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Building owner-focussed benefit-cost analysis of seismic strengthening including market forces

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ABSTRACT: Benefit-cost analyses are frequently used in earthquake engineering to aid understanding and inform decision making. These analyses are usually based upon the joint perspective of a large body of stakeholders. This paper suggests that a more complete understanding of seismic strengthening decision problems can be attained by accounting for important market forces and considering the specific perspective of building owners in the analysis. A simple mathematical framework is set out to enable these changes to be incorporated as extensions to "traditional" earthquake engineering benefit-cost analysis methods.

1 INTRODUCTION

The Canterbury Earthquake Sequence caused widespread damage in the Canterbury region of New Zealand and resulted in the loss of 185 lives. In response to these devastating events, and the findings of a detailed commission of enquiry (Cooper et al. 2012), the New Zealand Government proposed an Earthquake-Prone Buildings Amendment Bill (New Zealand Parliament 2013) requiring all existing (non-residential) buildings in New Zealand to be assessed within a 5 year time frame and retrofitted within a 15 year time frame if they are found to be "earthquake prone". An Earthquake Prone Building (EPB) is here defined as a building that is likely to have its ultimate capacity exceeded in a moderate earthquake (33% of a design level event) and also to cause injury if it were to collapse. Minor editions to the policy's content have been proposed (e.g. see Smith 2015). However, these editions have not impacted on the fundamental characteristics of the policy, such as the use of percentage of the New Building Standard (%NBS) as a seismic assessment metric and the mandatory characteristic of the assessment and strengthening operations. Martin Jenkins (2012) and Smith (2003) estimate that there are approximately 15,000 and 25,000 EPBs in New Zealand, and Smith (2003) suggests that the total cost to assess and strengthen these buildings is in the order of $800 million New Zealand Dollars (NZD). Given the large costs involved, it is critical that the entirety of the decision and risk problem is well understood and the important issues are clearly and effectively communicated to stakeholders.

1.1 *Benefit-Cost Analysis (BCA)*

BCA is a structured procedure in which the costs of pursuing a decision option are weighed up against the benefits, in monetary terms. BCA is commonly used in earthquake engineering literature as a decision-making framework, principally because the decision options can be easily identified and both costs and benefits can readily be quantified (Zerbe and Falit Baiamonte 2001). Two notable studies have investigated the costs and benefits of implementing the proposed EPB policy in New Zealand through BCA, one by Hopkins and Stuart (2003) and another by the consulting firm Martin Jenkins (Martin Jenkins 2012). The findings from the two studies are summarized in Figure 1 (note that the Hopkins and Stuart study considered the benefit-cost problem at the city level where the Martin Jenkins study considered the benefit-cost problem at the national level). When interpreting the results of these studies, it is first critically important to be aware that the results are sensitive to a number of uncertain input assumptions and are thus intended to be interpreted as broadly indicative outcomes rather than accurate final solutions. Framed in this light, the Hopkins and Stuart (2003) study nonetheless demonstrate that expected benefit-cost ratios are highly location dependent, and vary more significantly by location than is captured by the earthquake loading code hazard factor, Z (Standards New Zealand 2004). The model by Martin Jenkins is of particular interest here, as it was prepared expressly as a submission for the evaluation of the Earthquake Prone Buildings Amendment Bill. The results of that study suggest that the expected benefits of the proposed EPB policy could be significantly less at a national level than the expected implementation costs. However, the quantity of available data and knowledge in the earthquake loss and BCA modelling fields are expanding rapidly in New Zealand and thus there exist numerous possibilities to extend upon these BCA studies. One of the possible routes for extension is the inclusion of the effects of market forces, which is the topic investigated herein.

