ABSTRACT

Title of Document: PUBLIC-PRIVATE PARTNERSHIP FOR NATURAL HAZARD MITIGATION INVOLVING RETROFIT AND INSURANCE

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Public-private Partnerships (PPP) involving governments and insurers have been used globally in natural hazard mitigation. Yet high expense on building retrofit and catastrophe insurance still prevents government from providing effective mitigations. This thesis introduces a new framework that governments can utilize to motivate insurers to insure property owners with an affordable premium and receive a high proportion of reimbursement on retrofit investment. Two case studies in the thesis show a high feasibility of this partnership on hazard-prone areas and a higher total benefit than similar methods. The case study result indicates a wide feasibility of the proposed framework in risk mitigation of various natural hazards by providing building retrofit and catastrophe insurance incentive to property owners. This solution is likely to provide policymakers with a PPP program as a new tool for motivating the insurers and the property owners to undertake building retrofit and mitigation of natural disasters.

PUBLIC-PRIVATE PARTNERSHIP FOR NATURAL HAZARD MITIGATION INVOLVING RETROFIT AND INSURANCE

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Chapter 1: Introduction

1.1 Background

Natural disasters have been a growing issue for most regions and jurisdictions in the United States and globally. In United States alone research shows that natural hazard causes an average economic losses of 7.6 billion annually (Cutter & Emrich, 2005), while a single hazard can cause up to 200 billion economic losses (Burby, 2006). Yet although statistics have proved that the benefit cost ratio (BCR) achieves as high as 4.0 for overall hazard mitigation projects by Federal Emergency Management Agency (FEMA), investment on risk mitigation and transferring is still insufficient (Rose et al., 2007). The low occurring frequency of natural hazards lead to insufficient investment to risk management procedures, including building retrofit and catastrophe insurance, as a result of which natural hazards always causes a great amount of fatalities and economic losses, and can have long term effect to the fiscal situation of the affected jurisdiction.

To bring a more resilient living environment and prevent catastrophic events from occurring after natural hazards, governments in various jurisdictions and countries are trying different methods to implement risk mitigation and insurance to local households. Government investment or subsidies to building retrofit projects and catastrophe insurances have been a major procedure of improving regional resilience. Other methods including insurance price rewards on high hazard-resistant buildings and mandatory catastrophe insurance purchasing are also implemented to different regions, while the effect of these methods is quite limited. A new method of effectively improving the natural hazard resilience with lower expenses to both government and residents is needed.

1.2 Problem Statement

Bringing affordable catastrophe insurance to market is difficult, due to low frequency but severe consequences of natural hazards. For instance, though earthquake risk is well understood by residents of California, the earthquake-insurance penetration rate is as low as 12% (Michel-Kerjan 2010). To reduce the potential damage from flood and hurricane, more than 68,000 flood insurance policies have already been implemented in force in Maryland according to data for 2009, while leaving the rest 98% households unprotected by flood insurance (FEMA, 2009b). The lack of effective risk reduction places hazard-prone areas of the U.S. and world wide under potential significant loss from natural hazards. This problem becomes even more serious in developing countries, where both property owners and governments are more reluctant to invest in risk mitigation and transferring procedures (Linnerooth-Bayer *et al*. 2011).

Major procedures for risk management against natural hazards can be classified into two types, risk mitigation approaches including retrofit to building and facilities, and risk transfer approaches such as catastrophe insurance. The low penetration of these two methods to regions subjected to natural hazard threat can be attributed to several reasons. High cost of implementing building retrofits has been the main reason to natural hazard vulnerability of residential areas, especially the relatively old communities. The high expense of retrofit implementation and indirect, unstable benefits lower the priority of building retrofit from both investment of property owners and subsidies from the government. As for catastrophe insurance, the low frequency and high consequence of occurrence and highly correlated claims result in a much higher risk to the insurance firms compared to other types of insurance. Thus the expense of providing catastrophe insurance is more costly to both insurers and residents.

In order to enhance the resilience against natural hazards and reduce the potential damage from emergency events, the problems mentioned above need to be solved. A new partnership framework combining different risk management methods is proposed in this thesis to solve the problems and help build a more resilient community.

1.3 Objectives

As stated above, the main problem in implementing risk mitigation and transferring methods can be divided into two parts: 1. The relatively high cost of building retrofit and insufficient government subsidies to the retrofit work. 2. The high-risk nature of the catastrophe insurance, which results in a high cost and less incentive for providing and purchasing the insurance.

On the other hand, risk mitigation methods including building retrofit can reduce the damage and economic loss when natural hazard occurs, which makes the mitigation cost-effective over a long period of time in some cases. The aim of this thesis is to propose a new framework of partnership between government and insurance companies, which utilizes the potential benefit of mitigation methods to reduce the cost of risk mitigation and transferring methods, and stimulate the intention of purchasing and implementing these risk management procedures in the most endangered regions.

Upon proposing the new framework, this thesis also focuses on evaluating the feasibility and effectiveness of this framework in various regions against multiple natural hazard scenarios. Feasibility will be examined by investigating the amount of benefit generated by this framework, while effectiveness will be evaluated by comparison to other similar methods on the cost effectiveness and other criteria.

1.4 Thesis Organization

This thesis is divided into 5 Chapters.

Chapter 1 gives a general introduction to the background of this framework. The sever impact of natural hazard to the economy and society to different jurisdictions in the United States and also to other countries around the world is presented. The potential problem of implementing effective risk mitigation and transferring method and a potential solution is also discussed.

Chapter 2 provides a detailed review of the former research on most of the natural hazard risk management methods, including catastrophe insurance, building retrofit and the use of Public-Private Partnership (PPP) in risk management.

Chapter 3 proposes a new PPP framework that has a potential of solving current problems and stimulate the implementation of risk management procedures. The methodology related is also discussed.

Chapters 4 and 5 evaluate the feasibility and effectiveness to multiple hazard scenarios and regions by investigating two cases, a seismic risk mitigation project in Israel and a flood risk scenario in Florida. A comparison between the proposed framework and other possible methods is also presented.

Chapter 6 provides an overall evaluation to this framework in natural hazard management based on the assessment and case studies. This thesis concludes with a summary of conclusions and proposals of problems for further research.

Chapter 2: Literature Review

Governments have been subjected to significant economic burdens associated with covering the immense losses suffered by property owners in the wake of major natural hazards. The Chinese central government provided nearly 60% of the cost of building reconstruction after the Wenchuan earthquake of 2008 (Dunford, Li 2011). State-issued compensation following the Kobe earthquake in Japan in 1995 and Italy's Umbria earthquake in 1997 was likewise very significant, at 40-50% of property owners' total losses (Linnerooth-Bayer, Mechler 2007). Three major natural hazard risk-management practices are reviewed in this thesis: 1) Use of catastrophe insurance to transfer natural hazard risk; 2) use of building retrofit to reduce potential damage; and 3) the fostering of mutual motivation between the insurance industry and natural hazard-retrofit decision-makers. Additionally, prior research on public-private partnerships (PPPs) that involve natural hazard mitigation methods is reviewed in this chapter.

2.1 Use of Catastrophe Insurance for Hazard Risk Transferring

Destruction of the built environment resulting from natural disasters has recently increased due to the repercussions of climate change and rapid urbanization in hazard-prone areas; as a result, worldwide catastrophe insurance payouts have increased more than tenfold in the last 50 years (Grossi *et al*. 2005) and often place significant financial burdens on the insurance industry. Taking the 1994 Northridge earthquake in the United States as an example, the insurance industry financed more than 60% of the reimbursed loss, or approximately 30% of the total losses (Linnerooth-Bayer and Mechler 2007). Nevertheless, the level of penetration of catastrophe insurance in many hazard-prone regions is still very low: in low- or middle-income countries, an average of only 1% of losses are covered by insurance (Linnerooth-Bayer *et al*. 2011), and even in developed countries such as the United States, around 50% of the single-family homes in flood-prone areas are not covered by flood-insurance policies (Landry and Jahan 2011). One of the main reasons for these low penetration rates is that the high premiums charged for catastrophe insurance tend to deter property owners from purchasing it, an effect that is magnified in low-income communities (Linnerooth-Bayer *et al*. 2011). These high premiums mainly result from the abnormality of the events covered. In contrast to the high-frequency, low-consequence risks that the insurance industry typically deals with, such as petty theft, car accidents and so forth, the nature of natural disasters, i.e. low-frequency and high-consequence – requires insurers to maintain very large capital sums as a strategy for forestalling insolvency in the face of significant potential payouts (Nguyen 2013).

Although several financial mechanisms have been identified as solutions to this insolvency issue, most of them have been found to be too expensive for practical implementation. Reinsurance or catastrophe bonds, for instance, were investigated for their applicability to spreading the insolvency risk associated with earthquakes in Mexico (Cardenas *et al*. 2007); the results indicated that, although these mechanisms could successfully help a government to withstand an earthquake with a return period of 100 years without any financing gap, the expense of the scheme could also be substantial. Moreover, studies have indicated that moral hazard and adverse selection operate in catastrophe-insurance markets, making private insurers reluctant to offer catastrophe insurance to property owners (Miranda and Glauber 1997; Lin 2013).

2.2 Use of Building Retrofit in Risk Mitigation

Whereas the main purpose of insurance is to transfer losses to other parties, the objective of natural hazard retrofit is chiefly to reduce the losses per se, especially from casualties. A number of researchers have investigated the natural hazard retrofitting of old buildings to enhance their structural performance, and in particular the social and economic benefits that can be ascribed to retrofit, in terms of reductions to both expected fatalities and recovery costs (Smyth *et al*. 2004; Kappos and Dimitrakopoulos 2008; Li 2012; Valcárcel *et al*. 2013). While in many cases, retrofit actions have been justified as economically feasible during buildings' service lives, several factors still prevent this mitigation option from being widely adopted in real-world settings. The high upfront cost has been identified as the main reason that property owners have been unwilling to take the action, even in situations where this initial investment could be compensated by the long-term benefits (Nuti, Vanzi 2003). Another reason for low intention in mitigation purchase is the uncertain nature of the benefit, unlike the high upfront cost of mitigation, the benefit of mitigation shows in the form of uncertain loss reduction in natural hazards, and often unable to sufficient purchasing incentive for property owners (Godschalk *et al.* 2009). Consequently, several studies have utilized PPPs as a means of motivating property owners to undertake retrofit actions, specifically, by arranging that retrofit costs be reimbursed by the private sector. For instance, the Israeli government developed a national policy to encourage real-estate developers to retrofit old buildings in exchange for granting them the right to add additional dwelling units to the retrofitted structures. Understandably, however, this policy has only been found to be successful in areas with high housing prices (Nahum-Halevy 2013) – despite the fact that areas with low house values tend to be more vulnerable to, and therefore more in need of protection from, natural hazards (Schmidtlein *et al*. 2011).

