10]. ROA considers managerial flexibility and the volatility of a project's cash flow [11–13]. Recent studies on economic assessment for adaptation investment under CC recommend ROA as a methodology that can not only capture uncertainties but also evaluate economic feasibility. Ryu et al. [14] implemented ROA, using delay and abandon options, to assess FCF for the Yeongsan River Basin in South Korea and suggested the priority ranking of adaptation methods by traditional DCF and ROA. Kontogianni et al. [15] showed that ROA supported the assessment of costs associated with sea-level rise and adaptation benefits under climate uncertainty in Greece, by using an option to defer. Kim et al. [16] proposed a real options-based decision-making model to estimate the economic feasibility of adaptation projects in urban areas, using representative concentration pathway (RCP) climate scenarios. Gersonius et al. [17] used a real options analysis for urban drainage adaptation in England, using the volatility of rainfall intensity and CC modeling data. Woodward et al. [18] employed a flood risk analysis to evaluate a flood system in the Thames Estuary in London, England, using real options, under the uncertainty of sea-level rise. Harrison et al. [19] used rainfall patterns to assess the financial viability of an existing hydropower plant and applied CC scenarios to analyze project risks. In a review of the related literature, there were no studies that investigated flood adaptation for multiple local municipalities' areas in a flood zone, using a real option approach.

Many studies have dealt with issues related to the feasibility of adaptation investment, using ROA. They have used historical climate data or future CC scenarios to estimate future climate information. These studies have achieved the advanced investment decisions method for FCF. However, historic data is not a good basis for ROA when climate futures are very different from historic trends. An extreme weather event simultaneously affects flood damage in many local municipal areas. Thus, a response of mutual cooperation is needed in cases where a river crosses government boundaries. It is not easy for local municipalities with one flood source to combine resources, in terms of flood disaster prevention facilities. Investment in adaptation measures depends on both the extent of flood damage for different municipalities and the investment cost for FCF. In addition, climate-related risks will continue to increase with a rise in natural disasters, as compared to the past [2]. So, an adaptation strategy of FCF should be derived, not from past climate information, but from the future, using scenarios across a range of future climate conditions. Thus, we propose a methodology that provides a strategy for FCF adaptation for multiple local municipalities within one flood zone. The proposed methodology can consider future CC impacts in a flood zone and determine the economic feasibility of FCFs using ROA and CC scenarios. The proposed methodology could help policy-makers develop adaptation strategies for sustainable FCFs under CC.

If policy makers are able to estimate future damage costs for each municipality, they can develop sustainable adaptation strategies to CC. Over the past decade, South Korea has incurred costs of about US$550 million from damage every year, due to typhoons, river floods, and heavy rains [20]. Some rivers in South Korea pass through more than 20 municipalities. Often the villages nearest the river suffer from floods. Unexpected floods, triggered by extreme precipitation, cause serious damage to nearby residents' properties and lives. Local municipalities need new adaptation strategies for a flood zone, to cope with the increasing impact of CC. The strategies should deal with investment costs, implementation time, and priority. The proposed framework can provide the investment priority and costs for multiple local municipalities in a flood zone under future CC.

We suggest a framework for making investment decisions on adaptation to CC regarding FCFs for multiple local municipalities within a flood zone. The proposed framework suggests ROA to cope with future floods, projected by RCP climate scenarios, that are representative concentration pathways for emissions, that are based on different assumptions affecting those pathways across low to high emissions levels. This framework provides a method to estimate economic losses from future floods under RCP climate scenarios and the economic feasibility of investments in FCFs under CC. The RCPs project the impacts of CC. The scenarios are composed of four different pathways, including a preindustrial level scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and an extreme greenhouse gas (GHG) emission scenario (RCP8.5) [2,21].

Figure 1 shows the investment decision framework of a flood zone for a suggested adaptation investment to climate uncertainty. The first step is to define a flood zone that includes municipalities near a river that have suffered from floods. Within this, we need to identify flood sources, including precipitation, melting ice, and sea-level rise. The second step is to define future scenarios that include CC scenarios. We estimate the extent of flood risk, using future CC scenarios. The third step is to estimate the cost of damage under future conditions. Historical information regarding flood damage helps us estimate future damage with economic factors. The fourth step is to identify the target flood control criteria with consideration to future damage costs under the selected CC scenarios. Local municipalities reduce flood risk by upgrading FCF capacity, considering future CC. The return period of a flood event should be increased, to reduce the level of damage to the target level. The fifth step is to conduct ROA to analyze the economic feasibility of FCFs, aiming to adapt to future CC. Using a binomial lattice approach, we calculated the adaptation profits for investment decisions under each climate scenario. The sixth step is to develop adaptation strategies that suggest priorities and investment costs for local municipalities. A detailed explanation of the proposed framework is presented in Section 2.

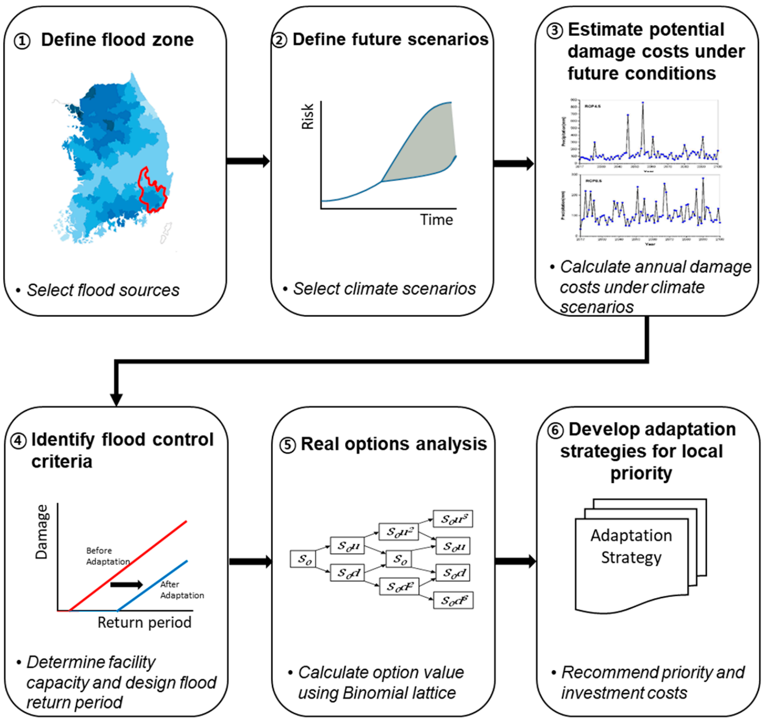

Figure 1. Investment decision framework of a flood zone.

2. Methods

Climate-related risks result in future damage costs from floods in cases where the existing FCFs cannot prevent flooding. The level of damage can be estimated using CC scenarios to project future climate-related risks. To estimate the damage costs of floods, we use past information to show the relationship between the damage and the return period of the floods. Future damage costs are calculated by assuming a log-linear relationship between the damage cost of a flood event and the corresponding return period [6,7]. The future damage costs will be similar to historical damage costs for the same level of damage. However, the damage costs are increased with the rate of inflation. Equation (1), developed by Kim et al. [16], estimates damage costs of a flood event, using the log-linear relationship.

$$D_i = a\ \ln(R)(1 + r_i)^{i-1} \tag{1}$$

where D_i is the future damage cost in year i, R is the return period of the flood event, a is a constant based on the historical data of extreme weather events, and r_i is the inflation rate.

Because of climate uncertainty, it is not easy to invest in the FCFs of a local government, to protect against future flood events. ROA can be used to analyze the economic feasibility of an investment under CC [22]. Decision-makers can use managerial flexibility to hedge future uncertainties in climate. The benefit of FCF investment is the reduced future climate-related risk through the adaptation measure [8]. Climate scenarios inform climate-related risks. To capture climate risk, we estimate the volatility of benefits arising from FCF investment under CC. The volatility (σ) can be obtained by applying the logarithmic cash flow returns approach to the cash flow of future returns by the FCF investment. The volatility is calculated by Equation (2) [23].

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{2}$$

where n is the number of cash flow returns, x_i is the individual cash flow returns, and $\overline{x}$ is the average of x_i. In general, the data is converted into annual data, using the equation $\sigma(T_2) = \sigma(T_1) \times \sqrt{T_2/T_1}$ [24], where $\sigma(T_2)$ and $\sigma(T_1)$ are the volatilities of the time steps T_2 and T_1, respectively.

Managerial flexibility has the right to exercise options in a project [25]. If climate impacts are expected to change in the future, the investor may execute options for adaptation to CC. By executing options to abandon or expand investments, in order to reduce future damage, decision-makers have an opportunity to reduce risks and improve project value.

An underlying asset value adopts the present value of the most likely cash flow for an ROA [26]. The present value of the underlying asset (S_0) is estimated using Equation (3), and NPV can be obtained by Equation (4).

$$S_0 = \sum_{i=1}^{n}\frac{D_i}{(1 + r_d)^{i-1}} \tag{3}$$

$$\text{NPV} = \sum_{i=1}^{n}\frac{x_i - c_i}{(1 + n)^{i-1}} \tag{4}$$

where n is the project period of the FCF, r_d is the discount rate, and c_i is the investment cost at year i.

The option values are calculated by the formulation of the up (u) and down (d) movement per node in the binomial lattice approach, calculated by Equations (5) and (6), respectively [23].

$$u = e^{\sigma\sqrt{\Delta t}} \tag{5}$$

$$d = \frac{1}{u} \tag{6}$$

The risk-neutral probability (q) and option value (C) are represented by Equations (7) and (8), respectively [24,27].

$$q = \frac{\left(e^{r_f t} - d\right)}{u - d} \tag{7}$$

$$C = e^{-r_f t}[qC_u + (1-q)C_d] \tag{8}$$

where Δt is a time-step increment, r_f is the risk-free interest rate, C_u is the option value if the underlying asset value (S) increases, and C_d is the option value if S decreases. ROA investigates a project value by the binomial lattice approach, which effectively visualizes the results using risk-neutral probability [22]. The option value (C) of each node represents the value maximization, with options to try to lessen climate uncertainties, such as deferral, abandonment, expansion, and growth.