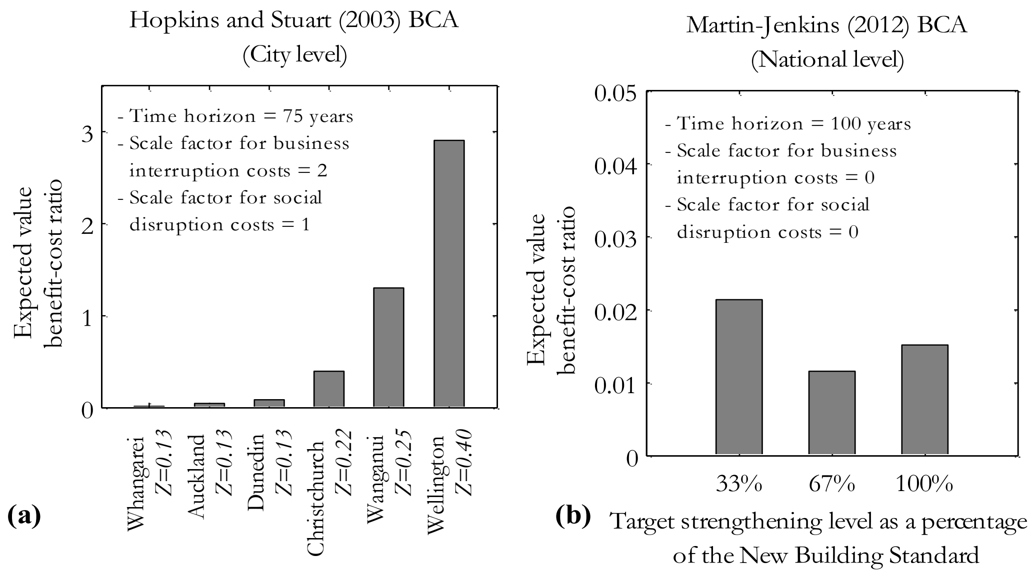

Figure 1. Key results from the (a) Hopkins and Stuart (2003) and (b) the Martin Jenkins (2012) BCAs.

1.2 *The role of market forces on the outcome of investments in earthquake risk mitigation*

Market forces can stimulate cash flows that are significant within the context of BCAs but are unrelated to the actual earthquake risk. For example, societal demand for buildings with high seismic performance can drive increases in building market value, which represents a direct capital gain for the building stakeholders. Societal demands for buildings with sound seismic performance are also likely to increase rental demand for such buildings. Moreover, insurance policies (annual premiums, deductibles and insurance policy limits) can be volatile after large earthquake events. These effects and have the potential to greatly impact both the expected benefit-cost ratio of seismic strengthening and the decision-making processes of individual stakeholders. However, they have not been considered as part of ‘traditional’ earthquake mitigation BCAs or loss analyses that consider all stakeholders (i.e. owners, tenants, insurers, lenders, government and the public) as a single group. A noteworthy exception is the study by Porter et al. (2004), which investigated the comparative importance of seismic and market risks for real estate investments. A series of case studies were set out in which market risks were found to be much more important to real estate investors than seismic risks and, thus, earthquake risks were only deemed to be consequential when expressed in terms of expected annual loss.

Market effects are particularly important after large earthquakes that arouse significant public interest, or after the introduction of regulations stimulating public demand for buildings with improved seismic performance. For the case of Los Angeles, FEMA (1997, p. 30) analysed the effects of market forces on building owner outcomes during the implementation of the Earthquake Hazard Reduction Ordinance (“Division 88”). The legislation was enacted in 1981 and required mandatory seismic retrofitting of vulnerable buildings within specified time frames. A repeat sales analysis performed by Cochrane (1992) showed that compliance with the ordinance raised the sales prices of the city’s unreinforced brick masonry (URBM) bearing wall buildings by an average of +37%. FEMA (1997) suggested that the benefits from increases in sales prices were significant enough for building owners to be able to recoup the strengthening costs imposed on them by the ordinance. Additionally, Comerio (1992) found that one third of Los Angeles’ URBM buildings applied for rent increases and that an average rent increase of +20% was granted.

Recent studies in New Zealand have investigated the effects of seismic strengthening EPBs on market values and rental demands. Powell et al. (2015) presented preliminary research findings from a survey including 11 EPB owners in Wellington. Of the 11 buildings considered, 7 were described as "character buildings" (buildings constructed between 1900 and 1930 with salient heritage value) and 4 were described as "modern buildings" (buildings constructed between 1960 and 2000). For the "character buildings", the study reported increases in market value ranging from+17% and +1054%, and corresponding increases in rental income ranging between +50% and +150%. For "modern buildings", the study reported increases in market value ranging between +23% and +72% and increases in rental income ranging between +0% and +103%. Most of the survey respondents were also of the opinion that commercial property market in Wellington city was characterized by greater supply than demand, such that earthquake strengthening was necessary in order to attract and maintain tenants. Note that the recorded increases do not distinguish between buildings that undertake seismic strengthening only vs. buildings that undertake seismic strengthening in conjunction with renovations and/or a change in use. This distinction is presumably important in understanding some of the higher changes in market value (e.g. +1054%) and rental rate (e.g. +150%).