2.3 Mutual Motivation between Insurance and Mitigation and Potential Partnerships

Several studies have examined the effect of natural hazard retrofit on the behavior of insurers. (Kleindorfer, Kunreuther 1999) investigated the role of retrofit in improvements to insurers' solvency by examining the expected economic impacts of natural hazards that were attributable to retrofit action. Their results show that smaller insurance premiums and lower deductibles can both be achieved through the implementation of building retrofits. Grossi et al. (2005) found that, as the percentage of property owners adopting retrofitting increases, so does the percentage of homes for which insurers are willing to provide coverage. On the other hand, some studies indicate that property owners' motivation to undertake retrofit actions diminishes when they already have insurance coverage: a dynamic that would tend to increase the difficulty of combining these two supposedly complementary risk-mitigation strategies (Kleindorfer and Kunreuther 1999; Kelly and Kleffner 2003). However, a more recent study concludes that a combination of mandatory insurance and subsidized retrofitting could provide incentives to all parties involved in risk management plans (i.e., insurers, government and property owners), due to the positive effect retrofitting has on reducing insurers' risk of insolvency (Peng *et al*. 2014). Since this positive effect of insurance coupled with building retrofit was first identified, a number of researchers have begun to focus on how to enhance this joint mitigation strategy through the implementation of PPPs.

In fact, many governments have utilized PPP approaches in cooperation with insurance companies to provide affordable natural-hazard cover to property owners. The Japanese central government, for example, has partnered with insurance companies to provide discounts on premiums of up to 30%, depending on the levels of seismic retrofit implemented (Tsubokawa 2004). Nevertheless, the involvement of insurance companies remains very low, with insurers only responsible for around 10% of the total liability associated with seismic insurance, as against the government's 87% (Tsubokawa 2004). A national obligatory insurance program to mitigate earthquake impacts in Turkey, known as the Turkish Catastrophe Insurance Pool (TCIP), was established in 2001 as a partnership between the Turkish government and local insurance companies. The objectives of the TCIP include providing earthquake-insurance coverage to property owners at affordable yet actuarially sound rates; limiting the government's financial exposure to natural disasters; and encouraging risk-transferring and risk-mitigation practices in residential construction (Gurenko 2006). With the help of its mandatory nature, as well as the reasonable premium levels that have resulted from state-of-the-art earthquake risk assessment, TCIP reached a 20% penetration rate within six years of its establishment (Cummins and Mahul 2009).

Meanwhile, several PPP projects involving natural-hazard insurance have also been implemented in low-income regions. Micro-insurance, for instance, has become an increasingly popular hazard-insurance mechanism in the poorest parts of India. Micro-insurance aims to provide low-income people with protection against specific hazards, such as earthquakes or drought, in exchange for a premium payment that is acceptable to the policy holders, i.e., is low enough that the schemes must rely on the support of government or NGOs. For this reason, micro-insurance has reached more than 10% penetration in low-income parts of India, as compared to the average of just 1 percent for low-income regions worldwide (Clarke and Grenham 2013).

On the whole, despite the affordable insurance premiums that have resulted from most PPP frameworks developed in the past, low penetration rates due to the reluctance of property owners to purchase insurance still place a great financial burden on governments, while at the same time presenting a serious threat to insurers in the form of greater risk if only financial methods are used and no retrofits are implemented. Therefore, with the intention of addressing such gaps and utilizing the positive effect of retrofit in reducing insurers' insolvency risk, the present study proposes an innovative PPP framework, involving the government, insurers and property owners, which is capable of lessening the financial support for retrofit works required from the government; reducing the insolvency risk of insurers; and motivating property owners to undertake these two risk-mitigation actions. It is hoped that the present research presented herein will serve as a basis for further studies of natural hazard mitigation through PPP approaches that combine retrofit and insurance.

Chapter 3: PPP Framework Statement

3.1 Natural Hazard Risk

Natural hazard events in this study are considered as events with certain probabilities of occurrence. To describe a hazard event, two properties are used in this thesis, including the level of significance k and the probability of occurrence p_k within a return period, which is taken to be one year for purposes of this thesis. The damage to a building inventory in an natural hazard event k is calculated using HAZUS software, a standardized GIS-based risk assessment software developed by FEMA (FEMA, 2013a), which calculates damage status based on local conditions and can also be customizable based on other research assumptions. Damage to buildings after a catastrophic event is then classified into five groups as defined by HAZUS software, which are no damage, slight damage, moderate damage, extensive damage and complete damage respectively. According to the loss estimation from HAZUS simulation for each damage state, the total direct loss from a natural hazard event *i* is calculated as L_i. Historical data on catastrophe losses and occurrence probabilities in the study region is used to calculate the annual average loss (AAL) for that region, according to the equation presented below (Patel *et al.* 2005).

$$AAL = \sum_{k} p_k \cdot L_k \tag{1}$$

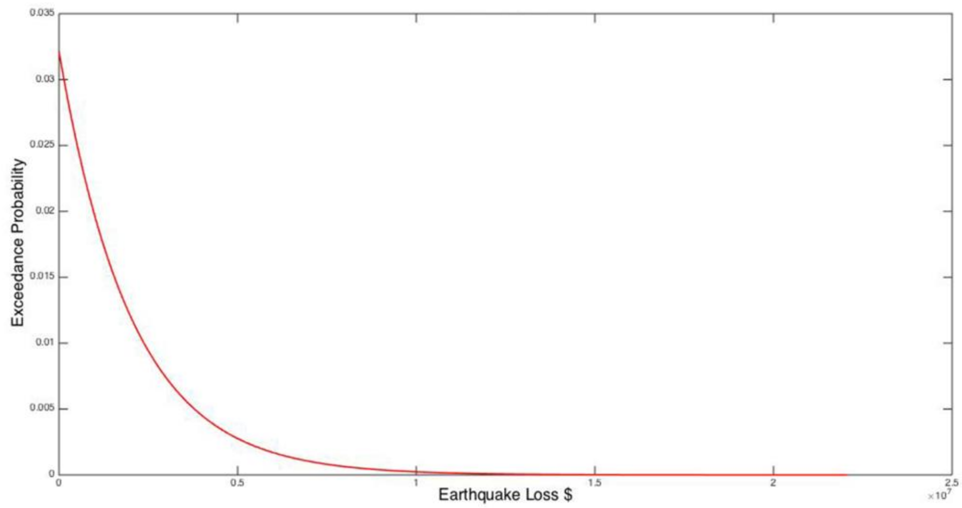

Fig. 1: Typical natural hazard EP curve

As is shown in Fig. 1, the exceedance probability (EP) curve for natural hazard risk in the study region is calculated from the AAL, with p_e as the dependent variable and L_e as the independent variable. Based on the relationship between the magnitude and the return period of earthquakes, EP curve will contain a low-end, a mid-range, and a right-hand tail, representing a relatively high probability of low-level losses and a low probability of extremely high losses. Pre-hazard retrofit can help reduce the potential consequences of various natural hazard scenarios. Depending on the different levels of pre-hazard retrofit that are applied to the building inventory, the cost of retrofit and the retrofitted buildings' expected performance during a natural hazard can vary sharply. Nevertheless, by reducing potential levels of damage in a natural hazard, for example, earthquakes of different magnitudes, pre-hazard retrofit methods help reduce both the worst-case loss, and AAL from natural hazards (Patel *et al*. 2005).

3.2 Insurance-Firm Insolvency

In order to provide natural hazard coverage to policy buyers in case of extreme events, each insurance company seeks to maintain a certain capital value so that its annual probability of insolvency will not exceed a certain level, and the amount of capital value maintained to keep solvency is defined in this thesis as Required Holding Capital (RHC). To simplify this calculation for purposes of this thesis, financial methods of transferring insurers' risks, such as reinsurance, are not considered, since risk transferring methods ultimately costs as much as, if not more than maintaining capital holdings. The amount of capital holding, then, is directly related to the potential losses to the insured properties in major natural hazards, defined as worst-case loss (WCL) (Patel *et al*. 2005). For insurance policies that include no deductible or a fixed deductible, the RHC for an insurer is considered almost equal to WCL, since WCL can be significantly larger than the aggregate amount of the relevant deductibles. Taking deductibles as a certain proportion ξ of the total loss associated with a group of policies, the relationship between RHC and WCL can be presented as:

$$RHC = (1 - \xi) \cdot WCL \quad (2)$$

where: RHC – Required Holding Capital; WCL – Worst Case Loss; ξ – Deductible Proportion.

For a given building with insurance coverage, WCL is calculated from the building's EP curve as the level of loss at an annual EP of δ, which may change based on regulations imposed by government, and/or solvency considerations on the part of the insurer. The WCL at an exceedance probability of δ can be deduced from the EP curve referenced in Fig. 1. The shape of the EP curve for insurers is affected by various issues:

the left-hand tail can be influenced by elements including premiums and deductibles; while the shape of the right-hand tail, which is related to the RHC, can only be improved by risk-transfer methods such as reinsurance or catastrophe bonds at a substantial cost, or else improving the resistance level to natural hazards of the building itself.

An effective natural hazard mitigation project can change a building's EP curve significantly. In general, because natural hazard mitigation improves the resistance level of the building to natural hazards of different magnitudes, the EP curve of the mitigated building would be located below its original EP curve, indicating that the EP of a particular amount of loss drops. For different parts of the curve, however, the EP may drop to different values below the original value, reflecting the varying performance of the mitigated building at different magnitudes of natural hazard. As previously mentioned, the influence that natural hazard mitigation has on the reduction of RHC is expressed by the potential loss at an EP of δ. The reduction of potential loss at an EP of δ varies with the effectiveness of the natural hazard mitigation work. The benefit, for instance, reduction of this potential loss, should be weighed against the cost of natural hazard mitigation to determine whether mitigation alternative is desirable.

3.3 Proposed PPP Framework

Reduced insurance premiums have been widely used to incentivize property owners to undertake natural hazard-retrofit projects, with the premium reductions achieved through reduction of expected AAL. The proposed framework provides dual motivation for property owners – to undertake natural hazard retrofit and to purchase natural hazard insurance – funded by applying part of insurers' benefit in terms of reduced RHC to natural hazard-retrofit reimbursement. The reduction in RHC caused by natural hazard mitigation is comparable, in certain cases, to the cost of the mitigation itself; and the opportunity for insurance companies to use such RHC reductions for further investment is of great value, which may be able to compensate for the cost of mitigation.

As shown in Fig. 2, the proposed PPP model involves three parties: a relevant government agency, the insurer, and the property owner. For the property owner, an immediate building retrofit is encouraged by the offer of “free mitigation with the purchase of catastrophe insurance”, provided on the condition that they agree to sign a contract to purchase catastrophe insurance for multiple years, defined as the duration of insurance i. The government agency provides full building retrofit subsidies to the property owners who take up such insurance contracts, and is reimbursed for a large proportion of the subsidy money by the insurance company over the following years. The insurance company contracted with the property owners and the government agency is asked to reimburse certain proportion of the retrofit cost to the government agency in the contracted year j. This reimbursement will come from the insurer’s extra benefit in the RHC savings achieved by insuring a retrofitted rather than a non-retrofitted property. Thus, in regions where this framework can be applied, the partnership provides a beneficial alternative for all three parties.

