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Break-Even Economic Assessment of Residential Housing Climate Adaptation Strategies for Sydney

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Abstract

The paper applies break-even analysis to compare the risks, costs and benefits of climate adaptation strategies for new housing in Sydney. The measure for cost-effectiveness is Net Present Value (NPV) or net benefit equal to benefit minus the cost. Increasing the design wind classifications in the AS4055-2012 for all new housing in Sydney can lead to risk reductions of 50-65%, at a cost of no more than 1-2% of house replacement value. If risk reduction is over 50%, discount rate is 4%, and there is no change of climate, the break-even analysis shows that adaptation is cost-effective for Sydney if the adaptation cost is less than 9.3% and 5.5% of house replacement cost for foreshore and non-foreshore locations, respectively. A changing climate will increase these break-even adaptation costs by up to 1%.

Introduction

The Australian Standard "Wind Loads for Houses" AS4055-2012 is based on AS1170.2-2011 and is used to determine the appropriate wind classification for design of residential (domestic) housing. In this case, residential housing is designed to resist ultimate limit state wind speeds with annual probability of exceedance of 1 in 500. The standard AS4055-2012 classifies design loads on houses into categories N1-N6 for non-cyclonic regions. Each increase in wind classification (e.g. N1 to N2) raises the design wind speed that is equivalent to at least a 50% increase in design wind pressure. These wind classifications are then used in AS1684-2010 "Residential Timber-Framed Construction" and other standards called up by the Building Code of Australia to determine appropriate deemed-to-comply sizing and detailing requirements for residential construction. However, the wind classifications specified in AS4055-2012 may be inadequate if wind speeds increase due to a changing climate. Hence, an appropriate adaptation strategy may be one that increase wind classifications for new houses leading to reduced vulnerability of new construction.

Stewart et al. (2012, 2013) have assessed the damage risks, adaptation costs and cost-effectiveness of this adaptation strategy for residential construction in Cairns, Townsville, Rockhampton and Brisbane assuming time-dependent changes in frequency and intensity of cyclonic and non-cyclonic winds to 2100. Advanced spatial and temporal stochastic simulation methods were used to include uncertainty and variability of climate and building vulnerability on damage risks. Costs of adaptation, timing of adaptation, discount rates, future growth in new housing, and time-dependent increase in wind speeds with time were also included in the analysis - for exposures up to 2100. The criteria for cost-effectiveness were: (i) Net Present Value NPV (or net benefit equal to benefits minus the cost), and (ii) probability that NPV>0. Four climate change scenarios were considered including no change, and 10% and 20% increases in wind speeds by 2100. It was found that, assuming 'business as usual' (no adaptation measures), a changing climate can increase mean wind damage losses for Cairns, Townsville, Rockhampton and South East Queensland by up to $20.0 billion by 2100.

There is considerable uncertainty associated with stochastic modelling of the existing wind field (no climate change), projections of changes to wind field due to a changing climate, wind vulnerability models for housing, and risk reduction and cost of adaptation. This necessarily makes any absolute predictions of costs and benefits of climate adaptation somewhat speculative. (e.g., Stewart et al. 2012). An alternate approach is a 'break-even' economic assessment. In this case, the conditions under which a climate adaptation strategy is cost-effective can be assessed, and decision or policy-makers can decide if such minimum conditions can be met in practice. For example, a break-even analysis may show that an adaptation measure is cost-effective if it reduces risk by at least 25% and at a cost not exceeding $5,000. While precise predictions of risk reduction and adaptation cost may not be available, or only known approximately, if there is consensus that a higher risk reduction is easily achievable for an adaptation cost of only $2,000-4,000 then the adaptation measure is clearly cost-effective. On the other hand, if there is general agreement that a 25% risk reduction is not possible even for an adaptation cost of $10,000 - then the adaptation measure is not cost-efficient as the cost exceeds the break-even value. The break-even approach is widely used in areas of parameter uncertainty, such as homeland security applications (e.g., Stewart and Mueller 2011, 2013), and is well suited to climate change and adaptation policy decisions where uncertainties dominate hazard, vulnerability and consequence predictions.

The paper applies break-even analysis to compare the risks, costs and benefits of climate adaptation strategies for new housing in Sydney. The wind hazard is dominated by synoptic winds. Break-even estimates of risk reduction and adaptation cost for designing new housing to enhanced standards are calculated for three wind pattern scenarios to 2070: (i) no change, and (ii) B1 and (iii) A1FI emission scenarios. Stochastic methods are used to predict levels of existing risk (economic loss). The effect of changes to the probabilistic model of existing wind hazards and changes to discount rate are also investigated.