3. A Case Study of the Nakdong River Basin

3.1. Project Description

The Intergovernmental Panel on Climate Change (IPCC) [2] reported that precipitation is expected to be heavier and more frequent in many regions over the next few decades. The Korea Meteorological Administration reported that annual precipitation in South Korea is anticipated to increase by 16%, from 2000 to 2100, under the RCP8.5 scenario and by 17.6% under RCP4.5 [28]. Nakdong River is located in the southeast region of South Korea and passes through 23 municipalities (Figure 2). The length of the river is 521 km, and the basin where floods frequently occur during the summer season is 23,817 km^2 [29]. A number of reservoirs, detention basin, drainage systems and flood control dams have been installed to prevent floods in the Nakdong River Basin. These FCFs are those widely-used for flood control in river basins in South Korea. However, flooding in the Nakdong River Basin has resulted in damages of US$2.58 billion, from 1986 to 2015 [20]. The ROA can be used to assess the robustness and flexibility of a number of FCFs and other flood risk reduction options that can reduce exposure to future flooding under changing climate conditions. The main cause was heavy rainfall that exceeded the design standards of existing FCFs. The design of FCFs should follow government regulations, which meet the 200-year return period of flood, based on a cumulative 48 hr of rainfall [30]. However, precipitation will increase over time, and thus, the capacity will be insufficient to cope with future floods under CC. Local municipalities have tried to prevent floods by implementing adaptation measures that lessen flood-related risks, but these programs have suffered from budget limitations. ROA for investment decisions in FCFs under CC was applied to establish future adaptation strategies for the case study. The investment decision framework of the flood zone will deal with a case study on 23 municipalities of the Nakdong River Basin and demonstrate the validity of the framework using ROA. The 23 municipalities are Goryeong-gun, Gumi-si, Gimhae-si, Dalseo-gu in Daegu, Dalseong-gun in Daegu, Mungyeong-si, Miryang-si, Gangseo-gu in Busan, Buk-gu in Busan, Sasang-gu in Busan, Saha-gu in Busan, Sangju-si, Seongju-un, Andong-si, Yangsan-si, Yecheon-gun, Uiryeong-gun, Uiseong-gun, Changnyeong-gun, Changwon-si, Chilgok-gun, Haman-gun, and Hapcheon-gun.

Figure 3 shows the 10-year sum of flood damage costs within the 23 local municipalities of the Nakdong River Basin between 1971 and 2010 [20]. Flood damage has significantly increased throughout those 40 years. If local municipalities do not implement various adaptation measures to cope with future floods, the intensity of damage will worsen significantly over time. However, adaptation strategies for investments in FCFs place a burden on local municipalities, due to the lack of financial support for such projects. Herein, we present guidance for establishing adaptation plans for the case study. Using the proposed framework, we investigate future damage costs and conduct an economic assessment using ROA under future CC.

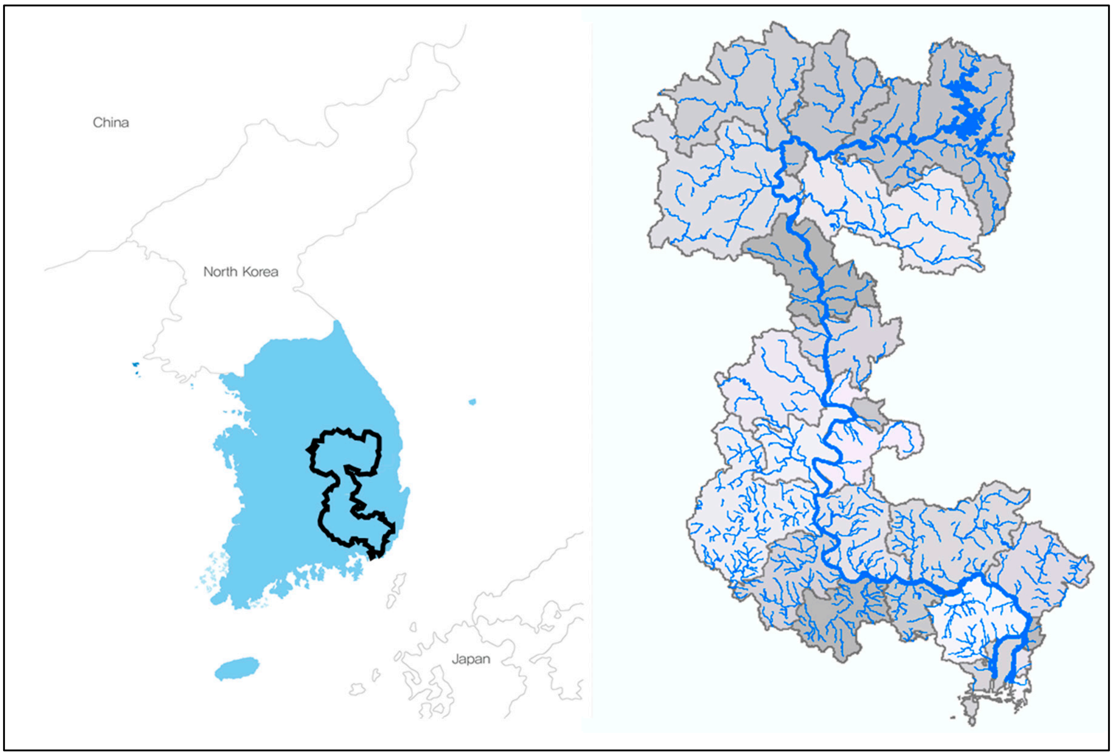

Figure 2. Location of the Nakdong River Basin.

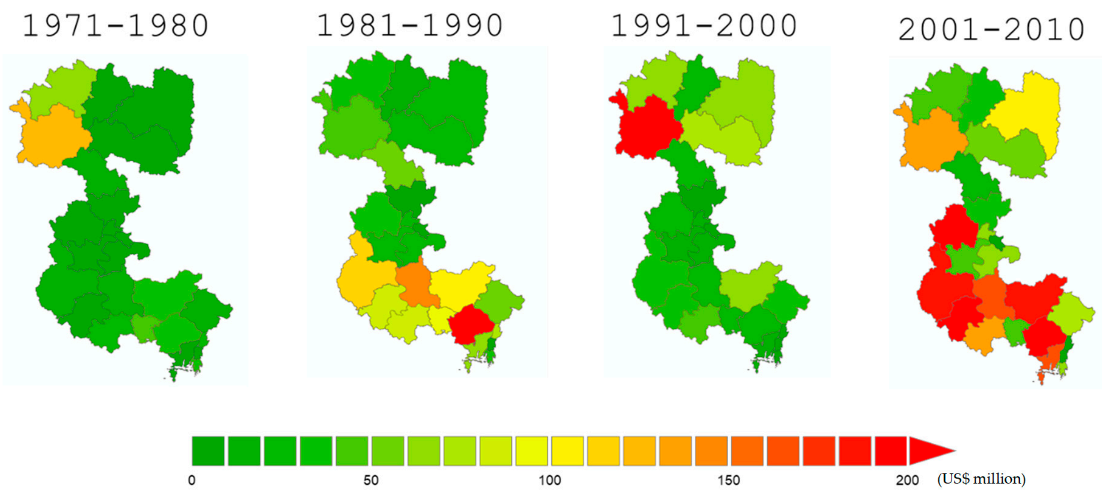

Figure 3. Ten-year sum of flood damage costs considering the inflation rate in the 23 local municipalities in the Nakdong River Basin between 1971 and 2010 (US$ million).

3.2. Case Study Conditions and Input Parameters

To establish adaptation plans for future floods, we needed to determine the expanding capacity of the FCFs. According to the RCP climate scenarios, the annual precipitation in the Nakdong River Basin will increase to the year of 2100 [28]. Because of the insufficient capacity of existing FCFs, flood damage is anticipated to increase in all of the 23 local municipalities. RCP8.5 is the so-called "baseline" scenario that does not contain any climate mitigation targets [31] and RCP4.5 is a stabilization scenario involving the obligation of reducing GHG emissions [32]. Thus, to analyze future climate risk, we used the RCP4.5 and RCP8.5 climate scenarios for the case site in the Nakdong River Basin.

It is important to identify economic parameters to determine the economic feasibility of the investment projects [16]. The historical precipitation data and damage costs from floods came from records obtained from 1986 to 2015 for the 23 local municipalities. The precipitation data and historical damage costs were used to estimate future damage costs under the selected climate scenarios. The risk-free rate, the inflation rate, and the risk-adjusted discount rate were assumed to be 5% per year, 3% per year, and 13% per year, respectively. The annual operation and maintenance (O&M) costs were assumed to be a yearly 3% of the damage costs in the case of a flood occurrence. We assumed the project period of the case study to be from 2017 to 2100.

The river basins in South Korea did not have sufficient FCFs to prevent precipitation-induced floods. In 2016, the central government decided to invest US$8.7 billion, until 2020, for adaptation measures to avoid damage by future floods [33]. The adaptation measures include the installation of FCFs with a design level corresponding to floods with a 200-year return period. However, the climate scenarios of RCP4.5 and RCP8.5 show that extreme precipitation above the design level will occur in many of the local municipalities in the case study. Higher precipitation increases than those in the past, as well as regional differences, are remarkable [22]. Figure 4 shows the anticipated precipitation change rate from 2041 and 2070, as well as from 2071 and 2100, based on the 10-year average, from 2001 to 2010, under RCP4.5 and RCP8.5.

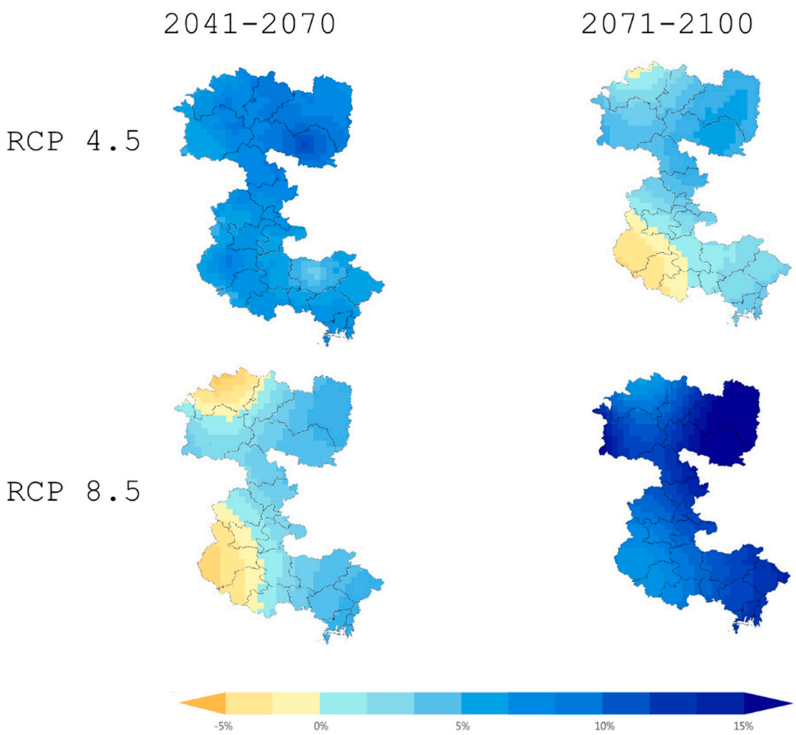

Figure 4. Change rates of annual precipitation under RCP4.5 and RCP8.5.