Fig. 2: PPP framework for natural hazard mitigation

As shown below in Table 1, the benefits of this PPP to a government include improved natural hazard-hazard resistance, increased insurance penetration, major reductions in the expected human and economic losses on its territory, and large reductions in the aggregate amount of government compensation payable to natural hazard victims. The property owners receive both natural hazard mitigation and insurance at the price of natural hazard insurance alone – or possibly a lower price than their insurance would have cost if mitigation work had not occurred. Finally, insurers are able to secure multi-year contracts on relatively low-risk buildings, allowing their expected profits to increase, even after payments to the government are factored in.

	Baseline Situation	Situation under PPP'
Government	Low Mitigation & Insurance Coverage	Providing the Mitigation Mortgage and Subsidy
	High Potential Loss & Fiscal Deposit After Natural hazard	Higher Mitigation & Insurance Coverage for Vulnerable Regions
Insurer	High Premium Resulting in Low Policy Quantity	Reimbursing Part of Retrofit Cost
	High Potential Risk to Each Policy	Guaranteed Multi-year Policies with Lower Potential Risk
Property owner	High Cost for both Mitigation and Insurance	Purchasing Multi-year Insurance Policy
	High Natural hazard Risk and Casualty Rate	Free Mitigation with Discounted Insurance Coverage

Table 1: Cost-benefit comparison for participating parties

Chapter 4: Framework Evaluating Methodology

4.1 Feasibility Measurement Criteria

The proposed framework is economically feasible only if there is enough benefit to insurance companies that they are able to pay the cost of mitigation. The mitigation cost for a region k is denoted as C_k^M, and results in a reduced RHC denoted as $RHC_k{}'$. As stated previously, the EP of WCL is p_k^{RHC}, while the RHC needed before mitigation is defined as RHC_k. The reduction in RHC for building k, $\Delta RHC_k = RHC_k - RHC_k{}'$. The benefit received by the insurer (Π_k) from mitigation is the opportunity cost for the reduction of RHC, which in this case can be calculated as:

$$\Pi_k = \Delta RHC_k \cdot \left(1 + \frac{rf}{\gamma}\right)^t - \Delta RHC_k \qquad (3)$$

where: rf – Risk-free Rate of Interest; γ – Standardization Factor; t – Duration of Contract; ΔRHC_k – reduction in RHC for building *k*.

Let us imagine a partnership in which the insurance company would like to use a certain proportion, defined as returning proportion (η), of its annual benefit from the reduction in RHC to fund reimbursement of the government's building-retrofit outlays. This reimbursement takes the form of one payment annually during each of the contracted years. For purposes of comparison with the retrofit cost, the total of annual reimbursements in future years is translated into current values. Then, for the duration of the contract j_k (taking one year as the unit), the proportion of reimbursed retrofit cost ζ can be calculated as:

$$\zeta = \frac{\Pi_k \cdot \eta \cdot \frac{(1+r)^{j_k} - 1}{r(1+r)^{j_k}}}{C_k^M} \tag{4}$$

where: r – Annual Interest Rate; Π_k – Total Annual Benefit Received from this Framework; η – Proportion of Benefit Used for Retrofit Reimbursement; C_k^M – Cost of Retrofit; ζ – proportion of reimbursed retrofit cost; j_k – contract year

To guarantee the insurer a stable benefit income with which to pay the mitigation reimbursement, the duration of insurance (i_k) should be no less than the reimbursement time, as:

$$i_k \geq j_k \tag{5}$$

where: i_k – duration of insurance; j_k – contract year

While implementation of this framework will always be profitable for the insurance company as long as $\Delta RHC_k \geq 0$, the most appropriate decision-making criterion for its feasibility should be the reimbursement ratio ζ. The larger the value of ζ, the greater the economic viability of the partnership.

4.2 Effectiveness Measurement Criteria

While the reimbursement ratio ζ reveals the economic feasibility of introducing the proposed PPP framework in different regions, the total benefit produced by this framework also needs to be calculated and compared against other traditional methodologies. The total annual benefit to all parties in region k under this framework is Π_k (Eq. 3). Accordingly, to compare the benefit of this new framework with the typical benefit from natural hazard retrofit, define the reduction of AAL – the *Framework*

Benefit Factor (λ) – as the ratio between the total benefit from this framework (Π_k) and the reduction of AAL achieved by the same level of retrofit (ΔAAL_k):

$$\lambda = \frac{\Pi_k}{\Delta AAL_k} \tag{6}$$

where: λ – *Framework Benefit Factor*; Π_k – Total Benefit Received from this Framework; ΔAAL_k – reduction of AAL.

A higher value of λ indicates a greater benefit generated from the proposed framework, while a λ value greater than 1 may suggest a more efficient way of utilizing natural hazard retrofit than traditional risk-mitigation instruments, such as a discounted insurance premium.

4.3 Government Benefit-Cost Ratio (BCR)

While in Section 4.3 the reimbursement ratio ζ is defined to present the financial "benefit-cost ratio" for the government agency in this PPP framework, the real BCR for the government investment is also an important factor that presents the effectiveness of this partnership in the aspect of government agencies.

A higher value of BCR indicates that the project would have a higher amount of benefit, which refers to a higher effectiveness in development of regional resistance to natural hazards specifically in this partnership, compared to other risk mitigation projects. This factor also helps to determine the investment priority of this partnership compared to other potential projects.

As defined, the real BCR for government agency in this partnership can be calculated as:

$$BCR = \frac{B_g}{C_g} \tag{7}$$

where C_g is the total amount of cost that government agency has made in the partnership, while B_g presents the gross benefit, or reduction of hazard loss to the government in the following years until the building inventory reaches the end of its life-span.

The government investment in this PPP framework can be divided into two parts, the initial subsidy invested for pre-hazard building mitigation and gross current value for the annual reimbursement received from insurance firm. As defined in Section 4.1, the initial subsidy invested is presented as C_k^M, while the gross current value for the annual reimbursement can be presented as ζC_k^M. Thus, considering the reimbursement to the initial investment, the total amount of investment can be defined as:

$$C_g = C_k^M \tag{8}$$

On the other hand, the benefit on the investment in the life span of building inventory, which can be defined as the total reduction of hazard loss to the government, can also be divided into two parts: 1. The reduction of economic loss of building inventory rehabilitation; 2. The reduction of fatalities and injuries during natural hazard. As defined, the gross return to the government agency through this partnership can be calculated based on the expecting AAL of the natural hazard and the years of life span for building inventory. By assuming the average life span of building inventory as l_s, the gross return to the government agency based on this partnership can be defined as:

$$B_g = \Delta AAL_k \cdot l_s + \zeta \cdot C_k^M \tag{9}$$

Compared to the measurement factors given in Section 4.1 and 4.2, BCR values for government agencies provides a practical instruction to the effectiveness and priority of a given PPP project from the perspective of a government agency. The comparison between BCR values for this project and for other government funded mitigation projects will help better evaluate the significance of the proposed PPP framework from the government's perspective.

Chapter 5: Earthquake Case Study

The expected economic losses that would be suffered by old reinforced-concrete (RC) buildings were estimated in all 12 neighborhoods of the city of Tiberias, Israel, under varying seismic scenarios. Two sets of assessments covered the as-built and retrofitted building inventories over their service lives (assumed for the purposes of this research as 30 years). The proposed methodology was then verified in each neighborhood based on the expected losses to both types of inventories.

5.1 Earthquake Loss Estimation

Economic losses from earthquakes in the form of repair costs for a portfolio of 3,220 old residential RC buildings in Tiberias were evaluated using HAZUS. The old RC building stock was found to be the riskiest in terms of predicted seismic casualties: representing 40% of the total buildings in the city, with 48% of total annualized human losses from earthquakes (Wei *et al.* 2014). Three sub-cases: the as-built building inventory, and inventories retrofitted via two different design methods proposed by Shohet et al. (2013) were investigated for their seismic performance. The two retrofit approaches, RC_{rm} and RC_{rh}, were designed to satisfy different levels of seismic performance: RC_{rh} to achieve HAZUS high-code performance at a high-level retrofit cost, and RC_{rm} to achieve HAZUS moderate-code performance at a mid-level retrofit cost. The seismic events assumed were 12 synthetic earthquake scenarios along four active and suspiciously active faults that were recently modeled by the Geological Survey of Israel based on local maps of the seismogenic zones (Shohet *et al.* 2013). Each event was named for its associated fault followed by its magnitude: Jordan 7.0, for instance, indicates a hypothetical 7.0 MW earthquake caused by the Jordan Fault. Finally, in Table 2, the expected number of buildings that would be placed in each of the four building-damage states defined in the HAZUS technical manual (FEMA 2013b) was obtained using HAZUS.

Earthquake Scenario	Return Period (years)	Damage State			
		Slight	Moderate	Extensive	Complete
Jordan 7.5	1500	92	340	513	1024
Poria 6.5	1200	182	496	626	597
Almagor 6.5	900	273	575	600	346
Jordan 7.0	850	288	578	581	326
Jordan 6.5	800	418	568	402	95
Almagor 6.0	650	436	559	368	64
HaOn 6.5	600	438	542	349	64
Jordan 6.0	500	454	469	250	29
HaOn 6.0	250	430	344	139	8
Bet HaKerem 6.0	200	430	327	121	5
Almagor 5.0	150	248	110	23	0
Poria 6.0	100	2	4	3	1

Table 2: Number of buildings damaged in historical earthquakes (Wei *et al*. 2014)

Based on data generated by prior research on the same region (Wei *et al*. 2014), the EP curves are created for the as-built inventory and both retrofit designs: RC_{rm} and RC_{rh};

these three curves are depicted in Fig. 3. From the right tails of the EP curves, one can indicate that the reductions in economic losses associated with retrofitted buildings become more significant with the increasing severity of the seismic magnitudes (lower EP).