Risk-Based Decision Analysis

The standard definition of risk is:

$$(\text{Risk}) = (\text{Hazard}) \times (\text{Vulnerability}) \times (\text{Consequences}) \qquad (1)$$

where

- Hazard - probability there will be a climate hazard.
- Vulnerability - probability of damage or loss (that wind will damage a roof of a house) given the hazard.
- Consequences - loss or consequence if the hazard is successful in causing damage.

Equation (1) can be re-expressed as:

$$E(L) = \sum \underbrace{\Pr(C)\Pr(H|C)}_{\text{HAZARD}} \; \underbrace{\Pr(D|H)}_{\text{VULNERABILITY}} \; \underbrace{\Pr(L|D)L}_{\text{CONSEQUENCES}} \qquad (2)$$

where Pr(C) is the annual probability that a specific climate scenario will occur, Pr(H|C) is the annual probability of a climate hazard (wind, heat, etc.) conditional on the climate, Pr(D|H) is the probability of infrastructure damage or other undesired effect conditional on the hazard (also known as vulnerability or fragility) for the baseline case of no extra protection (i.e. 'business as usual'), Pr(L|D) is the conditional probability of a loss (economic loss, loss of life, etc.) given occurrence of the damage, and L is the loss or consequence if full damage occurs. The summation sign in Eqn. (2) refer to the number of possible climate scenarios, hazards, damage levels and losses. If the loss refers to a monetary loss, then E(L) represents an economic risk.

Net Present Value (NPV) is the criteria used to assess the cost-effectiveness of adaptation strategies. The 'benefit' of an adaptation measure is the reduction in damages associated with the adaptation strategy, and the 'cost' is the cost of the adaptation strategy. The net benefit or net present value (NPV) is equal to benefit minus the cost. The decision problem is to maximise NPV

$$\mathrm{NPV} = \sum \mathrm{E(L)}\Delta\mathrm{R} + \Delta\mathrm{B} - \mathrm{C}_{\mathrm{adapt}} \qquad (3)$$

where ΔR is the reduction in risk caused by climate adaptation measures, C_{adapt} is the cost of adaptation measures (including opportunity costs) that reduces risk by ΔR, ΔB is the expected co-benefit of adaptation such as reduced losses to other hazards, increased energy efficiency of new materials, etc., and E(L) is the 'business as usual' risk given by Eqn. (1). Climate adaptation measures should result in risk reduction (ΔR) that may arise from a combination of reduced likelihood of hazard, damage states, safety hazards and and/or people exposed to the hazard. For any climate adaptation measure the risk reduction ΔR can vary from 0% to 100% (or even a negative number for an ill-suited adaptation measure).

Figure 1 shows a schematic of time-dependent increase in reduced damages and adaptation costs if an adaptation strategy is implemented in 2015. In this case we assume that the adaptation cost is constant with time and so is a one-off expense. The benefits increase with time due to reduced vulnerability, so the NPV accrues over time.

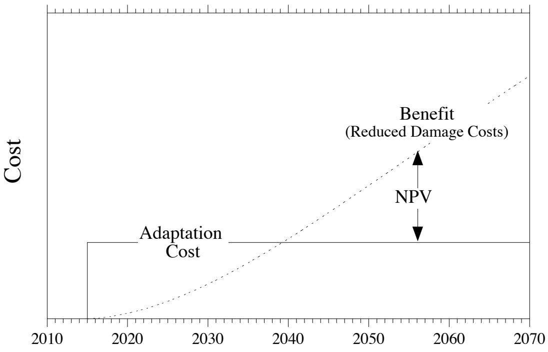

Figure 1. Schematic of Net Present Value (NPV), and Adaptation and Reduced Damage Costs

Wind Hazard and Climate Projections

Non-cyclonic gust speed for Sydney is modelled as a generalised extreme-value distribution (Wang et al. 2013). The Australian Standard AS4055-2012 assesses design wind speeds for housing and so is used herein to determine terrain and shielding effects for houses in an urban environment for the following two exposure categories:

- foreshore (500 m from coast).
- non-foreshore (more than 500 m from coast).