An initial cost of US$2 billion was invested in 2017. We determined the execution timing of the expansion option based on the RCP climate scenarios projecting the frequency and the intensity of future extreme weather events. After 2040, many extreme floods will occur. For example, RCP4.5 projects 37 flooding events that will exceed the design criteria of the 200-year return period, until 2100. In Uiseong-gun, one of the case sites, the year 2083 presents an extreme rainfall event of 671.8 mm in a 48-h period, which is half of the annual precipitation under the RCP4.5 scenario. RCP8.5 shows 65 floods that exceed the design standard. In Saha-gu, Busan, another case site, an extreme rainfall event of 1100.9 mm in a 48-hr period is projected to occur in 2097. This precipitation is equal to the total annual precipitation at this site. US$17.5 billion for the expansion option in 2040 is assumed to be able to prevent up to five times as much future damage to the existing facility. This case study analyzed the expansion option. Table 1 lists the input parameters used in the analysis.

Table 1. Input parameters of the case study.

Parameter	Value
Case study site	23 local municipalities in the Nakdong River Basin
Risk-free rate	5.0%/year
Inflation rate	3.0%/year
Yearly O&M costs	3% of the damage costs
Climate scenarios	RCP4.5/8.5
Project period	between 2017 and 2100
Option type	Expansion option
Initial investment costs in 2017	US$2 billion
Second investment costs for expansion in 2040	US$17.5 billion

4. Results and Discussion

4.1. Future Damage Costs

Using the relationship between damage cost and return period of a flood, the future damage costs in the 23 municipalities were estimated. For Goryeong-gun, the equation of the log-linear relationships between damage cost and return period is the transformation of Equation (1), as follows: $D_i = 12,915,270.7211\ ln(R)(1+0.03)^{i-1}$. The damage resulting from each extreme weather event was derived from the specified equation for each local municipal area. In order to estimate the trend line for calculating future damage costs in the case study areas, we used historical rainfall data and damage data in the case study area from 1986 to 2015. The points in Figure 5 represent past flood events, and the trend line shows the log-linear relationship between the biggest damage cost and the corresponding return period for a site. Future damage cost can be estimated by each equation of the log-linear relationship of the 23 municipalities, where each equation is a modification of Equation (1). Figures 6 and 7 show the damage costs in the 23 municipalities under RCP4.5 and RCP8.5, respectively. Damage from flood events under the RCP scenarios are anticipated to rapidly increase after 2040. Appendixs A and B show damage costs projected under RCP4.5, and 8.5, respectively.

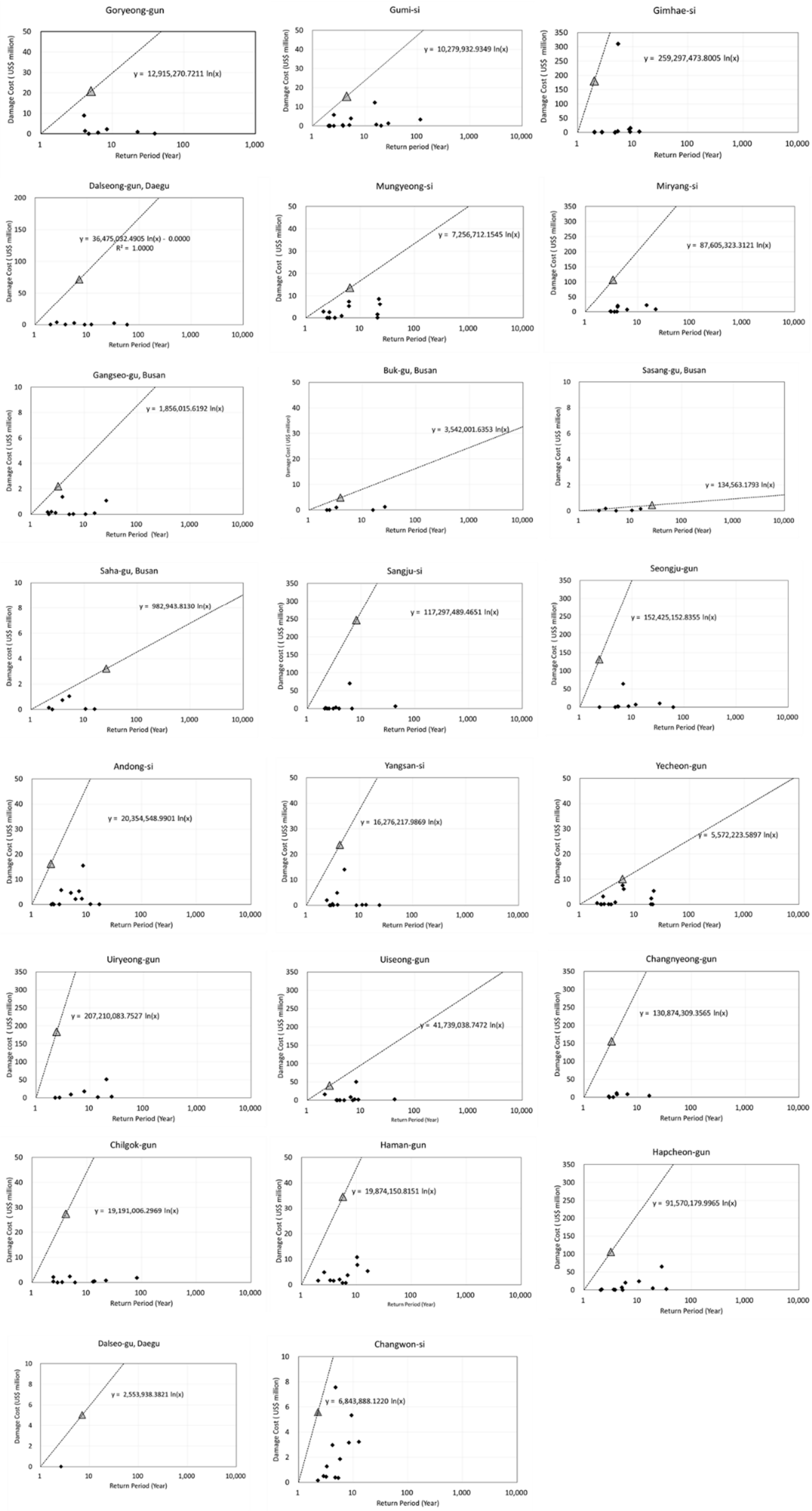

Figure 5. Relationship of historical damage cost and return period in the 23 municipalities in the Nakdong River Basin.

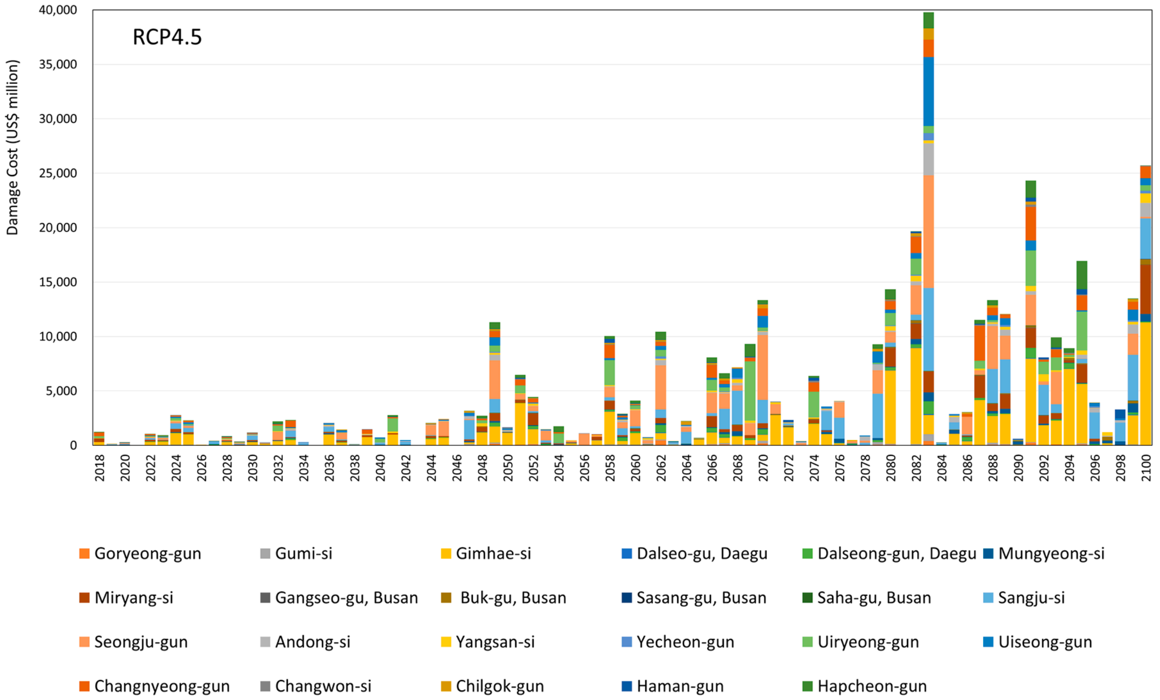

Figure 6. Future damage between 2018 and 2100 under the RCP4.5 scenario.

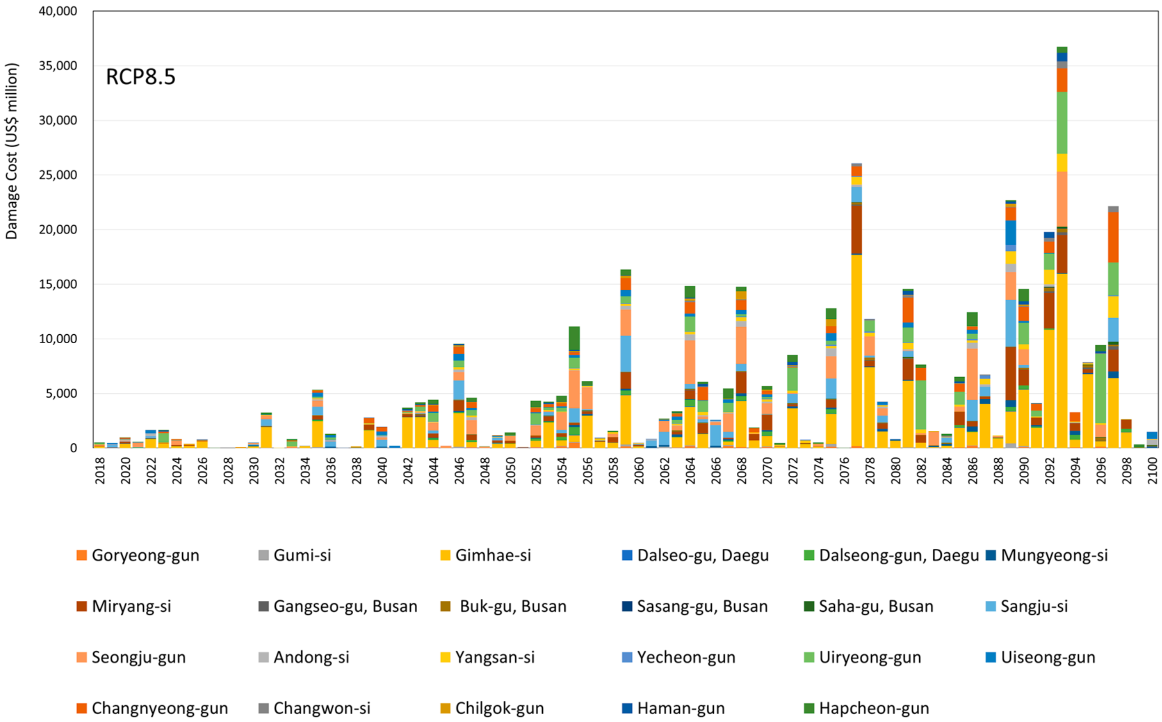

Figure 7. Future damage between 2018 and 2100 under the RCP8.5 scenario.