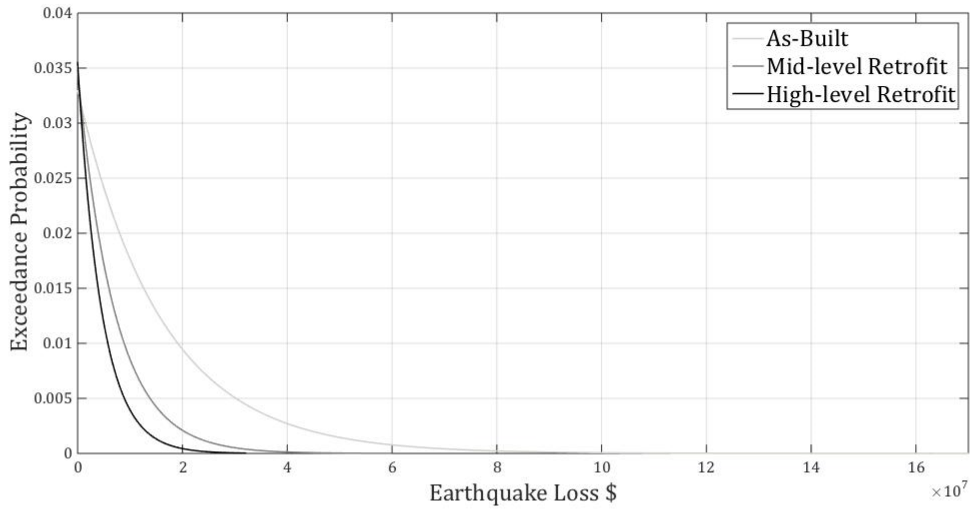

Fig. 3: EP curves for different retrofit levels

5.2 Retrofitting Reimbursement Calculation

With regard to the EP curve for seismic building loss in the study region and each of its 12 sub-regions, the expected reimbursement in a period j_k can be calculated using Eq. 4 & 5. The contract term is assumed to be 10 years, and the London Interbank Offered Rate (LIBOR) is used just as the offering rate rf in this case. For annual benefit, rf in this case can be defined as an interbank offered rate for three months and $\gamma = 3$, in a financial standard, while $t = 12$ indicates that the benefit is counted once every 12 months (Brealey 2012). In consideration of the highly fluctuating nature of rf and the relatively long-term contract investigated in this thesis, the value of rf is used as an average of U.S. dollar LIBOR from the last 10 years, provided by the Federal Reserve Bank of St. Louis

(ICE Benchmark Administration Limited (IBA) 2014). The insurer's acceptance level of annual insolvency probability (δ_k) is assumed to be 1%, based on the annual average insolvency rate of insurance companies (Zanjani 2002). The annual interest rate is assumed to be 7% (Patel *et al.* 2005). We also assume that the benefit from reduction in RHC is evenly shared by the government and the insurer, which means $\eta = 50\%$ in this case. For insurance policies with no deductibles ($\xi = 0$), the estimated largest possible payback ratio, by contract year, is shown in Fig. 4.

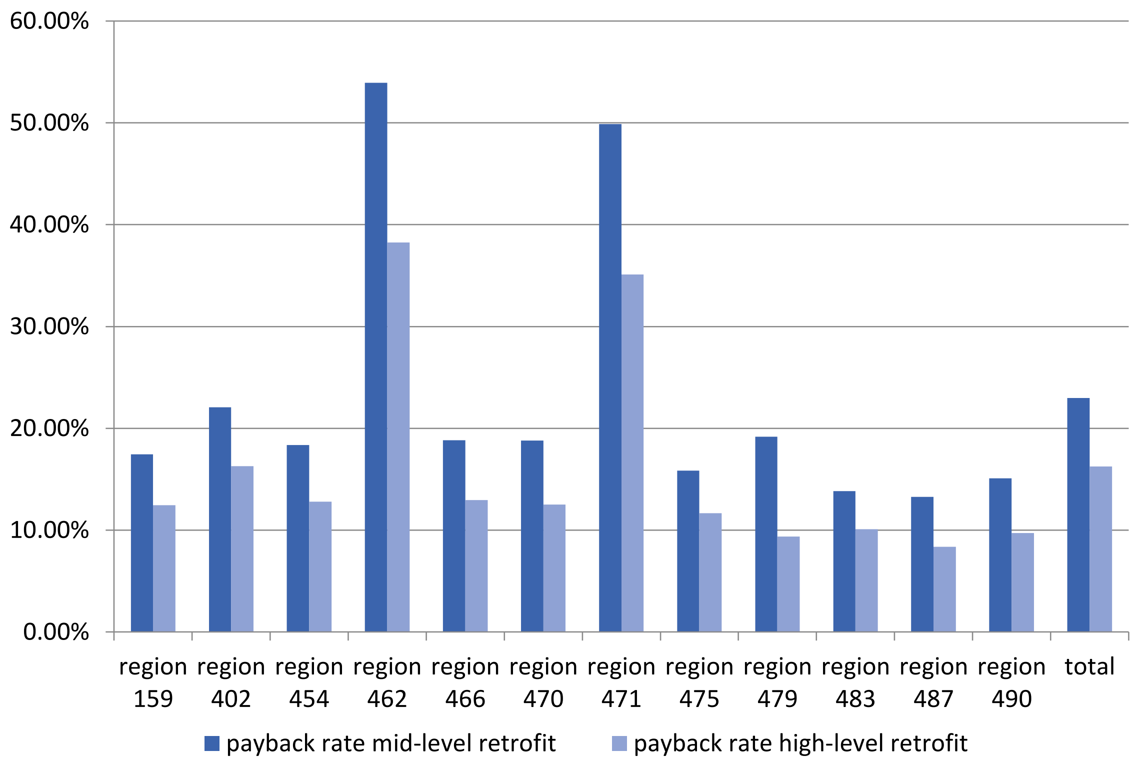

Fig. 4: Estimation of seismic mitigation reimbursement ratio ($\eta = 50\%, i = 10$)

To better understand how the benefit generated by this framework may differ from the pure benefit of seismic retrofit, the Framework Benefit Factor λ has been calculated for each of the study's 12 sub-regions.

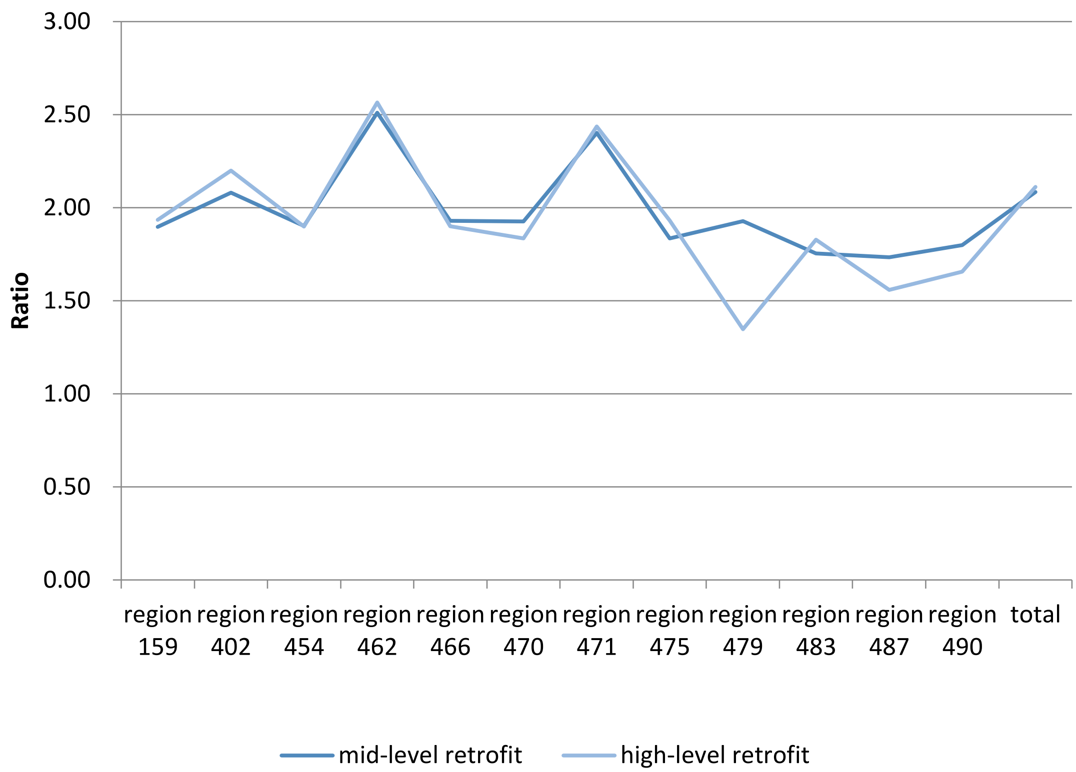

Fig. 5: Estimation of framework benefit factor (seismic) ($\eta = 50\%, i = 10$)

In the aspect of government agencies involved, the BCR of this PPP framework is also investigated based on the equation in Section 4.3. Based on the mitigation cost C_k^M, the reduction of AAL due to the implementation of building retrofit, and the reimbursement ratio ζ, assuming that the life span of average building inventory is 40 years l_s. The BCRs of this PPP framework to government agency in each study region are listed below in Fig. 6:

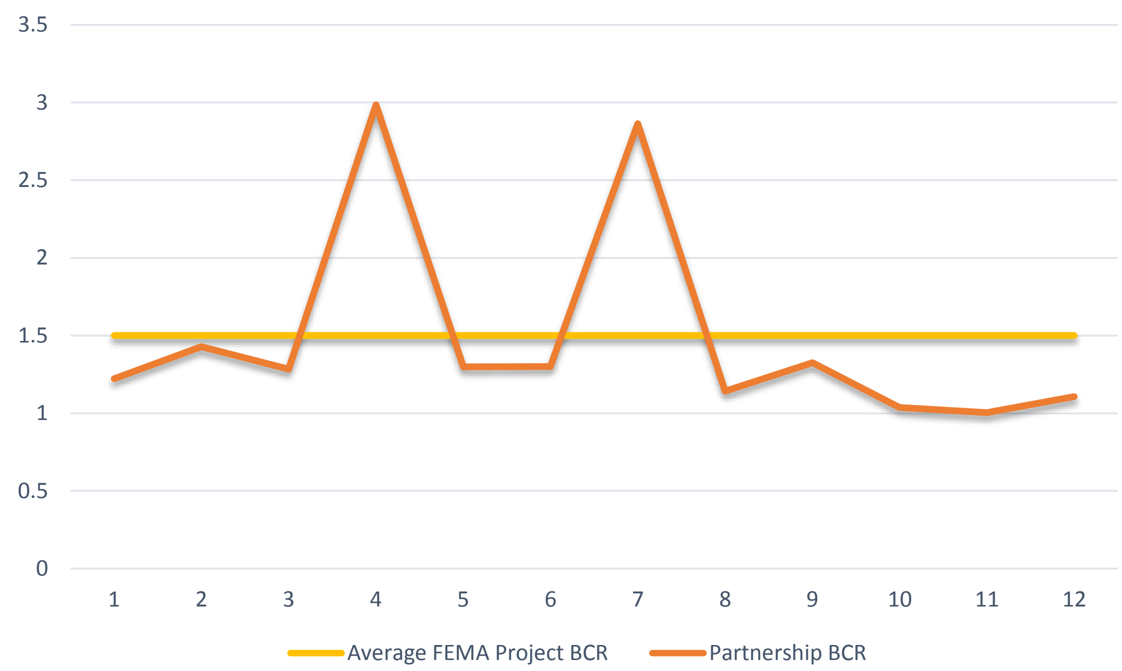

Fig. 6: Estimation of real BCR for government (seismic)

As shown in Fig. 6, compared to the average BCR in FEMA invested earthquake mitigation projects, which is equal to 1.5 (Rose et al., 2007), the average BCR in the partnership proposed can be higher or at the same level. Unlike the traditional investments, a large part of the benefit to the government is direct financial reimbursement instead of only expected loss reduction. In specific cases where the regional vulnerability is relatively high and earthquake mitigation is more needed, the PPP framework BCR can achieve as high as 2.99, which is 99% higher than the average BCR of FEMA earthquake mitigation projects.