The terrain category for the foreshore and non-foreshore exposures are TC1.5 and TC3, respectively (AS4055-2012). The terrain multipliers are influenced by region, terrain category and roof height and are equal to K_t=1.0 and K_t=0.83 for foreshore and non-foreshore locations, respectively (AS4055-2012). Since houses are in urban environments then AS4055-2012 assumes full shielding with K_s=0.85. AS4055-2012 adopts a correction factor of 0.95 to "account for the variation of orientation of houses within suburbs and groups of suburbs"; hence, wind speeds can be reduced by 5% resulting in K_s=0.95×0.85≈0.80.

CSIRO (2007) suggest the average annual change in mean wind speed is projected to decrease by 1% in Sydney by 2070, with 10^{th} and 90^{th} percentiles of -15% and +12%, respectively, for the A1FI (high) emission scenario, and mean, 10^{th} and 90^{th} percentiles of 0%, -8% to +6% for the B1 (medium) emission scenario. Note that climate projects are relative to 1990 levels.

Although there are still many uncertainties to accurately define the future trend of severe wind in Australia, considering recent findings for Australia, three wind pattern scenarios are considered based on CSIRO (2007) wind speed projections to 2070 for B1 and A1FI emission scenarios. Truncated normal distributions are used to represent uncertainty of changes in wind speeds where 10^{th} and 90^{th} percentiles provided by CSIRO (2007) allow the standard deviation of the two truncated normal distributions each with cumulative probabilities of 50% to be calculated (σ_L is standard deviation of lower half of the distribution, and σ_U is standard deviation of upper half of the distribution). In this case, σ_L=6.2%, σ_U=4.7% (B1) and σ_L=10.9%, σ_U=10.1% (A1FI). The 'no change' scenario consists of σ_L=σ_U=0%. A linear time-dependent change in wind speed is assumed.

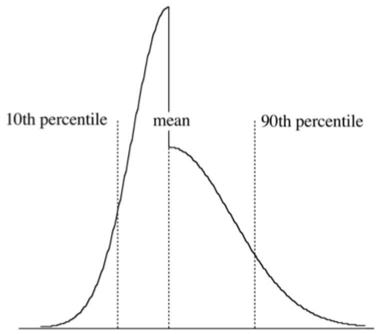

Figure 2. Probability Distribution of Changes in Wind Speed.

Wind Vulnerability

A wind vulnerability function expresses building damage or loss as a function of wind speed. The vulnerability function for damage to residential construction is shown in Figure 3 for post-1996 (new) brick veneer residential housing with tiled roof (Wehner et al. 2010).

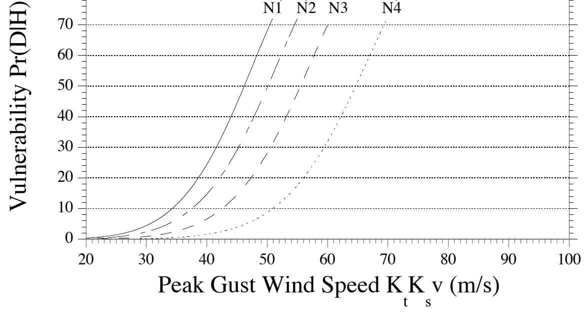

Figure 3. Wind Vulnerability Curves.

Loss Function

The average cost per new house in Sydney is approximately \$270,000 in 2012 dollars. The insured value of the house is higher than the replacement value due to many homeowners also holding contents insurance. The average insured value of a house is approximately 25% higher than house replacement value. The loss L is equal to insured value of the house, normalised to L=1.25 of house replacement value. The analysis considered direct losses (structural damage and contents losses) and indirect losses (business interruption, clean-up, loss during reconstruction, and changes to demand and supply of intermediate consumption goods), see Figure 4.

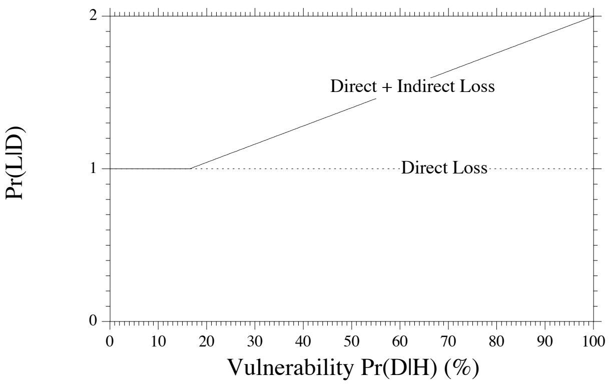

Figure 4. Direct and Indirect Costs as a Function of Vulnerability.