4.2. Decision Making on an Adaptation Strategy

Using Equation (2), the volatilities were calculated to be 41.6% and 29.2%, under RCP4.5 and 8.5, respectively. This means that the intensity and frequency of floods is more severe under RCP4.5 than under RCP8.5. The present values of the underlying assets and NPVs were estimated using Equations (3) and (4), respectively (Table 2). The option values were estimated using Equation (5).

The expansion option can be exercised at any time, up until the expiration year of 2040. Appendixs C and D show the binomial lattices that illustrate the option values under the RCP4.5 and RCP8.5 climate scenarios, respectively. The result of the option value is US$4.8 billion, and the NPV is −US$6.9 billion in 2017 under RCP4.5. In view of a traditional economic assessment, the negative NPV means that the project is not feasible. However, the project value was improved by the expansion option, and the difference between the option value and the NPV is the added value by holding the right of real options. Local municipalities can decide whether or not to invest in the expansion project if the RCP4.5 climate scenario occurs. The result of the case study is thus demonstrated to be feasible. Similarly, the result of RCP8.5 denotes that the expansion option is available in this case study. Table 2 lists the volatility, option value, and NPV, under each RCP climate scenario.

Table 2. Results of the real options analysis (ROA) under representative concentration pathway RCP4.5 and RCP8.5.

Result	RCP4.5	RCP8.5
Volatility	41.6%	29.2%
Option value	US$4.8 billion	US$4.8 billion
Net present value (NPV)	−US$6.9 billion	−US$6.7 billion

Under the RCP scenarios, the 23 municipalities in the Nakdong River Basin are anticipated to face more severe floods. Thus, the expansion of FCFs should be invested in. By ROA, we believe that it is economically feasible to exercise the expansion option of an investment of US$17.6 billion in 2040. The monetary profits occur from avoiding flood damage through an investment in the expansion option. By analyzing the damage costs, we prioritized the higher-risk municipal governments. Gimhae-si is the most vulnerable to floods, and the cumulative damage costs are US$101 billion until 2100. The damage in Gimhae-si is approximately 100 times the damage of Sasna-gu in Busan. Municipalities should investigate future climate risks when establishing an investment plan for FCF projects. Holding options secures the economic feasibility of adaptation projects under CC. The findings of this case study will help local municipalities establish proactive investment plans for FCF projects.

This study had limitations that can be improved upon through future research. First, the case study did not explain the type and level of design criteria for the FCF under each RCP climate scenario. In a future study, analyzing the level of the flood events in each municipality could allow for the proposal of detailed adaptation design standards. Secondly, the study did not investigate the interaction of upstream and downstream on the Nakdong River in the case of extreme flood events. Hydrological analysis by advanced methodologies in future studies will upgrade the level of assessment of flood damage for each municipality in the Nakdong River Basin. Third, using more scenarios would give a better idea of the sensitivity of the FCFs across a range and their robustness over time. This enables the decision-maker to assess the flexibility of the FCFs chosen to accommodate changed flood frequency and magnitude over time. However, here, we only used the RCP4.5 and RCP8.5 scenarios to represent two plausible future conditions, for the purposes of testing the ROA methodology in the case study. In real-life decision situations, a wider range of CC and socio-economic scenarios would be used for testing robustness and flexibility of FCFs.

5. Conclusions

The objective of this study was to propose a framework to suggest an adaptation investment for FCFs of a flood zone under CC. The framework is a real option-based tool to assess the economic feasibility and suggest investment priorities in multiple municipalities for adaptation to CC. The framework shows the damage costs and option values of the municipalities in a flood zone. Each damage cost was determined using the log-linear relationship between the highest damage cost and the corresponding return period for a site, under each future climate scenario. A case study of the Nakdong River Basin of South Korea was conducted, to demonstrate the ability of the framework, to determine the economic feasibility for an adaptation investment considering future climate scenarios (RCP4.5/8.5). Through an expansion option, the project value improved in the case study, which included the 23 municipalities in the Nakdong River Basin. The damage costs from 2018 to 2100 were estimated, using a log-linear relationship between damage and the return period of a flood event, under RCP4.5 and 8.5 climate scenarios. The volatility showed the fluctuation of the future flood damage under CC. The level of damage costs indicated the priority of the investment. To reduce climate uncertainties, investment decision-holding options will provide more financial feasibility. The results of the case study showed that investments in the FCFs of the 23 municipalities in the Nakdong River Basin under RCP4.5 and 8.5 scenarios were feasible.

This paper proposed a framework to assess the economic feasibility of FCF projects in multiple municipalities under CC. The contribution of our study to the current body of knowledge is two-fold. First, the proposed economic assessment framework supports local municipalities in estimating future damage costs through the projection of RCP climate scenarios. Second, the ROA improves the level of economic assessment for proactive adaptation plans where there are uncertainties. Managerial flexibility, such as an expansion option, improves the profitability of FCF projects under climate scenarios. The proposed economic assessment framework will assist policy-makers in planning adaptation investment strategies to cope with climate-related risks.

Acknowledgments: This research was supported by Korea Institute of Construction Technology (Project name: Development of Floodplain Maintenance Technology for Enhancement of Waterfront Values, Project number: 2017-0100) and by the Yonsei University Research Fund (Post Doc. Researcher Supporting Program) of 2017 (project number: 2017-12-0032). We also thank the anonymous reviewers for their valuable comments, which greatly improved the manuscript.