5.3 Sensitivity Analysis

Sensitivity analyses are conducted using two criteria: the reimbursement ratio ζ representing the feasibility of the framework, and the framework benefit factor λ representing its benefit level. Because of the highly changeable nature of financial parameter utilized in this framework, one can investigate the sensitivity of this framework via several parameters involving the value of *rf*, contracted year *i*, and the annual interest rate *r*. The other parameters will remain the same as in Section 5.2, and the mid-level retrofit and its consequences vis-à-vis the whole study region are considered in this analysis. The data for reduction in AAL (ΔAAL) was analyzed and presented in a previous study (Wei *et al*. 2014).

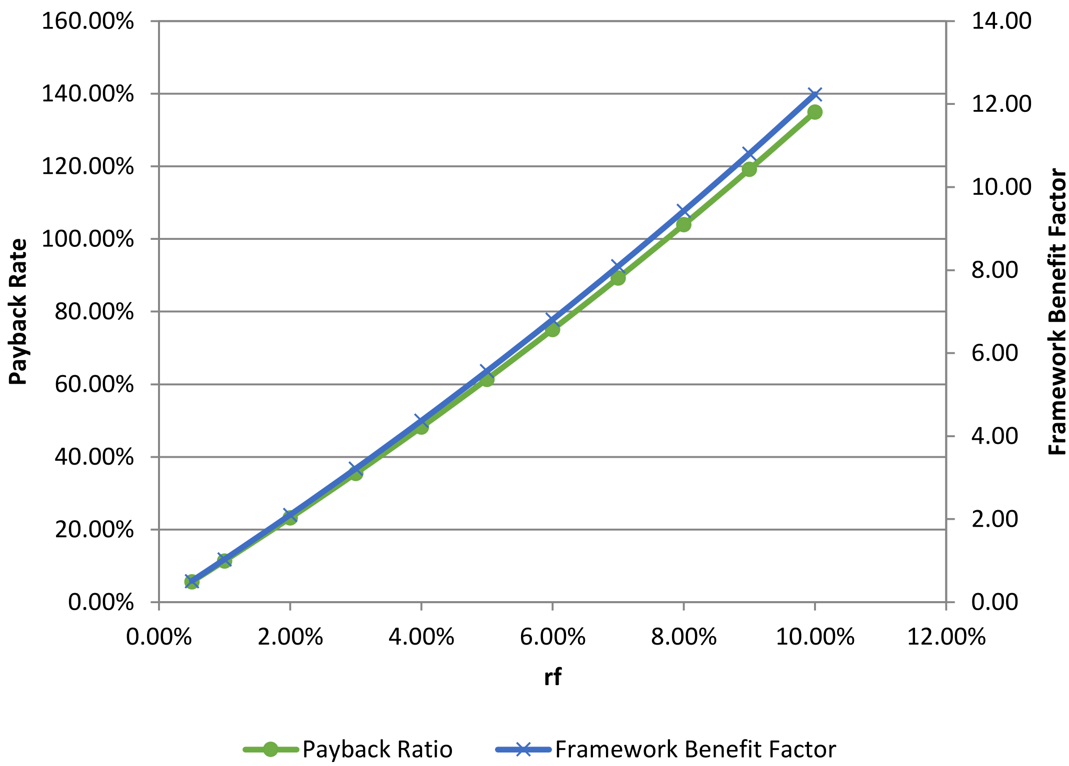

Fig. 7: Sensitivity analysis based on varying *rf* (seismic)

The LIBOR rate for the U.S. dollar, used here to calculate *rf*, has been a highly fluctuating variable in recent years, with a range from about 0.5% to 12%. Fig. 7 shows the feasibility and relative benefit of the proposed framework for its best performing region – Region 462, under *rf* values from 0.5% to 11%. It is worth noting that the reimbursement ratio ζ and framework benefit factor λ both have near-linear relationships with the risk-free rate of interest *rf*, and that the feasibility of the framework is highly influenced by *rf*. For the lowest point, i.e. where *rf* is 0.5%, the 10-year reimbursement ratio is only 5.65% and its positive effect on retrofit is likely to be minor; whereas when *rf* reaches 8%, a full reimbursement can be achieved within 10 years. Considering a highly fluctuating *rf* and a relatively long period of framework implementation, the use of average reimbursement ratio presented in Retrofitting Reimbursement Calculation Section can be a more accurate estimation.

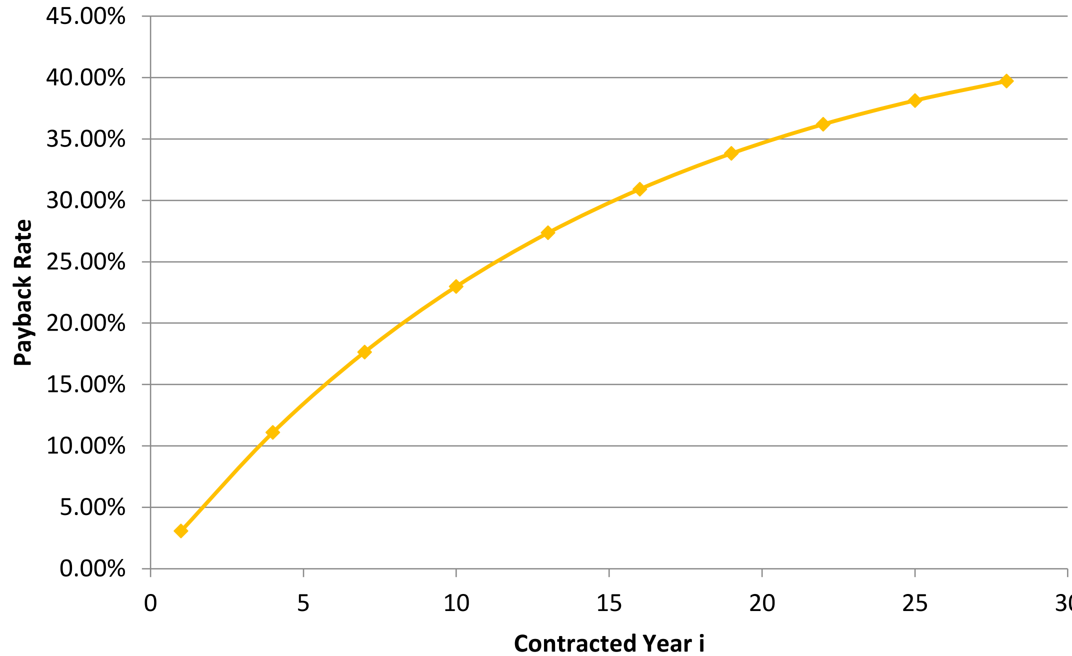

Fig. 8: Sensitivity analysis based on varying contract term (seismic)

Fig. 8 sets forth the average reimbursement ratios for possible contract lengths ranging from one year up to the expected building service life of 30 years. Since λ is an annual measuring factor and therefore unaffected by variance in the contract term, it is not included here. Due to the loss for future incomes as current value, the relationship between contract year and reimbursement ratio is not linear, and yearly benefit from the framework diminishes. Over a building's service life, the framework is expected to provide 40% reimbursement of the retrofit cost.

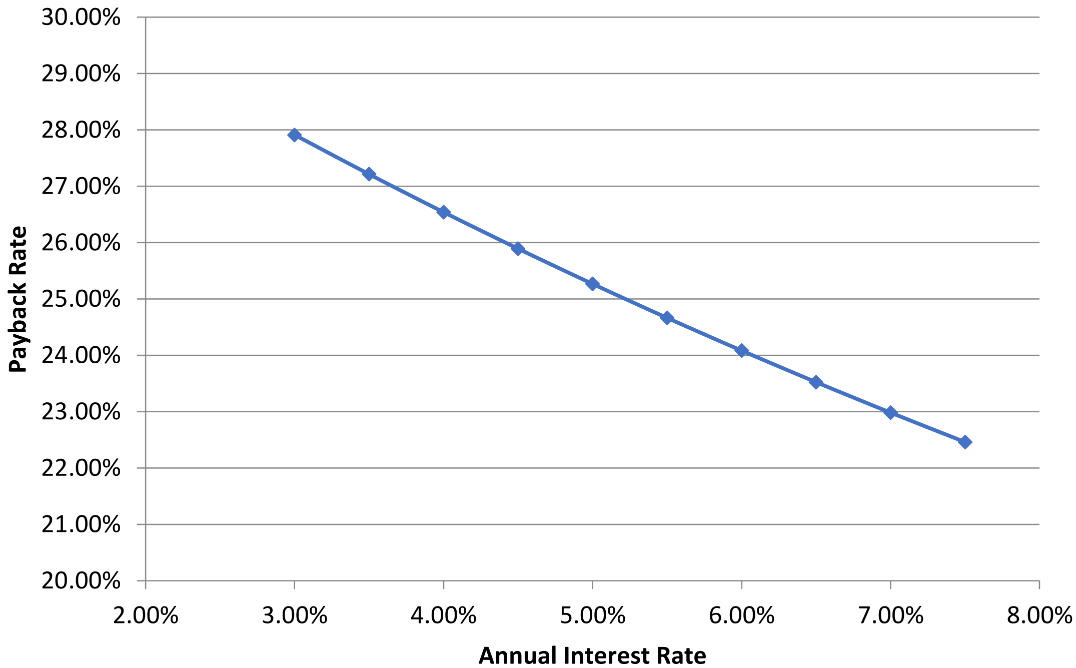

Fig. 9: Sensitivity analysis based on varying annual interest rate (seismic)

The effect of the annual interest rate (*r*) in this framework ranges from 3% to 7.5%. Again, as in the case of contract length and for the same reasons, only the reimbursement ratio is investigated. As shown in Fig. 9, the average reimbursement ratio exhibits a minor decrease as the annual interest rate increases, since the standard (*r*) of calculating equivalence current value from future incomes changes.

5.4 Discussion

From the results presented in Section 5.2, it can be seen that the benefit from retrofit-derived reductions in RHC can, in some cases, offset the entire retrofit cost within 10 years. However, the ratio of the benefit to the original retrofit cost varies immensely, between less than 20% and more than 100%, depending on regional characteristics and the available retrofit alternatives. In the particular case discussed in this thesis, a mid-level retrofit would always be more cost-effective than a high-level one. As regards differences between sub-regions, one can assess the mid-level retrofit's effectiveness level in different neighborhoods by considering the reduction of completely damaged buildings as a proportion of the total building inventory in the region, following major earthquakes (i.e. with return periods of 1,500, 1,200 and 900 years). The results of this assessment are shown in Fig. 10.