Adaptation Strategy: Strengthen New Housing

The adaptation strategy involves the design of new housing to enhanced design codes; in this case, increasing the current wind classification by one category. For example, for Sydney this means that new construction would be designed for wind classification N3 rather than the current requirement of N2 for foreshore locations. New construction and alterations would be designed to resist at least 50% higher wind pressures.

It seems reasonable that any proposal to change design standards and building regulation within the Building Code of Australia would take several years, and then more time before builders change their design of houses. A feasible time of adaptation is five years from 2013, hence t_{adapt}=2018.

If we modify Eqn. (3) for this decision problem then the NPV for a single house built to enhanced standards at time t_{adapt} is

$$NPV(T) = \sum_{t=t_{adapt}}^{T} \frac{\Delta R \times E_{WC}(t)}{(1+r)^{t-2018}} - \frac{C_{adapt}}{(1+r)^{t_{adapt}-2018}} \qquad (4)$$

where NPV is expressed as percentage of replacement value of the house, C_{adapt} is the cost of adaptation expressed as percentage of house replacement value, $E_{WC}(t)$ is the expected loss per house associated with current wind classification, ΔR is the reduction in risk associated with increasing the current wind classification by one category, and r is the discount rate (4%). Co-benefits are ΔB=0. Costs and benefits are normalised in terms of house replacement value at time of adaptation in 2018 where L=1.25 to include value of contents. Discounting applies from 2019.

Risk Reduction (ΔR)

The overall reduction in risk calculated as percentage change in risk E_{wc} caused by the adaptation strategy is ΔR=50-65% for houses in Sydney. An overall risk reduction of more than 50% seems possible assuming the vulnerability models shown in Figure 3 are accurate. While there is uncertainty with the vulnerability models, there is clear acknowledgement from King et al. (2012) that structural adaptation can provide 'significant' improvements in vulnerability. Hence, a lower bound on risk reduction may be conservatively taken as ΔR=50%.

Cost of Adaptation (C_{adapt})

If residential construction is subjected to a change of wind classification, then AGO (2007) estimated a C_{adapt} of no more than 1.1% of the value of the house. The adaptation costs from AGO (2007) are from one source only, so there is uncertainty that these costs are realistic.

Results

The vulnerability, loss and adaptation costs are subject to considerable uncertainty due to lack of available data and models. The models described herein are the best available models, but as described previously, have their limitations and uncertainties. For this reason, calculations of risks, costs and benefits will be imprecise - although they will be useful in illustrating the comparative costs and benefits of adaptation. Hence, a 'break-even' analysis is conducted herein where minimum risk reduction or maximum cost of adaptation necessary for adaptation to be cost-effective is selected such that there is 50% probability that benefits equal cost - i.e. mean(NPV)>0. Results are calculated using Monte-Carlo event-based simulation methods. Costs and benefits are calculated for the 52 year period 2018 to 2070 as 2070 is the limit of projections of wind hazard provided by CSIRO (2007).

Figure 5 shows the maximum (break-even) adaptation cost for the adaptation measure (per new house) to be cost-effective for risk reductions of 10-100% for Sydney, for foreshore and non-foreshore locations.