Author Contributions: Kyeongseok Kim and Ji-Sung Kim designed the research and wrote the paper; Kyeongseok Kim collected data; Ji-Sung Kim contributed to progress of research idea; all authors have read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Priority	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Year	Gimhae-si	Seongju-gun	Sangju-si	Uiryeong-gun	Miryang-si	Changnyeong-gun	Uiseong-gun	Hapcheon-gun	Andong-si	Dalseong-gun, Daegu	Yangsan-si	Mungyeong-si	Chilgok-gun	Haman-gun	Gumi-si	Yecheon-gun	Buk-gu, Busan	Goryeong-gun	Changwon-si	Gangseo-gu, Busan	Dalseo-gu, Daegu	Saha-gu, Busan	Sasang-gu, Busan
2018	294,123,178	8,067,410	-	163,040,810	344,395,022	334,067,931	-	44,255,325	-	-	31,042,474	-	-	10,217,336	-	-	4,072,191	3,019,201	5,195,247	1,621,119	-	666,960	127,446
2019	-	-	87,803,567	-	-	-	12,957,016	-	3,545,565	19,573,177	-	-	3,917,693	-	876,171	-	-	-	-	-	2,103,674	-	-
2020	-	107,055,093	54,061,854	-	-	-	46,939,767	-	2,406,827	-	-	59,193,163	10,201,189	-	-	2,476,417	-	-	-	-	171,393	24,108	-
2021	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2022	287,002,268	66,733,640	157,104,871	50,425,642	137,934,815	110,703,252	65,852,164	29,263,210	25,712,946	55,799,923	23,047,965	15,101,166	15,525,814	-	10,519,791	2,656,227	5,048,658	8,782,804	523,145	2,667,948	3,952,639	1,506,324	214,813
2023	326,513,462	180,990,012	20,866,661	11,685,704	87,000,596	-	57,981,154	87,641,968	18,956,725	33,998,802	26,919,303	13,144,486	29,087,630	3,278,832	7,926,911	-	8,350,570	14,062,597	1,921,351	2,982,225	2,380,556	1,271,596	256,914
2024	1,075,135,824	143,548,636	528,885,615	240,782,694	271,544,129	65,556,855	135,205,845	-	11,662,146	22,591,986	61,809,286	52,581,080	25,533,287	5,077,431	51,276,390	11,333,907	10,704,093	1,123,661	21,575,412	20,740,558	1,726,979	7,540,174	1,157,749
2025	933,936,210	173,834,158	396,014,644	135,110,286	137,782,741	105,600,012	154,476,975	32,419,814	26,573,622	31,605,214	27,690,121	21,978,194	9,640,209	19,902,315	54,013,386	4,114,029	17,944,692	2,872,952	18,719,623	6,446,347	1,522,557	2,035,613	697,241
2026	-	-	-	-	-	-	-	-	32,277,909	-	18,130,946	-	-	-	-	-	613,298	-	-	-	-	-	-
2027	-	-	219,679,433	-	-	-	39,639,149	-	-	72,353,331	-	35,701,753	23,889,879	-	6,160,392	6,289,443	-	15,565,467	-	-	7,663,643	-	-
2028	312,057,656	71,278,490	-	117,065,744	72,858,781	69,589,137	-	71,096,313	8,569,313	47,087,678	27,045,713	5,554,384	7,500,146	12,696,852	-	-	6,027,428	9,949,347	6,189,421	3,066,511	3,102,585	2,070,033	251,189
2029	-	57,352,416	100,708,224	-	27,291,154	-	62,319,861	-	5,125,960	7,999,068	43,947,481	132,546	23,827,932	-	20,973,294	300,378	6,487,621	-	-	86,995	608,150	1,969,392	392,813
2030	292,444,412	2,711,943	431,804,268	-	119,878,198	70,488,717	44,150,265	-	21,826,988	-	64,587,797	60,703,174	10,079,903	15,829,475	6,016,962	10,125,059	5,573,461	-	3,149,394	897,779	-	903,471	98,067
2031	161,659,409	82,681,205	-	-	-	-	7,639,805	-	-	-	4,347,418	4,679,042	-	-	7,855,628	-	263,943	-	-	556,608	-	314,717	116,476
2032	361,636,113	757,420,620	-	517,668,718	29,204,400	111,772,638	-	249,595,626	-	17,617,161	39,190,314	42,387,882	-	31,870,130	-	4,912,750	14,916,305	27,221,328	10,534,365	5,541,283	471,961	3,715,026	592,920
2033	483,027,391	41,949,829	582,111,096	-	73,625,443	593,020,781	89,444,251	76,806,880	109,768,581	143,041,503	57,121,759	39,550,512	8,320,554	-	21,716,332	16,637,238	7,649,644	-	-	2,783,040	828,740	1,447,892	360,071
2034	-	-	195,536,166	-	-	-	50,420,029	-	38,063,690	-	1,612,679	19,026,364	-	-	7,040,264	9,335,374	-	-	-	-	-	-	-
2035	-	-	-	-	-	-	-	-	-	-	-	20,797,094	-	-	-	-	-	-	-	-	-	-	-
2036	972,893,926	-	479,722,760	-	91,872,357	-	106,626,300	-	111,510,973	-	50,212,133	130,074,602	-	-	17,424,735	47,501,622	12,115,616	4,170,696	3,910,071	4,447,388	-	2,678,920	541,144
2037	222,435,606	575,197,090	118,588,330	-	97,304,649	-	211,657,015	-	26,249,295	78,226,344	32,764,524	2,277,921	57,221,203	-	7,107,122	739,796	14,527,834	10,788,048	-	6,393,898	3,428,289	4,708,804	566,046
2038	-	-	44,991,069	-	-	-	2,221,423	-	10,927,632	-	43,116,439	-	-	-	-	2,513,633	7,177,481	-	-	298,714	-	-	22,403
2039	759,925,372	-	-	-	153,442,720	390,589,675	1,443,515	-	35,635,639	-	59,869,717	-	7,254,501	22,944,823	-	3,529,255	26,808,601	-	11,858,856	3,767,866	-	11,354,822	2,041,950
2040	-	9,898,760	183,202,919	329,795,450	-	-	68,867,535	-	33,680,643	-	-	51,265,443	-	31,228,378	11,797,205	3,344,241	-	-	-	-	-	-	-
2041	990,357,187	-	-	1,191,163,683	131,266,588	124,272,696	-	162,714,867	-	-	146,970,429	-	-	32,165,230	-	-	10,213,968	-	6,687,290	5,003,599	-	2,629,060	439,798
2042	-	-	277,027,218	-	-	-	74,252,787	-	68,364,279	-	-	49,399,475	-	-	16,730,279	17,018,287	-	-	-	-	-	-	-
2043	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2044	556,408,668	924,849,375	41,110,991	-	175,968,622	36,504,077	25,660,517	19,552,213	13,188,778	86,419,961	36,665,129	707,327	42,509,713	-	7,812,829	5,387,547	18,160,480	20,324,719	-	12,274,285	6,175,830	10,908,628	1,524,101
2045	702,990,948	1,310,077,020	-	-	93,107,226	34,113,996	111,139,017	-	45,997,027	40,191,799	37,523,545	3,347,478	22,639,371	-	11,168,082	7,157,313	7,161,084	66,811	1,004,599	2,600,875	2,672,776	945,159	198,200
2046	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2047	147,952,160	94,220,072	1,770,837,122	-	173,843,301	-	298,133,560	35,092,854	228,846,986	-	23,808,779	101,442,793	141,307,506	-	121,935,580	32,243,468	3,012,004	13,488,146	-	1,349,642	639,834	796,533	240,961
2048	1,171,057,324	-	-	291,119,107	418,248,530	145,893,364	-	238,160,527	-	58,363,241	264,738,443	10,682,240	-	2,007,748	-	493,558	77,465,048	556,699	35,421,982	12,784,206	-	5,624,426	1,806,118
2049	1,451,302,888	3,537,449,598	1,298,083,867	564,013,515	703,071,463	584,129,337	762,914,132	599,602,527	516,510,302	357,241,719	171,036,913	139,597,975	152,457,369	29,440,205	107,260,215	98,000,172	29,928,249	159,361,904	22,087,192	8,090,703	21,539,973	8,150,785	1,219,088
2050	1,161,533,928	-	36,084,180	-	-	-	127,331,581	-	76,157,539	-	37,765,372	9,998,763	-	39,490,822	6,851,591	30,172,119	30,475,255	-	84,430,229	29,098,627	-	11,607,603	1,969,822
2051	3,800,108,544	519,666,649	-	727,507,047	235,293,541	537,566,225	-	269,800,591	-	51,060,217	53,016,887	-	-	88,649,988	-	-	41,106,226	66,751,799	54,814,269	15,306,880	996,433	5,053,659	1,192,475
2052	1,375,584,763	455,004,530	172,615,720	-	1,074,853,796	370,320,679	83,356,224	76,608,591	24,544,647	287,422,561	200,102,696	63,624,610	48,051,770	-	31,308,937	-	13,263,296	90,919,214	23,552,531	24,956,692	13,753,496	13,134,613	1,789,077
2053	-	869,436,118	208,997,299	-	97,721,945	-	64,140,134	-	33,499,384	73,473,306	6,954,538	41,136,032	10,026,973	-	26,763,110	22,557,936	3,167,229	8,014,989	-	-	6,398,416	-	40,714
2054	-	-	-	895,601,595	90,212,769	107,849,605	-	552,044,623	-	-	2,125,549	81,271,340	-	-	-	23,907,700	-	11,555,747	-	-	-	-	-
2055	166,883,344	122,603,081	-	-	39,307,872	-	9,431,505	-	-	20,705,028	11,026,411	38,720,164	12,071,515	-	12,182,530	9,981,180	3,506,160	-	-	349,717	1,121,494	693,794	120,911
2056	-	1,013,914,195	-	-	-	-	18,787,880	-	22,813,667	41,403,105	-	-	-	-	-	-	1,354,921	5,169,364	6,020,333	-	3,895,486	-	67,984
2057	473,918,817	97,909,638	-	-	306,749,420	63,469,496	-	-	-	-	50,317,170	-	-	-	-	-	-	-	9,658,196	1,452,964	3,352,532	-	-
2058	3,004,509,607	930,149,189	299,752,189	2,279,333,808	780,096,700	1,231,495,935	175,058,781	271,293,455	63,550,762	156,331,401	120,928,819	44,737,025	125,691,428	348,866,432	55,007,270	26,329,065	12,715,079	46,343,973	50,225,529	6,114,517	8,871,135	1,963,738	412,995
2059	290,431,481	552,585,350	640,065,588	-	125,748,002	115,411,841	195,182,716	42,770,749	169,252,031	330,166,378	58,674,324	66,169,298	21,333,153	140,809,718	67,281,416	21,886,864	585,618	36,447,703	13,620,906	-	14,931,727	-	-
2060	1,040,205,782	1,451,787,056	168,993,096	289,023,277	192,837,496	56,749,902	34,107,595	243,965,387	36,282,221	147,235,585	92,014,286	26,790,912	70,542,805	35,225,911	42,123,216	35,543,335	43,214,839	33,310,408	13,419,714	23,314,971	12,153,510	19,510,167	3,253,372
2061	-	305,399,796	46,159,205	-	-	-	59,404,496	-	81,064,266	-	127,399,017	-	-	-	-	-	89,638,902	-	3,401,130	2,976,204	-	6,195,517	1,981,784