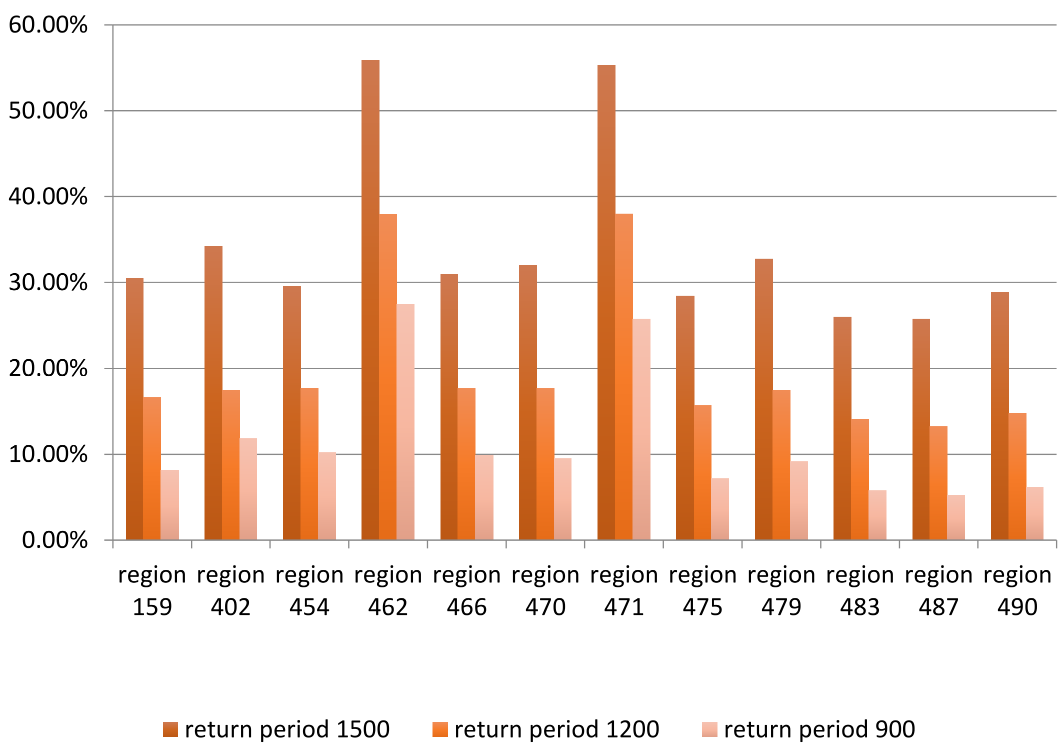

Fig. 10: Proportion of buildings in a state of complete damage

It can be seen that the values in Fig. 4 and Fig. 10 are highly correlated, meaning that the framework is more cost-effective in areas with higher vulnerability to earthquakes. This feature may be key to generating market-driving earthquake-mitigation partnerships. The framework may not be deemed worthwhile in highly earthquakeresistant regions, in light of seismic retrofit reimbursement of perhaps less than 20% and a payback time as long as 10 years; however, in highly vulnerable regions, a partnership between government and insurer alone can provide enough benefit to cover the whole retrofit cost, and this should make it attractive to all parties. Fig. 5 has also shown that the total benefit from this PPP is up to double the amount of benefit utilized from the reduction of AAL each year, which can provide a much higher motivation to undertake seismic retrofit in highly vulnerable regions. It is also worth noting the potential that the use of this framework is not necessarily limited to earthquake-mitigation purposes, but could have a wide range of applications in areas confronting other natural hazards and requiring similar patterns of building retrofit and catastrophe insurance. The detailed analysis for the implementation of this framework in flood mitigation is investigated in Chapter 6.

The sensitivity analysis has shown that the proposed framework is highly affected by the risk-free rate of interest, which is inherently highly fluctuating. Yet, if a mitigation project is maintained as a long-term partnership, the influence of rf can be minor. The research suggests that longer contract periods can result in a slightly lower marginal benefit, and so a partnership length at which the reimbursement ratio is satisfactory to the government is likely to be the optimum choice. A lower interest rate, meanwhile, can result in a slightly higher reimbursement ratio, yet such changes can be minor and may not affect the overall feasibility of the framework.

Chapter 6: Flood Case Study

The expected economic losses that would be suffered by old reinforced-concrete (RC) buildings in the county of Miami-Dade in State of Florida, under various flooding hazard scenarios, is estimated. Two sets of assessments covered the as-built and retrofitted building inventories over their service lives (which were estimated for purposes of this research as 30 years). The proposed methodology was then verified in each regions and flood zones, based on the expected losses to both types of inventories.

6.1 Flood Loss Estimation

Economic losses from floods, in the form of repair costs for a portfolio of 9669 single dwelling residential buildings in Miami-Dade county, were evaluated using HAZUS MH 2.2. The residential building stock was found to be the of high flood risk in this county, where most of the living areas are classified as Costal A Zone (Miamidade.gov, 2015). Two sub-cases – the as-built building inventory, and inventories retrofitted via house elevating – were investigated for their flood performance. The building performance in as-built protection level is estimated using the default value in HAZUS MH 2.2 database. As shown below in Table 3, the percentages of damage to each water depth for various stories of single dwelling residential houses are presented.

Building Code	Building Structure	Water Depth (feet)											
		-4	-3	-2	-1	0	1	2	3	4	5	6	7
R11N	one floor, no basement, A-Zone	0	0	0	0	18	22	25	28	30	31	40	43
R11B	one floor, w/ basement, A-Zone	7	7	7	11	17	21	29	34	38	43	50	50
R12N	two floors, no basement, A-Zone	0	0	0	0	11	12	14	18	20	22	24	26
R12B	two floors, w/ basement, A-Zone	4	4	8	14	19	21	26	29	34	39	44	50
R13N	three or more floors, no basement, A-Zone	0	0	0	0	5	8	12	17	19	22	24	25
R13B	three or more floors, w/ basement, A-Zone	3	3	6	10	12	14	20	25	31	36	38	41

Water Depth (feet)																
8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
43	45	46	47	47	49	50	50	50	51	51	52	52	53	53	54	54
54	55	55	57	58	60	62	63	65	67	69	70	72	74	76	77	79
30	34	38	39	40	42	43	44	45	47	48	49	50	52	53	54	56
55	57	59	61	63	65	66	68	69	71	72	74	75	77	79	80	82
30	35	38	39	40	42	43	44	45	47	48	49	50	52	53	54	56
44	48	50	52	54	56	57	59	61	63	65	67	69	71	73	75	77

Table 3: Damage percentage of as-built houses (FEMA, 2013b)

The elevation retrofit approach can lift the house an average of 4 feet with an average cost of $20350 per household, indicating that the percent of damage after retrofit would result in the amount of damage for a flood that is 4 feet lower than the original one (Kreibich *et al*., 2005). As shown below, the flood scenario is this study is assumed to occur on the eastern coast of Miami-Dade county.

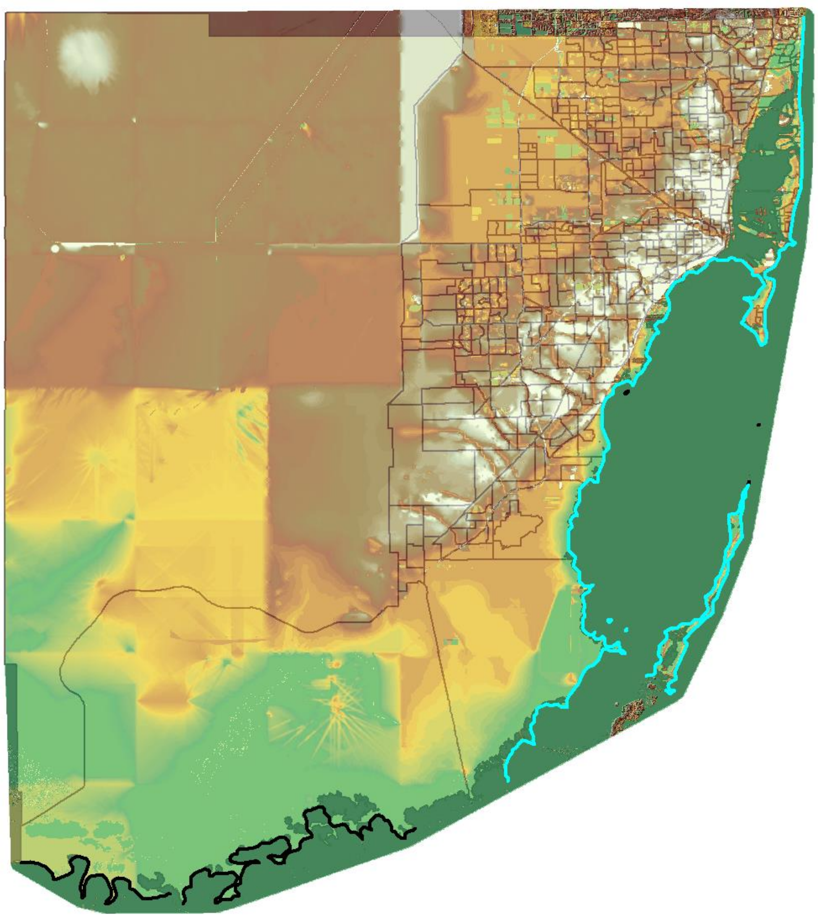

Fig. 11: Flood affecting coast layout (Obtained from ArcGIS)

The hazard damage estimation is calculated based on the historical data of Miami-Dade county. The 100-year stillwater elevation on the eastern coast for flood risk estimation is listed below in Table 4, and the estimated loss of 10-year to 500-year flood hazard as well as the AAL for the flood hazard is estimated using HAZUS MH 2.2 based on the data listed.

Coast	Stillwater Elevations (feet NGVD)				Zone	Base Flood Elevation (feet NGVD)
	10%	2%	1%	0.2%		
Eastern coast	5	6.2	6.6	7.6	AE	6

Table 4: Stillwater elevation data (FEMA, 2009b)

Based on data calculated above, one can created EP curves for the as-built inventory and retrofit design, the AALs and 100-year losses (WCL in Chapter 3.2) for each retrofit level are calculated from the EP curves for further estimation.

6.2 Retrofitting Reimbursement Calculation

Same as Chapter 4.2, with regard to the EP curve for flood building loss in the study region and each of the 7 major census blocks within, the expected reimbursement in a period j_k can be calculated using Eq. 3 & 4. The contract term is assumed to be 10 years, and the London Interbank Offered Rate (LIBOR) is used just as the offering rate rf in this case. For annual benefit, rf in this case can be defined as an interbank offered rate for three months and $\gamma = 3$, in a financial standard, while $t = 12$ indicates that the benefit is counted once every 12 months and the value of rf is used as an average of U.S. dollar LIBOR from the last 10 years as provided by the Federal Reserve Bank of St. Louis (ICE Benchmark Administration Limited (IBA) 2014). The insurer's acceptance level of annual insolvency probability (δ_k) is assumed to be 1%, based on the annual average insolvency rate of insurance companies (Zanjani 2002) and the annual interest rate is set to be 7% (Patel *et al*. 2005). One can also assume that the benefit from reduction in RHC is evenly shared by the government and the insurer, which means $\eta = 50\%$ in this case. For insurance policies with no deductibles ($\xi = 0$), the estimated largest possible payback ratio, by contract year, is shown in Fig. 12.