Filippova (2015) used hedonic regression to estimate the effect of the %NBS rating on rental demands in Auckland and Wellington. The author collected 67 records of leasing transactions in the Auckland Central Business District (CBD) from 2012 to 2014, and 97 similar observations in the Wellington CBD. In the Wellington CBD, strong evidence was found in support of an effect of %NBS on rental demand. No such evidence was found in the Auckland CBD, although a series of semi-structured interviews of experienced Auckland real estate agents carried out by Curtis (2013) offer evidence that %NBS ratings remain important drivers in the Auckland CBD office property market. Filippova found that, on average, Wellington CBD tenants were willing to pay $34 NZD per m^2 per year additional rent to occupy a low risk building (67% NBS rating) as oppose to an EPB (33% NBS rating). This represented a +15% increase on the average effective rental rate, which was $228 NZD per m^2 per year.

2 BENEFIT-COST ANALYSIS ON THE SEISMIC STRENGTHENING OF EARTHQUAKE-PRONE BUILDINGS

The first step in BCA is to establish a perspective and clearly define the "considered" and "status quo" decision options (Zerbe and Falit-Baiamonte 2001). For completeness, we consider three cases here (see Table 1), expanding from a "traditional" earthquake risk mitigation BCA toward a building owner-focussed BCA which considers the effects of market forces. In all three cases, the introductory background to the decision problem is the same: "A specific building has recently been notified as being earthquake-prone under the 2004 Building Act, and a BCA is to be conducted in order to help identify the optimal course of action from that point". Note that the specific decision options considered here represent just a select number of many possible combinations, selected based on perceived relevance or usefulness.

2.1 *Case 1 – Traditional BCA*

The first case is that of a traditional engineering-focussed BCA. The key inputs are:

- The life cycle time period of the building, denoted t_L
- The strengthening cost, denoted C_0 (incurred at the time t_S);
- The seismic hazard function at the site, denoted $\lambda(IM)$, which provides the expected annual rate of earthquakes with intensities exceeding the intensity measure IM;
- The expected value of economic loss as a function of the earthquake intensity, denoted $\mathbb{E}[L_S|IM]$ and $\mathbb{E}[L_0|IM]$ for the strengthened and unstrengthened buildings, respectively;
- The expected number of various casualty states (such as "minor injury", "serious injury", "critical injury" and "fatality") as a function of the intensity measure IM, denoted $\mathbb{E}[N_S(k)|IM]$ and $\mathbb{E}[N_0(k)|IM]$ for the strengthened and unstrengthened buildings respectively, where k is an index describing the casualty state.

The expected annual economic losses for the strengthened and unstrengthened buildings, denoted

EAEL_S and EAEL_0, are determined by integration over the hazard curve:

$$\text{EAEL}_S = \int_0^\infty \mathbb{E}[L_S|IM] \left|\frac{d\lambda(IM)}{dIM}\right| dIM \quad (1)$$

$$\text{EAEL}_0 = \int_0^\infty \mathbb{E}[L_0|IM] \left|\frac{d\lambda(IM)}{dIM}\right| dIM \quad (2)$$

Similarly, the expected annual casualty losses associated or the strengthened and unstrengthened buildings, denoted EACL_S and EACL_0, are determined as:

$$\text{EACL}_S = \sum_{k=1}^{\text{NCS}} M_k \int_0^\infty \mathbb{E}[N_S(k)|IM] \left|\frac{d\lambda(IM)}{dIM}\right| dIM \quad (3)$$

$$\text{EACL}_0 = \sum_{k=1}^{\text{NCS}} M_k \int_0^\infty \mathbb{E}[N_0(k)|IM] \left|\frac{d\lambda(IM)}{dIM}\right| dIM \quad (4)$$

Where: NCS is the total number of considered casualty states and M_k is the monetary value assigned to the casualty state k.

Table 1 – Summary of BCA analysis cases.