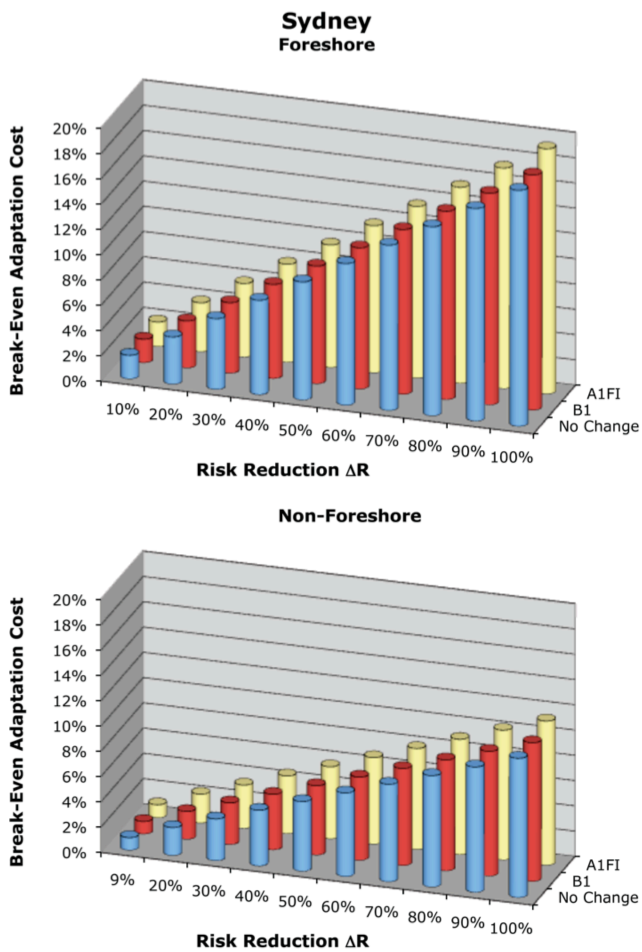

Figure 5. Break-Even Adaptation Costs, for Various Risk Reductions and Emission Scenarios, for Foreshore and Non-Foreshore Locations.

In this case, if risk reduction is over 50% and there is no change of climate, the break-even analysis shows that adaptation is cost-effective if the adaptation cost is less than 9.3% and 5.5% of house replacement cost for foreshore and non-foreshore locations, respectively. The effect of a changing climate will increase the break-even adaptation cost to 9.7% and 5.7% for foreshore and non-foreshore locations, for the A1FI emission scenario. These break-even values appear to be much higher than anticipates adaptation costs, and so the adaptation measure would be cost-effective.

We can look at this another way of course. The cost of adaptation is likely to be 1.1% for foreshore locations (N2 to N3), and less for non-foreshore locations (N1 to N2). If we adopt a cost of adaptation of 1.1% and 1.0% for these locations, and no change of climate then the break-even risk reduction must exceed 6% and 9% for foreshore and non-foreshore locations. Given that risk reductions of 50-65% can be achieved for Sydney based on the vulnerability models described herein, then it is likely that designing new housing to enhance wind classifications is a cost-effective adaptation strategy for Sydney.

The NPV per house is 4.5% for a non-foreshore location in Sydney assuming a medium (B1) emission scenario, modest risk reduction of 50% and cost of adaptation of 1.0%. Assuming house replacement cost of $270,00 in 2012 dollars, the NPV per house is approximately $12,100 to 2070. This increases to a NPV of 4.7% or $12,700 for the A1FI emission scenario. Residential dwelling in Sydney are expected to increase by approximately 25,000 new houses per year. Based on these projections, the NPV for new houses built in 2018 alone would be at least $300 million, and this NPV would rapidly accumulate year by year as additional new houses are built.

A 7% or 10% discount rate will still produce break-even adaptation costs for Sydney of 2.6-6.1% which are likely to be higher than actual adaptation costs. Discount rates of 1.35% and 2.65% used in the Australian 2008 Garnaut Review result in higher break-even values which increases the likelihood of adaptation being cost-effective.

Not surprisingly, the beak-even costs of adaptation are sensitive to wind hazard. However, if wind gusts decrease by 10% in Sydney then maximum costs of adaptation reduce to 2.8-4.7% for adaptation to be cost-effective, and actual costs are still likely to be lower then these break-even values.

Even if there is no climate change the adaptation strategy is still cost-effective. For example, applying the adaptation strategy to Sydney, and assuming a conservative adaptation cost of 1.0% for non-foreshore locations, the NPV is 4.5% for a modest risk reduction of 50% - or $300 million for new houses built in 2018 alone. Hence, even if climate projections are wrong, adaptation measures satisfies a 'no regrets' or win-win policy.

Conclusions

A 'break-even' economic assessment is developed to assess the conditions under which a climate adaptation strategy is cost-effective. Increasing the design wind classifications in the Australian Standard "Wind Loads for Houses" AS4055-2012 for all new housing can lead to risk reductions of at least 50% for Sydney, at a cost of no more than 1-2% of house replacement value. If risk reduction is over 50%, discount rate is 4%, and there is no change of climate, the break-even analysis shows that adaptation is cost-effective for Sydney if the adaptation cost is less than 9.3% and 5.5% of house replacement cost for foreshore and non-foreshore locations, respectively. Discount rates lower than 4%, such as those used in the 2008 Garnaut Review (1.35%, 2.65%), result in higher break-even values which increases the likelihood of adaptation being cost-effective. The economic assessment is very sensitive to probabilistic wind field model. For example, an increase of wind gust speeds of +10% can more than double damage risks. Deferring adaptation to 2025 reduces NPV by 25%. Earlier implementation of adaptation is preferred.

Acknowledgments

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