2062	584,147,793	4,074,739,955	771,630,422	607,012,025	467,539,968	364,909,516	388,643,325	731,944,559	475,608,869	703,356,166	117,062,007	161,562,599	177,299,078	26,632,878	85,937,584	195,282,731	9,761,856	453,510,879	2,028,993	3,127,569	55,284,250	1,623,126	226,752
2063	47,170,793	-	147,473,381	-	-	-	72,464,608	-	60,358,155	5,599,678	-	-	16,744,970	-	14,695,313	3,558,353	2,344,744	-	-	625,441	-	1,261,087	366,317
2064	-	426,949,984	1,093,429,830	-	-	-	49,368,149	39,759,548	131,956,707	-	6,982,118	119,987,404	341,324,363	-	15,678,505	26,265,237	-	-	-	3,307,652	155,889	3,103,155	596,149
2065	558,944,096	-	-	-	-	-	-	43,120,516	-	-	6,319,925	12,782,699	-	384,996	-	-	21,177,252	-	34,283,455	18,490,572	-	9,623,129	2,146,783
2066	1,064,343,249	1,837,679,643	295,145,196	998,196,886	1,017,315,453	1,185,832,524	176,735,481	443,417,199	50,058,618	404,013,756	143,873,843	51,061,363	149,496,368	59,872,586	37,691,520	18,670,603	10,648,683	76,705,510	26,238,247	542,191	25,036,222	1,963,982	504,450
2067	483,175,117	1,402,328,639	1,863,727,200	367,352,994	261,335,586	321,156,748	312,465,706	459,786,679	80,364,699	289,139,115	60,339,740	195,001,999	196,542,877	10,891,492	120,722,532	59,288,415	7,451,406	99,126,979	-	2,570,963	28,617,876	1,400,103	245,289
2068	716,336,043	504,384,319	3,108,168,691	-	542,552,315	39,953,984	830,182,907	-	225,636,036	56,132,204	338,727,920	422,742,221	81,741,588	-	82,226,611	141,729,543	22,807,328	16,487,759	-	23,202,881	4,055,023	19,754,976	2,182,944
2069	401,947,244	1,065,233,083	-	5,418,154,217	281,898,459	348,974,650	12,216,054	1,165,105,846	37,035,600	157,805,145	219,022,824	-	19,601,071	64,641,298	-	9,546,271	12,670,146	87,810,326	4,707,522	1,467,894	13,346,720	422,756	249,156
2070	539,977,586	5,970,107,706	2,148,147,785	317,887,413	446,015,016	721,233,266	1,032,851,031	371,718,503	286,442,670	475,062,184	58,609,304	99,978,440	348,582,386	17,271,011	238,319,152	34,425,984	2,984,866	191,333,949	-	1,776,039	38,727,180	2,126,288	142,211
2071	2,776,707,646	914,253,352	-	-	-	-	18,396,976	-	-	-	200,745,920	-	-	-	6,342,773	-	51,823,425	-	15,390,294	26,663,477	-	4,351,247	2,002,508
2072	1,678,236,218	-	196,353,726	-	-	-	-	-	-	-	62,580,108	63,614,212	-	183,144,184	-	32,545,991	45,464,084	-	37,830,531	21,265,349	-	12,021,316	1,711,929
2073	-	197,664,829	-	-	-	-	78,928,532	-	89,069,070	-	-	-	7,613,025	-	11,116,298	-	-	-	-	-	-	-	-
2074	1,960,508,561	-	-	2,342,498,962	305,525,102	844,397,183	-	158,105,918	-	39,767,619	119,988,237	-	-	288,576,474	-	16,080,139	91,057,449	20,423,910	145,290,891	30,704,351	-	12,027,437	1,582,823
2075	1,029,378,811	-	1,760,854,323	-	108,022,473	-	144,316,860	-	157,419,929	-	39,829,289	210,099,112	-	-	11,342,851	60,751,706	17,557,682	-	-	5,775,486	-	14,689,503	2,681,264
2076	164,788,843	1,441,013,961	1,925,448,445	-	-	-	-	-	66,550,414	38,058,449	-	365,975,660	22,723,321	-	20,498,032	4,315,264	-	14,079,247	-	-	13,332,170	821,524	105,584
2077	-	208,460,186	-	-	-	-	-	-	-	99,242,260	24,234,678	44,420,283	36,593,014	-	43,731,684	10,226,624	-	2,777,423	-	-	8,703,281	1,320,751	-
2078	-	192,824,165	196,435,292	-	-	-	86,819,054	-	400,808,210	-	-	12,351,775	-	-	22,894,819	-	194,202	-	-	202,453	-	4,986,525	436,950
2079	-	2,159,503,509	4,091,136,694	112,030,533	-	-	1,037,015,306	442,373,953	543,088,181	176,006,629	-	160,299,364	232,074,189	-	224,599,949	35,219,719	-	82,067,373	-	-	14,185,077	-	-
2080	6,716,484,438	982,635,467	389,483,441	1,146,294,207	1,705,381,353	779,019,285	319,708,176	897,778,523	117,203,196	271,133,534	428,454,782	65,957,614	51,995,239	55,802,742	90,604,783	53,588,770	60,348,987	75,998,556	84,398,180	31,409,339	10,049,846	12,033,057	2,272,049
2081	-	-	-	-	-	-	-	-	-	-	1,749,110	-	-	-	-	-	-	-	-	-	-	-	-
2082	8,790,733,631	2,693,971,989	492,515,825	1,493,306,420	1,383,494,209	1,463,048,440	530,216,792	39,018,591	368,100,822	342,406,576	520,461,083	492,313,072	269,697,598	137,800,080	86,722,465	76,598,438	259,649,384	41,928,669	71,978,429	51,438,236	31,995,356	25,370,414	6,879,049
2083	1,756,260,375	10,358,142,740	7,617,130,025	644,711,764	1,911,513,159	1,618,886,025	6,314,894,904	1,494,917,737	2,921,867,630	1,188,772,557	274,344,188	811,696,925	1,014,829,734	-	634,427,734	684,189,228	23,540,997	399,585,616	3,346,025	12,960,563	83,196,914	20,649,571	3,557,611
2084	-	-	98,578,562	-	-	-	3,861,919	12,246,785	11,831,612	33,093,602	-	55,968,448	8,172,853	-	20,872,827	24,301,014	-	-	-	-	2,235,750	-	-
2085	1,003,312,671	-	665,836,241	-	-	-	127,336,228	-	467,153,081	-	112,760,583	334,390,587	-	-	75,979,510	42,153,163	38,920,587	-	-	10,012,794	-	8,548,471	1,800,344
2086	304,900,834	1,613,844,624	94,663,408	-	103,040,793	238,887,830	-	8,959,160	-	376,849,650	4,054,619	27,645,963	168,555,456	-	4,478,176	4,881,833	8,846,821	61,626,637	-	2,977,573	28,675,731	1,250,421	285,235
2087	4,148,394,285	430,698,673	-	734,044,836	2,023,875,529	3,192,030,881	-	363,741,722	-	197,545,284	146,350,641	-	-	93,630,440	-	-	41,875,869	11,829,635	94,149,327	33,659,032	4,000,130	14,242,519	2,188,003
2088	2,430,953,183	3,923,899,690	3,157,127,379	136,694,252	660,673,376	669,544,070	468,048,684	501,600,375	215,688,802	227,685,448	160,417,787	226,138,848	206,583,704	3,806,942	192,288,040	36,831,708	32,931,530	63,576,473	6,859,446	10,443,636	15,071,642	10,332,516	1,875,612
2089	2,749,354,016	2,165,733,864	3,124,555,657	-	1,329,726,707	343,786,990	584,681,490	-	549,604,112	61,956,655	281,511,964	423,614,310	26,710,593	-	64,064,882	178,994,606	56,398,522	64,555,106	14,739,982	23,488,435	-	15,725,016	2,570,406
2090	79,496,324	-	-	-	-	-	-	-	-	-	13,688,784	293,318,767	-	92,937,714	-	35,327,499	52,839,377	-	-	8,903,839	-	25,218,964	5,048,374
2091	7,630,418,758	2,821,637,229	-	3,274,410,361	1,826,641,508	3,083,874,297	908,167,852	1,570,571,274	336,103,495	938,164,307	469,248,475	-	279,349,906	378,747,708	72,171,481	-	124,172,406	247,796,010	201,174,704	65,929,140	61,533,242	41,611,560	5,587,553
2092	1,843,222,726	294,895,769	2,789,622,092	1,163,946,665	722,876,777	178,594,431	-	-	-	18,351,952	674,526,665	149,121,285	-	175,762,699	-	3,272,835	23,985,243	-	31,314,130	9,902,995	3,498,283	7,288,001	1,470,688
2093	2,166,870,268	2,941,027,782	815,941,838	1,184,211,559	503,488,199	737,976,513	-	951,886,812	-	94,009,895	160,541,027	40,067,972	1,845,862	119,217,778	20,983,910	-	31,537,340	83,109,508	48,838,516	14,564,714	19,596,984	7,076,511	1,311,982
2094	7,008,580,383	-	-	212,272,699	219,617,582	110,761,179	-	439,970,946	-	539,895,483	92,692,932	17,287,622	-	-	-	-	145,242,298	8,358,663	71,419,553	36,924,286	25,929,876	3,638,638	4,848,170
2095	5,439,300,255	29,117,338	421,168,990	3,559,120,410	1,657,750,620	1,355,560,811	132,266,122	2,609,140,728	334,346,875	52,248,188	367,611,620	72,254,719	-	489,053,303	108,224,287	23,395,934	94,861,947	92,067,600	72,467,776	23,412,443	-	11,121,183	3,175,526
2096	-	-	2,392,532,044	-	265,742,884	-	303,575,913	-	419,584,662	123,452,370	23,701,003	227,029,766	18,397,393	-	-	152,717,189	-	-	-	-	8,179,618	-	-
2097	186,615,276	-	-	-	-	-	-	-	87,429,161	-	326,588,506	258,134,878	-	-	-	-	334,541,433	-	-	4,621,917	-	3,710,107	3,825,619
2098	-	-	1,720,065,059	-	-	-	129,027,609	-	210,080,204	-	-	381,208,744	-	831,092,405	-	33,559,722	-	-	3,877,823	-	-	-	-
2099	2,681,611,895	1,957,573,552	4,194,130,321	-	-	718,650,508	976,085,571	58,568,521	823,808,396	190,158,433	240,214,153	829,506,950	226,471,403	-	87,151,736	168,559,157	191,726,485	-	-	34,936,162	61,901,019	36,639,510	8,352,160
2100	11,295,758,049	140,201,532	3,743,008,829	520,445,881	4,526,907,991	1,083,927,405	651,741,394	13,551,533	1,267,187,933	94,160,010	873,479,959	673,169,252	17,452,972	-	1,743,786	238,346,390	492,535,631	-	46,331,463	24,538,882	1,039,793	1,194,247	5,336,990
Total	101,053,965,637	65,212,294,546	57,875,118,650	32,035,929,164	28,553,397,332	24,660,172,688	18,886,759,635	15,919,970,948	12,636,953,481	9,373,975,636	8,624,238,170	8,550,477,091	4,799,030,505	3,898,968,357	3,132,640,879	2,861,111,979	2,843,147,777	2,784,623,402	1,424,586,071	747,818,463	682,811,678	466,569,145	99,261,121