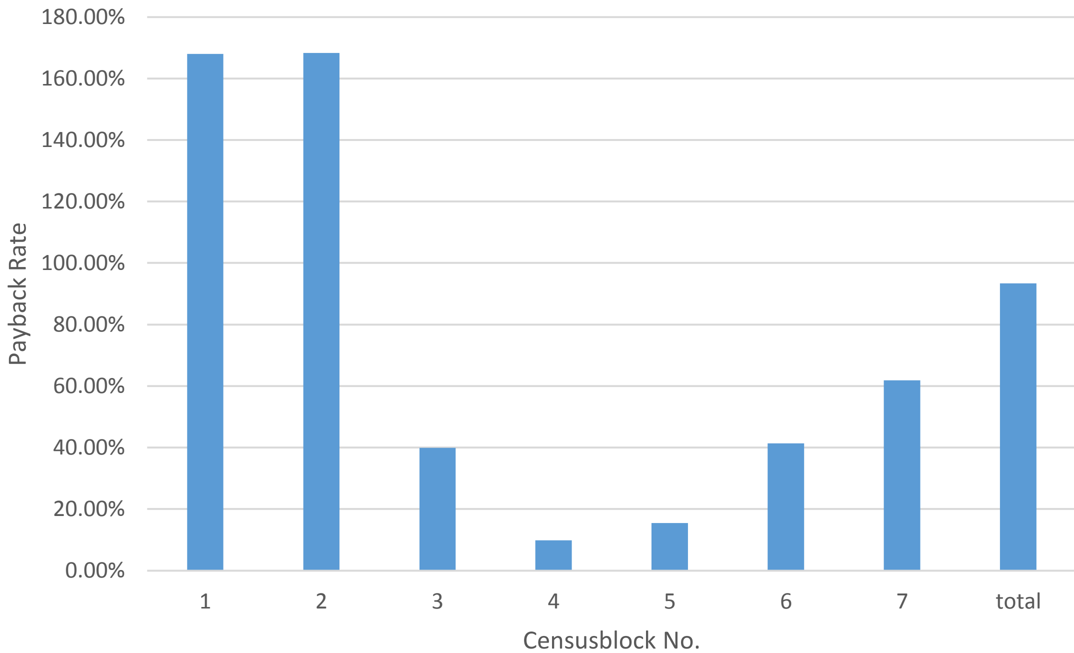

Fig. 12: Estimation of flood mitigation reimbursement ratio ($\eta = 50\%, i = 10$)

To better understand how the benefit generated by this framework may differ from the pure benefit of flood retrofit, the Framework Benefit Factor λ has been calculated for each of the study's 7 census blocks.

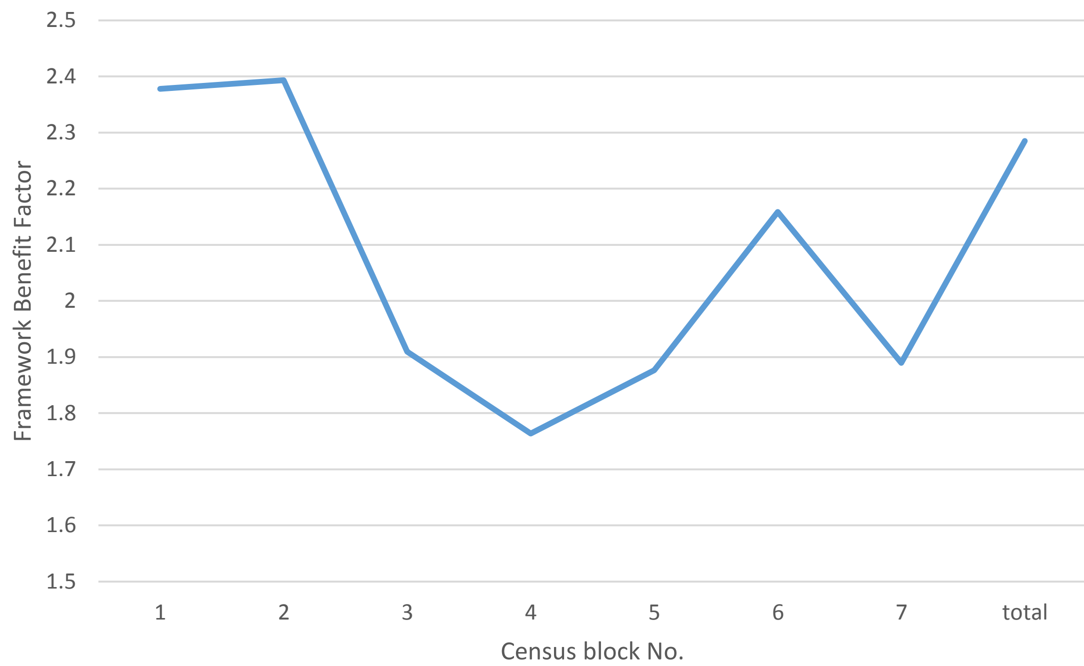

Fig. 13: Estimation of framework benefit factor (flood) ($\eta = 50\%, i = 10$)

BCR of this PPP framework is also investigated based on Eq. 7 in Section 4.3. Based on the mitigation cost C_k^M, the reduction of AAL due to the implementation of building retrofit, and the reimbursement ratio ζ, assuming that the life span of average building inventory is 40 years l_s. BCR values of this PPP framework for a government agency in each study region are listed below in Fig. 14:

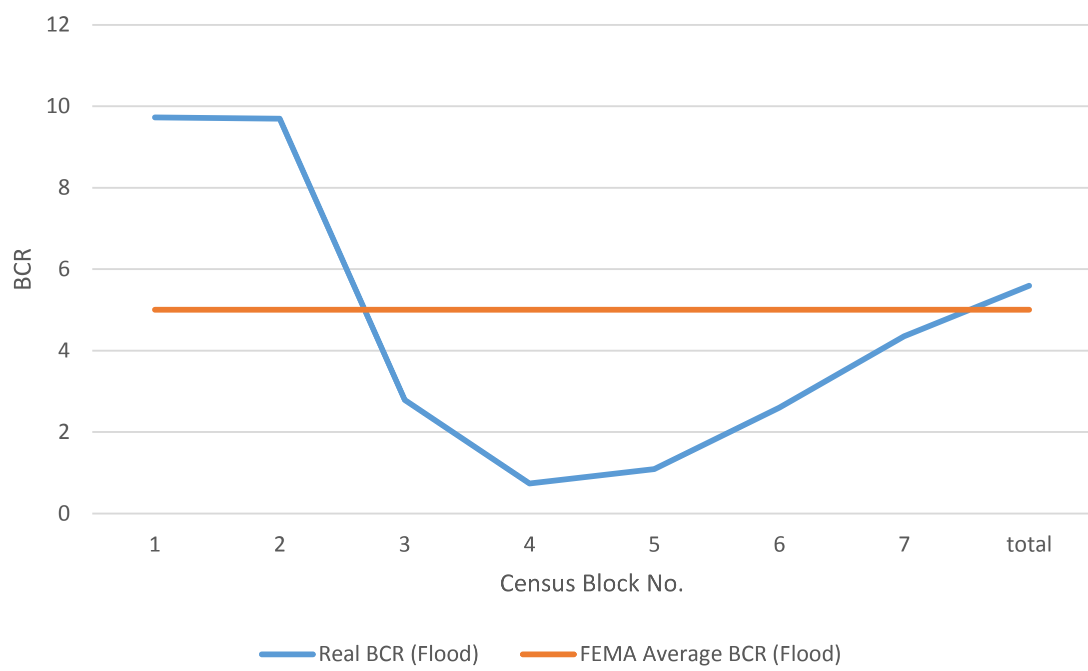

Fig. 14: Estimation of real BCR for government (flood)

As is shown in Fig. 14, compared to the average BCR to FEMA invested flood mitigation projects, which is 5.0 (Rose et al., 2007), the average BCR in the partnership proposed can be 12% higher in total. In specific cases where the regional vulnerability is relatively high and flood mitigation is more needed, the PPP framework BCR can achieve as high as 9.72, which is 95% higher than the average BCR of FEMA flood mitigation projects.

6.3 Sensitivity Analysis

Sensitivity analyses are also conducted using two criteria: the reimbursement ratio ζ representing the feasibility of the framework, and the framework benefit factor λ representing its benefit level. Because of the highly changeable nature of financial parameter utilized in this framework, one can investigate the sensitivity of this framework via several parameters involving the value of rf, contracted year i, and the annual interest rate *r*. The other parameters will remain the same as in Chapter 6.2, and the mid-level retrofit and its consequences vis-à-vis the whole study region are considered in this analysis.

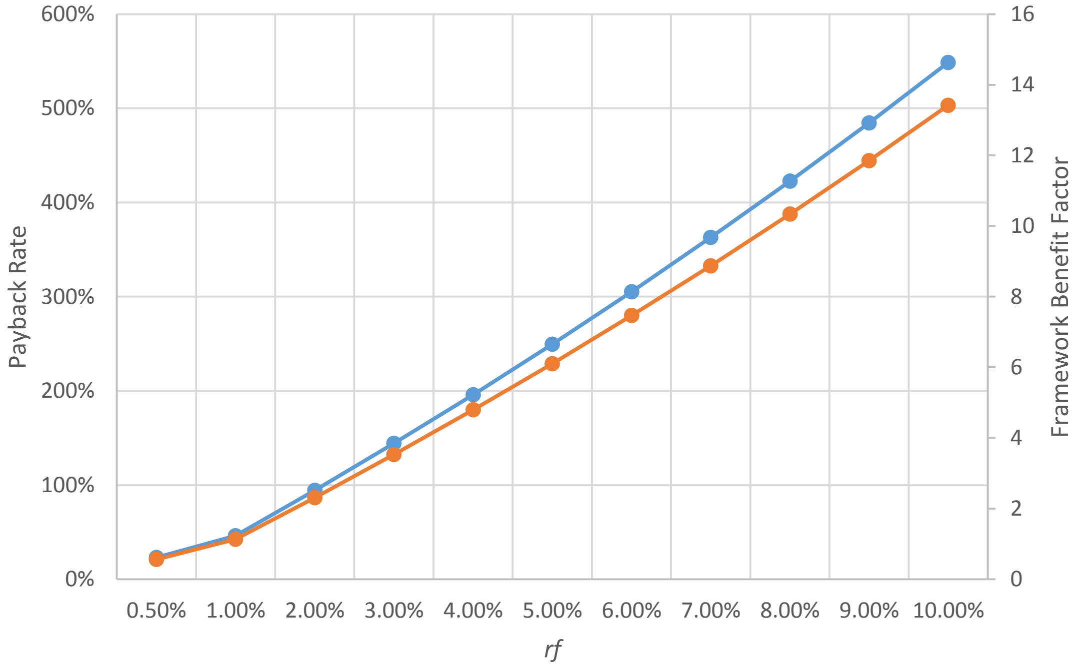

Fig. 15: Sensitivity analysis based on varying *rf* (flood)

The LIBOR for the U.S. dollar, used here to calculate *rf*, has been a highly fluctuating variable in recent years, with a range from about 0.5% to 12%. Fig. 15 shows the feasibility and relative benefit of the proposed framework in its best performing census block, block No. 2, under *rf* values from 0.5% to 11%. Same as the result from Chapter 5.3, the reimbursement ratio ζ and framework benefit factor λ both have near-linear relationships with the risk-free rate of interest *rf*, and that the feasibility of the framework is highly influenced by *rf*. For the lowest point, i.e. where *rf* is 0.5%, the 10-year reimbursement ratio is only 22.9% and its positive effect on retrofit is likely to be minor; whereas when *rf* reaches 10%, the reimbursement has already been more than 5 times as the original investment of the government agency. Considering a highly fluctuating *rf* and a relatively long period of framework implementation, the use of average reimbursement ratio presented in Section 6.2 can be a more accurate estimation.