Case	Perspective	Considered decision option	Status quo decision option	Use
Case 1 – Traditional BCA	All stakeholders (e.g. the building owner, lender, tenants, insurer government and the public)	Undertake seismic strengthening* at some time t_S	Do nothing**	Helping to identifying a decision that is broadly advantageous for all stakeholders***
Case 2 – Traditional BCA with insurance effects	All stakeholders noted in Case 1 *except* the insurer	Undertake seismic strengthening* at some time t_S	Do nothing**	Helping to identify a decision that is broadly advantageous for all stakeholders except the insurer***
Case 3 – Building owner focussed BCA	Building owner	Undertake seismic strengthening* at some time t_S, rent the property until the time t_R, sell the property after that time.	Do nothing. Sell (or demolish and sell) the property at the time t_R.	Helping to identifying the most economic decision for the building owner

* For Cases 1 and 2, only those upfront costs associated directly with the seismic strengthening need to be considered. Conversely, for Cases 3 and 4, all upfront costs should be considered including additional costs associated with renovations and/or change of use.
** For Cases 1 and 2, cash flows resulting from enforced building demolition under the proposed EPB policy are neglected. This is consistent with assumptions in previous BCAs (Martin Jenkins 2012, Hopkins and Stuart 2003)
*** This does not imply that the decision is advantageous for each specific stakeholder. Some individual stakeholders may "lose out" in the decision. It is important only that those that "win out" could potentially compensate those that "lose out".

The expected present value costs and benefits, denoted $\mathbb{E}[\text{Cost}]$ and $\mathbb{E}[\text{Benefit}]$, can thus be expressed as:

$$\mathbb{E}[\text{Cost}] = C_0 e^{-rt_S} \quad (5)$$

$$\mathbb{E}[\text{Benefit}] = \frac{\text{EAEL}_0 - \text{EAEL}_S}{r}\left(e^{-rt_S} - e^{-rt_L}\right) + \frac{\text{EACL}_0 - \text{EACL}_S}{\varphi}\left(e^{-\varphi t_S} - e^{-\varphi t_L}\right) \quad (6)$$

Where: r is a continuously compounding real discount rate for construction and repair costs (adjusted for the effects of inflation); and φ is a social discount rate reflecting social time preferences on the prevention of injuries and fatalities. The discount rate r is typically selected as between 2% and 7%, depending upon the application (private sector applications tend to place greater focus on short term profits and thus emphasize a high discount rate) (Zerbe and Falit Baiamonte 2001). The selection of a social discount rate is somewhat more contentious, with key ethical arguments favouring the use of $\varphi = 0$ (Zerbe and Falit Baiamonte 2001). Note that, if the social discount rate is selected as $\varphi = 0$, then Equation 6 should be adjusted to:

$$\mathbb{E}[\text{Benefit}] = \frac{\text{EAEL}_0 - \text{EAEL}_S}{r}\left(e^{-rt_S} - e^{-rt_L}\right) + (\text{EACL}_0 - \text{EACL}_S)t_L \quad (7)$$

The expected benefit-to-cost ratio $\mathbb{E}[\text{BCR}]$ can now be determined:

$$\mathbb{E}[\text{BCR}] = \frac{\mathbb{E}[\text{Benefit}]}{\mathbb{E}[\text{Cost}]} \quad (8)$$

2.2 *Case 2 – Traditional BCA with insurance effects*

Case 2 is similar to Case 1, except with some changes to incorporate insurance effects. Firstly, the expected economic losses $\mathbb{E}[L_S|IM]$ and $\mathbb{E}[L_0|IM]$ input to Equations 1 and 2 need to be adjusted to account for pay out from the insurer. The adjusted expected economic loss, here denoted $\mathbb{E}[L_S^*|IM]$ and $\mathbb{E}[L_0^*|IM]$, are determined as:

$$\mathbb{E}[L_S^*|IM] = \int_0^\infty h_S(L)\, f_{L_S=l|IM}\, dl \quad (9)$$

$$\mathbb{E}[L_0^*|IM] = \int_0^\infty h_0(L)\, f_{L_0=l|IM}\, dl \quad (10)$$

Where: $f_{L_S|IM}$ and $f_{L_0|IM}$ are probability densities at the loss level l for economic losses in the strengthened and unstrengthening buildings, respectively; and $h(L)$ is the function that adjusts loss to account for insurer pay out as:

$$h_S(L) = \begin{cases} D_S + L - \Psi_S & L > D_S + \Psi_S \\ D_S & D_S < L < D_S + \Psi_S \\ L & L < D_S \end{cases} \quad (11)$$

$$h_0(L) = \begin{cases} D_0 + L - \Psi_S & L > D_0 + \Psi_0 \\ D_0 & D_0 < L < D_0 + \Psi_0 \\ L & L < D_0 \end{cases} \quad (12)$$

Where: D_S and D_0 are the deductibles for the strengthened and unstrengthened buildings, respectively, and Ψ_S and Ψ_0 are the policy limits for the strengthened and unstrengthened buildings.