Figure A1. The damage costs projected under RCP4.5.

Appendix B

Priority	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Year	Gimhae-si	Seongju-gun	Miryang-si	Uiryeong-gun	Sangju-si	Changnyeong-gun	Hapcheon-gun	Yangsan-si	Uiseong-gun	Andong-si	Mungyeong-si	Dalseong-gun, Daegu	Haman-gun	Changwon-si	Chilgok-gun	Buk-gu, Busan	Goryeong-gun	Yecheon-gun	Gumi-si	Gangseo-gu, Busan	Saha-gu, Busan	Dalseo-gu, Daegu	Sasang-gu, Busan
2018	156,525,418	98,097,148	32,971,911	73,538,258	11,620,658	23,683,029	71,216,633	22,596,078	-	-	-	6,026,654	-	1,782,850	2,794,889	4,659,269	4,898,078	-	1,658,224	1,769,237	1,336,745	-	173,498
2019	-	-	9,943,388	-	210,452,524	-	-	-	75,967,031	84,672,161	25,285,544	7,995,226	-	-	-	-	-	21,637,351	10,054,645	-	-	-	-
2020	385,480,191	33,952,313	149,088,189	12,811,139	41,936,581	82,819,723	6,242,573	27,343,235	54,245,412	97,199,706	13,269,858	22,695,868	3,245,564	4,926,501	-	6,736,910	-	6,413,185	-	2,880,639	1,816,753	914,292	260,555
2021	-	400,847,270	-	-	40,871,138	-	14,303,867	-	9,281,342	17,369,798	10,921,808	37,835,009	-	-	8,565,201	41,959	9,489,570	7,192,812	-	305,229	827,604	3,079,185	67,262
2022	831,933,288	-	38,548,246	-	164,966,628	-	-	17,515,198	251,609,352	236,695,160	28,922,601	11,806,458	-	28,860	-	3,139,009	-	39,045,130	4,028,970	3,068,280	995,053	403,292	139,940
2023	418,732,214	-	32,854,090	853,291,156	-	127,888,782	54,227,792	34,160,535	-	-	-	-	102,009,299	14,823,732	-	15,478,206	3,896,106	3,339,463	-	5,498,642	3,307,302	39,688	710,125
2024	144,279,746	393,740,431	90,288,686	-	-	45,053,911	-	25,164,769	28,708,365	-	4,848,102	25,947,491	-	2,967,182	28,171,576	2,466,904	1,922	-	13,019,386	1,857,257	1,302,423	1,789,171	97,434
2025	216,833,030	-	70,801,076	-	-	-	-	60,056,200	-	-	-	-	-	232,151	2,964,763	7,475,224	2,907,964	1,157,269	2,244,898	3,591,457	4,115,279	-	816,107
2026	617,712,553	-	65,236,949	-	-	-	-	23,188,534	-	-	2,372,908	-	8,604,197	17,406,305	-	11,411,941	-	-	-	6,539,165	4,085,983	-	637,584
2027	-	-	-	-	-	-	-	-	-	-	1,693,160	-	-	-	-	1,433,164	-	-	-	-	250,097	-	23,999
2028	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2029	38,099,009	-	13,142,001	-	-	-	-	13,082,756	-	-	-	-	-	-	-	1,836,476	-	-	-	173,739	137,951	-	52,045
2030	165,539,501	120,087,697	-	-	83,265,539	-	-	-	25,217,409	19,874,784	91,381,890	-	-	-	-		-	9,949,779	-	-	-	-	-
2031	1,876,077,035	335,257,351	-	-	595,144,873	-	164,196,873	68,998,340	36,141,037	-	25,206,586	-	-	9,103,519	-	55,449,156	8,488,979	1,860,989	25,295,302	31,335,739	10,937,450	-	2,191,508
2032	656,427	-	-	-	-	-	-	5,422,673	-	-	-	-	-	-	-	781,644	-	-	-	116,605	207,787	-	18,137
2033	-	87,716,490	7,575,424	481,429,989	-	64,459,736	120,870,755	4,612,176	-	2,010,773	-	13,509,964	-	-	7,272,876	-	24,041,274	-	-	-	-	2,172,169	-
2034	163,539,362	-	-	-	-	-	-	2,832,959	-	-	-	-	-	967,366	-	2,992,560	-	-	-	1,796,651	1,029,123	-	117,666
2035	2,387,297,841	533,186,970	318,860,535	134,081,145	793,606,249	165,998,323	18,956,097	86,815,395	361,617,914	135,097,442	50,792,866	94,375,748	285,831	20,989,923	42,901,052	37,710,063	16,471,211	13,947,739	66,375,780	22,067,373	12,664,254	5,317,556	1,701,286
2036	-	56,335,734	-	216,920,189	473,061,870	-	137,599,095	18,864,271	188,520,350	73,659,436	108,949,151	-	-	-	9,010,321	-	2,086,718	20,921,377	12,636,508	77,898	233,867	-	14,086
2037	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15,232
2038	-	-	-	-	-	-	-	-	-	-	35,369,205	-	-	-	113,836,453	265,709	-	-	-	-	128,228	-	17,181
2039	1,599,834,699	-	468,680,377	17,267,210	-	459,799,332	-	79,573,805	-	-	-	64,257,812	14,138,989	20,822,262	-	20,559,788	-	-	-	7,954,346	6,525,003	3,465,725	1,143,769
2040	-	209,336,197	12,377,087	56,021,773	638,368,212	390,343,291	-	-	304,389,271	118,260,454	80,402,713	11,864,434	53,866,530	4,400,819	-	-	-	52,314,844	25,747,900	-	-	974,890	-
2041	-	-	-	-	-	-	-	-	191,031,823	6,536,306	711,230	-	-	-	-	-	-	32,401,280	-	-	-	-	-
2042	2,827,696,502	74,083,289	208,722,975	75,056,634	-	65,611,449	136,103,134	45,381,308	-	-	6,682,515	-	111,595,548	73,895,004	-	27,892,533	10,361,870	-	314,003	21,546,689	9,353,273	-	1,429,082
2043	2,823,405,061	57,322,280	111,170,778	386,495,926	59,948,232	111,685,974	175,641,688	80,690,473	4,238,697	45,159,390	21,478,184	19,886,820	67,321,025	48,816,541	-	47,747,943	11,864,832	27,138,597	789,872	62,223,664	28,272,665	144,384	4,183,097
2044	641,713,441	691,586,003	395,910,303	804,986,234	271,542,847	538,644,141	370,111,083	62,377,038	114,265,880	47,920,306	8,933,523	176,078,451	86,936,643	19,754,987	69,028,219	7,984,136	52,559,775	7,331,808	40,182,617	3,084,125	1,145,359	9,982,436	226,720
2045	-	207,232,323	-	-	-	-	-	-	-	-	1,969,335	-	-	-	-	-	-	-	-	481,270	1,407,578	-	76,178
2046	3,047,817,700	744,896,590	943,251,171	590,350,221	1,744,362,509	635,751,686	16,347,806	213,440,201	630,876,973	249,301,076	111,944,084	107,929,822	120,802,520	32,040,591	115,253,493	52,498,828	1,371,463	9,962,430	139,224,076	16,215,117	18,986,557	4,485,264	3,368,909
2047	451,953,547	1,325,762,394	484,896,127	512,127,423	-	517,509,619	362,259,516	142,402,466	176,214,237	270,518,284	229,235	185,783,299	29,654,723	11,682,412	30,809,708	5,329,810	66,825,571	7,489,286	20,182,467	2,054,455	967,169	14,755,137	177,663
2048	-	110,250,927	-	-	-	-	44,453,611	-	-	-	12,808,770	-	-	-	-	-	-	-	-	-	-	-	-
2049	394,551,171	1,128,640	213,578,965	-	236,194,277	37,094,736	-	54,930,346	74,296,496	43,456,571	27,290,499	37,177,354	-	-	21,277,774	6,525,037	-	14,472,015	18,209,036	1,005,012	596,368	2,255,869	148,245
2050	382,017,564	443,827,694	233,558,405	14,652,247	-	-	252,200,612	31,471,188	-	-	-	8,069,845	40,977,326	2,747,848	-	1,723,532	31,746,095	-	-	755,967	-	-	100,576
2051	-	-	18,403,623	-	-	23,482,773	-	8,500,221	26,441,663	-	-	-	-	-	-	101,846	-	-	1,739,190	635,101	820,483	-	71,790
2052	569,762,217	896,380,852	186,891,006	1,018,111,911	-	386,689,726	549,717,976	22,555,678	87,697,099	55,716,512	76,398,282	193,471,298	51,830,441	15,634,125	57,917,917	10,666,374	80,117,780	25,852,273	15,180,780	6,748,167	9,046,701	10,827,284	1,242,990
2053	2,340,071,031	52,294,789	431,135,062	199,065,312	343,831,033	250,412,553	98,676,187	125,177,289	52,643,017	-	41,450,416	65,313,647	107,042,128	45,443,413	-	35,673,952	10,507,291	4,718,948	-	27,509,810	12,484,978	2,244,507	2,053,764
2054	487,291,147	1,622,111,683	330,248,777	351,941,240	311,006,302	285,800,850	551,176,016	57,067,142	116,392,969	-	43,638	311,374,229	11,878,105	-	121,280,937	6,807,071	155,453,882	-	50,326,014	2,526,721	1,556,755	16,100,653	249,627
2055	572,521,232	3,446,830,944	179,958,060	977,581,242	1,292,104,989	227,582,836	2,164,727,178	147,636,868	253,038,525	50,177,630	192,711,995	675,501,326	91,734,437	49,745,038	76,883,749	48,604,242	494,959,951	14,145,127	93,862,185	-	17,612,926	70,034,705	3,163,913
2056	2,960,285,595	2,009,986,519	199,598,229	-	84,538,265	-	426,138,063	68,393,101	-	44,866,599	166,075,321	6,332,018	-	-	-	74,314,740	1,493,002	31,323,001	-	24,165,819	18,531,234	-	3,935,131
2057	573,342,789	-	39,397,431	-	-	-	-	175,464,843	-	25,563,034	8,171,801	-	44,181,020	35,291,285	-	13,328,229	-	946,807	-	20,686,410	12,336,513	-	1,704,542
2058	467,109,572	306,983,300	470,396,686	-	-	-	121,444,462	137,672,715	-	-	32,823,157	-	-	-	-	6,474,497	-	1,108,887	7,680,162	6,217,319	8,788,974	-	1,668,734
2059	4,472,920,197	2,418,136,870	1,497,349,814	657,414,977	3,296,633,714	1,110,223,602	555,436,474	194,545,983	562,667,884	316,377,870	152,805,312	429,283,204	18,683,508	-	211,345,419	28,258,074	151,710,234	38,811,797	199,632,300	18,874,716	6,832,969	23,855,107	1,302,476
2060	157,749,734	-	90,338,839	-	87,127,380	-	-	57,990,883	-	-	41,593,982	-	-	-	-	8,674,749	-	4,343,658	-	730,087	308,345	-	178,762
2061	-	-	-	-	531,245,769	-	-	-	-	79,902,202	175,304,223	-	-	-	-	-	-	53,797,348	1,543,229	-	-	-	-
2062	-	1,014,934,919	-	-	1,220,954,743	-	57,319,113	-	70,286,005	-	149,043,919	-	-	-	57,699,852	-	-	30,837,221	114,722,968	-	172,046	-	-
2063	910,623,578	421,371,813	261,452,304	333,934,691	-	222,377,913	131,931,304	137,006,654	301,586,853	42,851,928	190,825,315	67,486,174	40,892,649	26,241,858	58,704,280	76,886,240	29,395,593	36,405,459	35,393,141	9,739,590	16,938,132	2,755,657	3,686,247
2064	3,500,480,861	4,007,161,538	801,182,951	1,364,130,600	420,037,038	1,039,763,812	1,042,219,398	230,503,536	285,878,260	536,214,544	53,982,474	602,258,541	113,696,711	140,079,653	170,697,101	62,169,650	181,091,535	35,322,268	76,587,537	45,124,467	35,772,792	81,121,125	4,046,997
2065	1,276,580,197	243,336,916	901,112,035	1,023,974,449	323,870,847	1,205,633,236	197,784,073	289,826,561	41,816,737	121,058,948	38,653,111	4,614,326	239,927,839	52,762,471	-	46,912,438	-	3,501,049	16,595,742	23,268,034	15,027,987	-	2,518,785
2066	-	295,595,738	-	-	1,877,540,745	-	-	-	36,505,276	120,538,559	126,572,816	-	-	-	-	-	-	43,563,078	79,462,693	-	-	69,725	-
2067	312,971,672	1,672,833,433	115,184,025	832,793,623	543,832,305	-	919,573,358	46,121,859	321,643,984	62,938,404	127,652,275	129,427,885	6,141,360	14,795,587	37,859,504	1,736,709	196,180,443	46,730,415	67,742,186	-	-	-	31,699
2068	4,216,871,858	3,392,402,941	1,963,504,235	203,408,676	676,669,791	879,425,865	446,463,370	339,084,645	388,015,061	519,881,038	242,634,962	407,964,788	-	92,084,836	727,358,104	52,763,811	82,250,478	73,709,217	15,271,472	19,493,374	9,603,250	35,009,354	1,613,371
2069	697,052,517	67,541,918	568,604,808	-	-	370,084,075	53,413,133	100,068,739	-	-	-	-	-	19,945,963	-	247,022	1,164,168	-	-	5,865,827	2,527,547	-	739,531
2070	935,947,566	988,827,472	1,394,168,355	167,534,994	50,337,794	311,006,718	344,625,851	227,866,141	250,561,563	139,368,461	145,059,065	388,121,346	-	-	91,676,076	13,856,039	88,995,715	36,451,702	57,516,682	5,220,444	2,715,629	35,492,752	454,365
2071	131,849,084	68,180,589	-	-	-	-	157,633,918	81,183,648	-	-	4,562,140	-	-	-	8,786,697	5,470,116	-	-	-	1,733,804	246,161	-	334,506
2072	3,651,360,626	48,752,784	183,176,701	2,121,383,138	833,728,727	62,940,176	637,904,602	199,264,106	-	17,628,145	178,544,609	-	286,252,482	89,402,684	79,676,792	77,410,154	-	-	-	17,485,587	28,777,012	-	5,820,466
2073	380,260,409	-	62,048,901	-	-	-	-	239,333,838	-	-	-	5,425,239	3,812,612	10,017,240	-	8,897,369	-	13,598,580	-	11,235,326	3,350,769	-	404,138
2074	137,322,513	220,680,480	-	-	-	-	113,785,168	30,566,396	-	-	-	-	-	-	-	6,263,709	-	-	-	3,370,706	1,287,640	-	512,473
2075	2,738,062,203	2,020,369,834	721,138,671	355,607,551	1,859,736,842	620,045,079	1,003,010,207	201,048,345	698,730,109	737,820,697	146,981,251	387,663,167	4,667,282	17,460,163	637,393,462	65,129,172	122,339,149	142,207,063	271,840,940	23,115,340	12,550,929	28,828,659	2,112,361
2076	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	459,745	494,804	-	437,098
2077	17,490,008,466	-	4,374,431,420	-	1,399,821,147	884,003,836	-	717,082,089	-	213,626,061	129,219,918	-	26,632,945	238,867,332	-	164,832,182	191,993,005	85,000,675	-	125,622,244	19,630,982	-	2,004,827
2078	7,384,780,099	1,771,830,107	500,489,921	985,833,015	185,473,536	-	-	327,215,718	-	-	83,106,532	-	28,453,693	136,395,561	-	235,110,644	-	114,832,676	6,324,224	62,196,575	5,893,062	-	3,772,001
2079	1,521,298,536	665,174,164	505,812,656	-	629,307,244	-	-	110,916,574	220,171,556	171,871,267	232,559,555	-	-	13,404,511	-	41,073,041	-	72,087,833	3,303,192	28,852,404	4,477,599	-	1,032,877
2080	666,556,885	-	-	-	-	-	-	-	-	9,289,623	126,401,803	-	-	-	-	-	-	3,405,427	-	-	-	-	-
2081	6,073,609,041	23,919,605	1,881,528,708	1,370,820,014	548,328,775	2,264,595,106	190,971,043	597,268,662	458,018,765	123,657,634	84,884,414	20,662,480	362,467,712	221,506,531	22,013,289	39,409,875	15,222,065	48,942,651	63,562,682	68,806,250	82,765,365	3,648,107	1,195,408
2082	490,450,973	128,045,798	648,619,566	4,475,913,296	-	1,152,465,138	305,404,902	329,024,687	-	-	3,589,091	-	-	8,407,196	-	60,813,863	-	16,022,071	-	4,968,768	19,007,166	-	4,090,590
2083	79,322,010	1,271,305,711	-	-	-	-	-	-	-	-	128,136,525	-	-	-	38,116,855	1,598,839	-	-	23,117,830	-	-	-	-
2084	208,749,576	-	-	-	502,464,939	-	183,333,095	53,878,757	-	-	181,828,753	-	22,604,431	77,152,506	-	70,557,061	-	-	-	13,727,549	5,625,190	-	1,649,024
2085	1,807,134,057	463,144,151	1,203,433,104	1,200,882,647	-	699,443,988	415,959,669	165,106,334	-	-	-	238,309,117	156,296,176	47,190,871	31,040,959	14,930,649	50,136,718	-	-	6,791,714	2,175,899	14,002,357	431,055
2086	1,209,886,654	4,697,417,199	440,373,696	477,350,714	1,919,447,354	266,071,510	1,278,152,937	213,436,428	368,195,300	536,829,102	448,373,009	61,633,999	-	43,924,274	7,595,121	25,363,936	202,065,483	142,248,153	54,679,615	18,903,044	19,694,125	82,740	2,108,961
2087	4,026,062,216	-	225,769,270	-	885,046,453	-	-	508,990,066	-	224,237,228	464,120,838	-	-	95,784,875	-	13,168,229	-	303,732,466	-	-	789,291	-	106,465
2088	881,825,007	121,306,680	-	-	-	-	-	69,887,570	-	-	-	35,938,287	-	-	-	32,885,741	-	-	-	5,324,028	2,449,329	11,039,287	569,134
2089	2,900,144,104	2,536,165,835	4,836,106,844	-	4,265,700,528	1,188,304,305	117,038,230	1,158,158,419	2,243,066,898	754,747,792	599,121,519	420,499,703	209,336,078	62,941,882	275,139,021	38,263,991	-	571,778,744	443,784,016	27,460,755	20,029,337	13,348,753	1,965,672
2090	5,179,601,246	1,432,550,742	1,424,623,870	1,983,054,691	258,367,550	1,274,217,423	1,117,258,713	432,539,727	164,778,338	6,459,824	6,894,720	351,883,725	290,291,261	115,211,303	116,680,870	137,130,944	108,578,700	3,314,445	65,391,042	39,482,338	21,695,443	19,489,626	3,185,171
2091	1,845,341,233	-	691,535,112	546,474,140	-	589,818,873	43,117,278	96,811,829	-	-	112,512,570	132,950,177	42,118,175	27,475,626	-	238,161	-	2,704,772	-	2,909,642	-	5,203,177	-
2092	10,836,765,780	-	3,240,531,410	1,492,987,894	-	1,045,706,372	-	1,347,359,155	53,441,070	211,844,606	17,279,288	108,887,131	552,154,602	314,672,666	-	340,666,480	-	-	-	143,095,989	59,328,843	3,296,341	11,817,465
2093	15,961,303,842	5,044,062,924	3,499,169,915	5,686,501,435	-	2,163,707,268	533,539,451	1,622,853,604	-	-	59,141,285	-	804,865,510	612,506,903	-	329,524,694	-	-	-	238,950,415	145,836,228	-	24,383,300
2094	719,592,214	-	681,670,261	-	62,119,741	873,260,933	-	77,287,068	-	-	365,922,104	441,436,529	-	-	-	8,637,253	53,305,596	-	407,286	2,452,338	343,199	2,566,948	226,608
2095	6,758,241,570	-	345,962,312	-	-	-	-	125,888,476	-	-	122,003,697	-	-	81,993,070	-	199,989,800	-	-	-	150,148,050	63,036,186	-	10,073,448
2096	474,494,004	1,110,344,201	-	6,317,873,488	-	-	588,433,589	171,069,093	-	-	18,953,197	-	197,436,466	59,282,257	-	274,694,810	126,222,236	-	-	48,372,481	54,245,079	-	11,106,970
2097	6,401,393,040	-	2,012,806,342	2,998,598,261	2,175,985,413	4,628,396,968	-	1,971,871,974	-	-	594,194,923	4,197,361	-	537,062,646	-	139,563,829	-	99,738,504	-	305,781,512	247,234,535	1,788,584	27,409,210
2098	1,436,752,036	-	838,604,521	-	-	-	-	73,693,708	-	-	-	309,508,184	-	-	-	2,664,468	-	-	-	1,335,567	594,950	11,756,818	569,291
2099	-	-	-	-	-	-	277,729,302	-	-	-	23,414,044	-	-	-	32,738,108	7,153,190	-	-	-	-	-	-	434,721
2100	-	-	-	-	-	-	-	87,072,769	630,169,073	467,245,055	126,399,553	-	21,502,302	-	-	32,470,217	-	1,678,668	-	64,251,133	54,737,505	-	5,954,642
Total	145,415,444,491	50,404,630,188	41,668,216,125	41,372,201,546	31,950,601,101	27,291,804,666	16,568,649,198	14,495,211,841	10,158,367,592	7,038,444,411	6,891,411,167	6,631,384,135	4,374,338,122	3,590,073,181	3,312,490,439	3,183,527,900	2,590,194,451	2,379,436,339	2,145,630,791	1,830,037,743	1,158,003,762	442,341,324	170,278,491