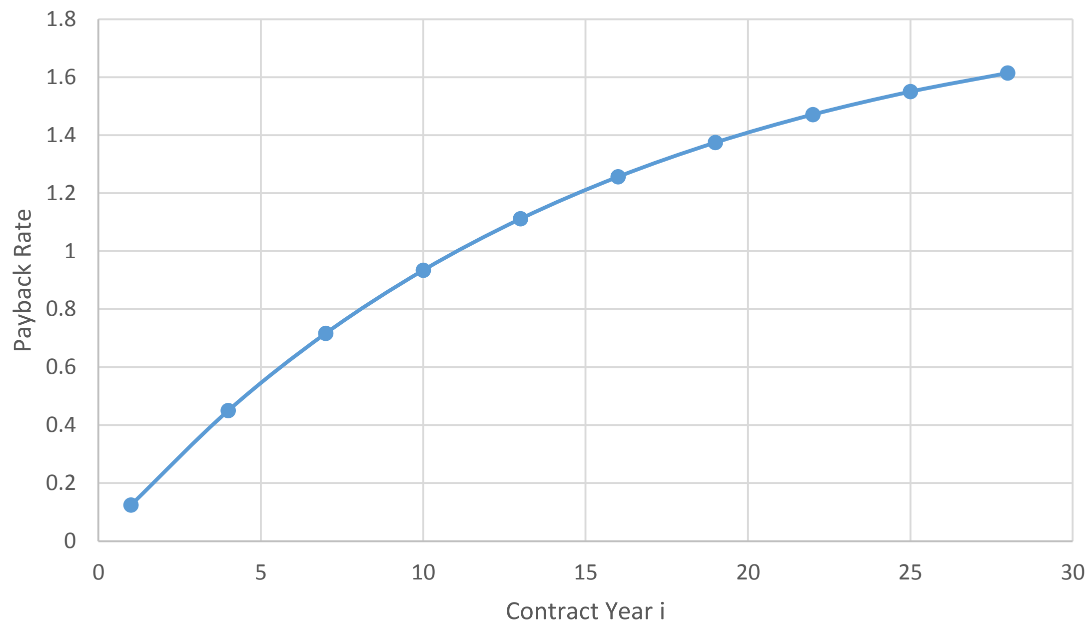

Fig. 16: Sensitivity analysis based on varying contract term (flood)

Fig. 16 sets forth the average reimbursement ratios for possible contract lengths ranging from one year up to the expected building service life of 30 years. Since λ is an annual measuring factor and therefore unaffected by variance in the contract term, it is not included here. Similar as the result in Section 5.3, the relationship between contract year and reimbursement ratio is not linear, and yearly benefit from the framework diminishes. Yet flood mitigation has a much better performance than flood mitigation, with a total of 160% reimbursement of the retrofit cost compared to only 40%.

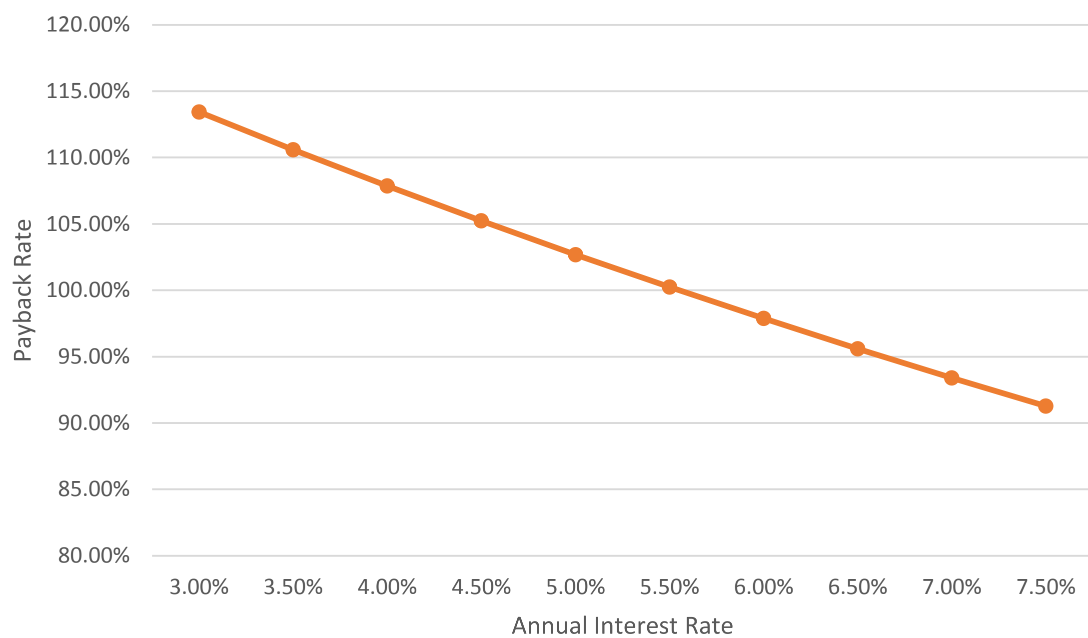

Fig. 17: Sensitivity analysis based on varying annual interest rate (flood)

The effect of the annual interest rate (*r*) in this framework ranges from 3% to 7.5%. Again, as in the case of contract length and for the same reasons, only the reimbursement ratio is investigated. As shown in Fig. 17, the average reimbursement ratio exhibits a minor decrease as the annual interest rate increases, since the standard (*r*) of calculating equivalence current value from future incomes changes.

6.4 Discussion

From the results presented in Section 6.2, it can be seen that the benefit from retrofit-derived reductions in RHC can, in some cases, offset the entire retrofit cost within 10 years. The overall performance of this framework in flood mitigation is shown to be much better than in flood retrofit. While the highest payback rate in flood partnership achieves only about 50%, the payback rate in flood mitigation under the same situation achieves as high as 160%. This result is also highly aligned with the total BCR of FEMA investment to seismic and flood mitigation projects, which may be resulted by the higher effectiveness and lower cost of flood retrofit itself.

Similar to the result in Section 5.4, the framework may not be deemed worthwhile in highly flood-resistant regions, in light of flood retrofit reimbursement of perhaps less than 10% and a payback time as long as 10 years in extreme cases; however, in highly vulnerable regions, this partnership between government and insurer alone can provide enough benefit to cover the whole retrofit cost within a much shorter time, for instance, the full reimbursement of census block 1 and 2 can be expected to achieve within only 5 years, and this should make it attractive to all parties, government agencies especially. Fig. 13 has also shown that the total benefit from this PPP is up to1.5 times of the amount of benefit utilized from the reduction of AAL each year, which can provide a much higher motivation to undertake seismic retrofit in highly vulnerable regions. Combining the result in Chapter 5 and Chapter 6, it is reasonable to conclude that this framework can be highly applicable to most natural hazard mitigations, as long as the vulnerability level is relatively high in the framework performing region. This can also be considered as a advantage of this framework, which will help to allocate the mitigation investment to the most vulnerable regions.

Similar to the result in Section 5, the sensitivity analysis in this chapter has also shown that the proposed framework is highly affected by the risk-free rate of interest, which is inherently highly fluctuating. Yet, if a mitigation project is maintained as a long-term partnership, the influence of rf can be minor. The research suggests that longer contract periods can result in a slightly lower marginal benefit, and so a partnership length at which the reimbursement ratio is satisfactory to the government is likely to be the optimum choice. A lower interest rate, meanwhile, can result in a slightly higher reimbursement ratio, yet such changes can be minor and may not affect the overall feasibility of the framework.

Chapter 7: Conclusion and Further Development

7.1 Conclusion

The two main methods of natural hazard mitigation, building retrofit and insurance, have been used around the world, yet not always successfully, due to their high cost and low incentives, both to governments and property owners. This thesis has presented a new PPP framework that, by involving the insurance industry, can fully utilize the projected future benefit from retrofitting to reimburse the cost of the retrofit projects themselves. The partnership between government and insurance companies in this framework provides additional benefits for the insurer in the form of natural hazard insurance and partial government subsidies for building-retrofit projects. It can also provide a high incentive for insurance and retrofit procurement among property owners.

A case study of earthquake mitigation carried out in a highly vulnerable city in Israel validates the general feasibility of this framework. The result also confirms the market-driving nature of this framework, which has the potential to generate momentum for mitigation action in most vulnerable regions through market behavior. The framework benefit factor, proposed and calculated in this research to compare the effectiveness and benefit of various schemes involving retrofit and insurance, shows the much larger overall positive influence of the proposed framework. The framework can also be used to mitigate other natural hazards including floods, hurricanes, etc., that require building retrofit and catastrophe insurance to improve resilience. In the case study of flood mitigation carried out in Miami-Dade county under continuous threat of flood, the framework achieves payback rate 3 times as much as it achieves in seismic retrofit project, which makes it possible for the government agency to have full amount of mitigation investment reimbursed within 5 years. The BCR values in these cases also achieves up to twice higher than the average BCR of FEMA invested projects in seismic risk mitigation and nearly 100% higher in flood risk mitigation. The result of these measuring parameters has shown a high potential of implementing this partnership to different natural hazard mitigation projects.

A potential partnership can be invested by any natural hazard risk mitigating organizations, which includes the Division of Emergency Management for each state, FEMA for a federal level and World Bank or NHMA for a cross-nation project. The investigation to the payback rate shows these government agencies or organizations can have a reimbursement of 50% of its initial investment or higher during the 10-year partnership, which enables the government agency, or any other investors, such as the World Bank in hazard mitigation projects worldwide, to invest on twice or higher the amount of projects as it can support without this partnership. Besides, this framework can also be utilized by insurance firms or government-run insurance companies as a method of motivating property owners in insurance coverage purchasing.

Besides the increased incentives on risk mitigation practices it generates to the government agency, the insurer and the property owner and the reduction in expense and increased benefit it can provide, this partnership also helps to provide a larger market of risk mitigation to contractors in building and facility rehabilitation. Further partnerships with contractors which may help reduce the expense in building retrofit can also be expected.

7.2 Further Developments

In future research, I intend to investigate the effectiveness of this framework vis-à-vis social and environmental factors, and to conduct a comprehensive analysis of its influence on decision-making by property owners and governments. This thesis has assumed that the property owners' intention to participate in this framework is increased based on the extra benefit in participating, while a more accurate investigation of the property owners' intention is still needed for the full estimation of this framework in the aspect of all participating parties. The contents in this thesis also includes only the case studies in the performance of this partnership in seismic and flood mitigation, while in the further research a consideration of multi-hazard mitigation implementation and the effectiveness of this framework should also be assessed.

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