Secondly, benefits from reductions in insurance premiums need to be determined using:

$$\mathbb{E}[\text{Insurance Benefit}] = \frac{\text{IP}_0 - \text{IP}_S}{r_I}\left(e^{-r_I t_S} - e^{-r_I t_L}\right) \quad (13)$$

Where: r_I is the real, continuously compounding discount rate for insurance payments, which can be estimated as a nominal interest rate less the average rate of inflation for insurance premiums.

These benefits must then be added to the right hand side of Equation 6 to determine an overall expected present value benefit. The benefit-to-cost ratio of the investment in seismic strengthening including the effects of earthquake insurance can then be determined using Equation 8. The alterations set out for Case 2 have thus far assumed that earthquake insurance is available and purchased for both strengthened and unstrengthened buildings. However, Nahkies (2015) and others note that EPB owners in New Zealand have often found it difficult to obtain any earthquake insurance. If earthquake insurance is unavailable for the unstrengthened building, then the adjusted expected economic loss $\mathbb{E}[L_0^*|IM]$ is simply equal to $\mathbb{E}[L_0|IM]$ and the insurance premium IP_0 in Equation 13 should be set to zero.

2.3 *Case 3 – Building owner-focussed BCA*

Case 3 considers the decision problem from the specific perspective of the building owner. Here, it is necessary to distinguish and identify the important cash flows between the building owner and all other outside groups or institutions, particularly the cash flows that are likely to be different depending upon whether or not the building is strengthened. The outside groups or institutions include not only the insurer and contractors responsible for the repair of earthquake-related damages (as in Case 2), but also tenants (e.g. rental income), lenders (e.g. interest payments on loans), the individual or group to which the property is sold after the holding period (e.g. capital gains), government (e.g. tax) and potentially many others. Limited available literature on the effects of the 2011 Christchurch earthquake and subsequent policy proposals (see Section 1.2) confirms that strengthening of EPBs is correlated with changes to insurance policies, increases in rental demand and increases in building market value, which suggests that it is (at a minimum) necessary to consider insurance premium, rental income and building sale cash flows within a building owner-focussed BCA. Mortgage principal and interest payments should also be included wherever mortgages are used to finance strengthening work. The subsequent estimation of total expected benefit as an independent sum of expected benefits from changes in rental demand, market value, insurance policies and lending is intuitively appealing but incorrect, principally because it neglects tax. Tax is complicated function of the building owner's net income and other factors, so a high fidelity assessment of the effects of strengthening on the actual financial outcome of the building owner (as in Porter et al. 2004) requires an extensive knowledge of the building owner's cash flows including all operating expenses.

A very simple approach is presented here that neglects tax cash flows entirely, allowing the total benefits of strengthening to be approximated as a simple summation of benefits due to changes in rental demands, market value, insurance policies and lending. This approach has obvious limitations in accuracy but nonetheless allows the analyst to estimate the "ball park" magnitudes of the various benefits that affect the building owner without the need for modelling more complicated cash flow structures. More detailed analyses may then be carried out (e.g. as in Porter et al. 2004), if an increase in accuracy is judged to be relevant to further decision making. It is noted that the method presented here is not novel. It re-uses concepts that are firmly established in introductory literature on real estate investment assessment (Brown 2005 and Kolbe and Greer 2006). Rather, the present work emphasizes the consideration of both *market risks and seismic risks within the framework of a single BCA*, as a route to increased understanding of complicated decision problems involving seismic risk mitigation.