Figure A2. The damage costs projected under RCP8.5.

Appendix C

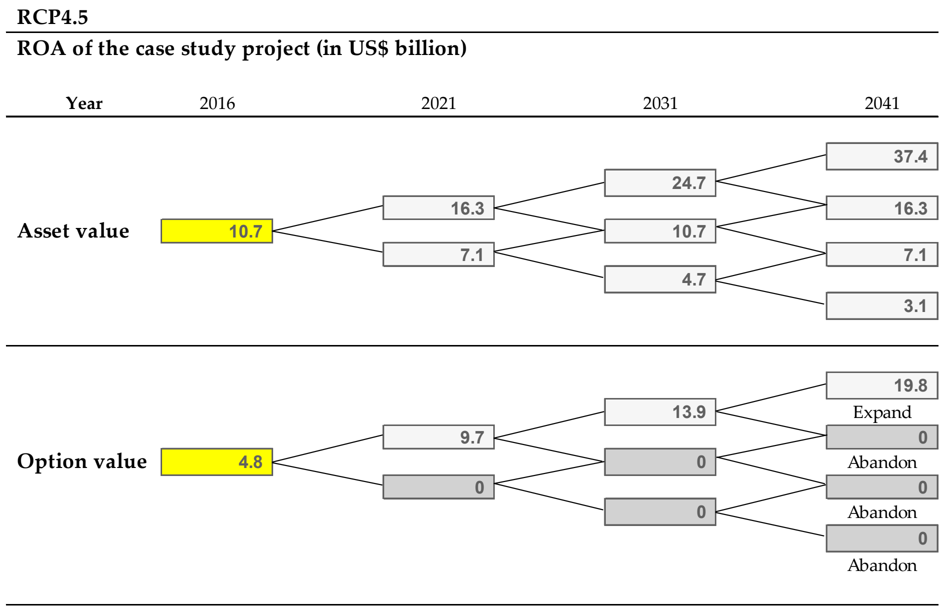

Figure A3. The binomial lattice of ROA under RCP4.5.

Appendix D

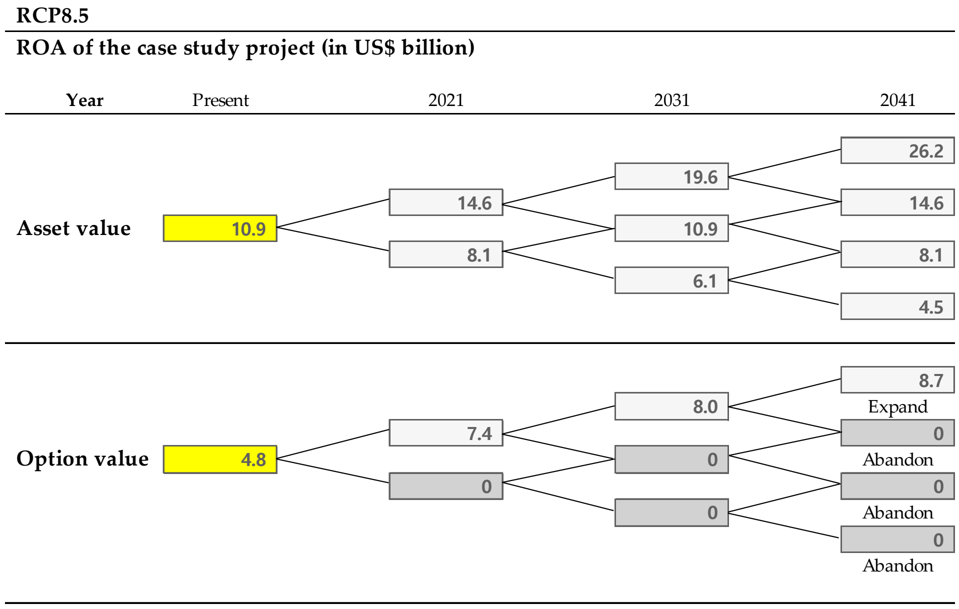

Figure A4. The binomial lattice of ROA under RCP8.5.

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