The "considered" decision option for Case 3 is the option to undertake seismic strengthening at some time t_S, to rent the property until the time t_R and to sell the property at that time. The "status quo" option is the option to defer seismic strengthening until the time t_R and to sell (or demolish and sell) the property at that time. The initial property value is here denoted $\mathcal{V}_0$ (this includes the value of the land is denoted $\mathcal{V}_{\text{LAND}}$ and the value of the building $\mathcal{V}_{\text{BLDG}}$) and it is currently collecting an average rental income of ARI_0. Assume that seismic strengthening is accompanied by an instantaneous and prolonged average relative increase in property value of k_P (i.e. a value of $k_P = 0.1$ implies a 10% prolonged increase in property value). This result is an expected present value benefit for the building owner of:

$$\mathbb{E}[\text{Sale Benefit}] = \begin{cases} k_P \mathcal{V}_0 e^{-r_P t_R} & I_{\text{DEM}} = 1 \\ (k_P \mathcal{V}_0 + \mathcal{V}_{\text{BLDG}} + C_{\text{DEM}}) e^{-r_P t_R} & I_{\text{DEM}} = 0 \end{cases} \tag{14}$$

Where: C_{DEM} is the cost of demolition; r_P is the real, continuously compounding discount rate for property sale cash flows, determined as a nominal discount rate less the average rate of inflation on property values; and I_{DEM} is an indicator variable equal to 1 if demolition occurs and 0 if demolition does not occur. Note that, if $I_{\text{DEM}} = 1$, then additional non-monetary benefits will accrue in support of the decision to strengthen the building, based on society's willingness-to-pay to avoid a loss in heritage value. These benefits are not considered here.

Assume also that seismic strengthening increases rental demand which in turn stimulates an immediate and prolonged average increase in rental income (adjusted for the risk of vacancy) of k_R. This generates an expected present value benefit for the building owner of:

$$\mathbb{E}[\text{Rental Benefit}] = k_R \frac{\text{ARI}_0}{r_R} \left(e^{-r_R t_S} - e^{-r_R t_R}\right) \tag{15}$$

Where: r_R is the real, continuously compounding discount rate for rental income cash flows, determined as a nominal discount rate less the average rate of inflation on rental income.

Combination of Equations 14 and 15 with the relevant developments in Cases 1 and 2, assuming that no demolition occurs and insurance is unavailable for the unstrengthened building, gives the following expected present value costs and benefits:

$$\mathbb{E}[\text{Cost}] = C_0^* e^{-rt_S} \tag{16}$$

$$\begin{aligned}\mathbb{E}[\text{Benefit}] = {} & \frac{\text{EAEL}_0 - \text{EAEL}_S^*}{r}\left(e^{-rt_S} - e^{-rt_R}\right) + k_P \mathcal{V}_0 e^{-r_P t_R} \\ & + k_R \frac{\text{ARI}_0}{r_R}\left(e^{-r_R t_S} - e^{-r_R t_R}\right) - \frac{\text{IP}_S}{r_I}\left(e^{-r_I t_S} - e^{-r_I t_R}\right)\end{aligned} \tag{17}$$

Where: C_0^* is the cost of seismic strengthening which includes both the costs of further renovations and/or a change in use, if applicable, and additional interest payments on borrowed money (valued at the time t_S); and EAEL_S^* is the expected annual loss associated with earthquake risk for the strengthened building, calculated by accounting for insurer pay outs as described in Section 2.2.

The outputs from Equations 16 and 17 can be used to determine benefit-cost ratios and also to compare the relative importance of the various earthquake risk-driven and market-driven benefit sources.

3 FUTURE WORK

The BCA framework set out in this paper has been applied in several preliminary case studies in Auckland and Wellington based upon approximate seismic hazard data. The results of these studies suggest that market forces are far more important as decision drivers for owners of EPBs than actual earthquake risk, particularly in Auckland. Research is ongoing in expanding and validating the proposed framework, gathering input data and applying the framework to a wider array of case studies, all based on state-of-the-art seismic hazard data.

4 CONCLUSIONS

New Zealand is currently in the process of implementing legislation requiring mandatory seismic strengthening of existing buildings vulnerable to earthquake ground shaking. Benefit-cost analyses have been undertaken as part of the implementation process to aid understanding and inform decision-making.

This paper firstly reviewed the effects of large earthquakes and mandatory strengthening legislation on building market values, insurance policies and rental demands. These effects were found to be non-trivial and thus represent necessary considerations within any extension to “traditional” earthquake engineering benefit-cost analysis that considers the specific perspective of New Zealand’s earthquake prone building owners. A simple framework was set out allowing simple and structured consideration of changes in important influencing factors that are driven by the free-market, including changes in rental demand, property value, insurance premiums and lending conditions. Development, validation and application of the proposed framework is part of an ongoing research effort.

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