Chi Truong (Australia), Stefan Trück (Australia)

Evaluation of investment options mitigating catastrophic losses under the impacts of climate change

Abstract

It is of significant concern that climate change will exaggerate the frequency and severity of extreme events such as: floods, storms, droughts and bushfires. As the value of properties under risk increases due to economic growth, also the probability of catastrophic events may be amplified by climate change impacts. Thus, there is a need for local governments to invest in adaptation measures in order to reduce potential losses from these catastrophic events. However, economic models that help local governments to evaluate those investment projects are currently lacking. Two challenges are faced when evaluating these projects. First, it is difficult to quantify the risk due to the lack of observations on catastrophic events at the local level. Second, investment costs are often lumpy and the investment decisions are irreversible, so that the investment strategy based on the net present value (NPV) criterion is not optimal. Under the uncertain growth of the stock of assets and the uncertain impacts of climate change, the optimal timing of investments into adaptation strategies that reduce catastrophic risks is of major importance. This paper presents a simple economic framework to quantify climate change risks and a real option approach to illustrate the optimal timing of investment strategies for local governments.

Keywords: real option, catastrophes, climate change, adaptation.
JEL Classification: Q51, Q54.

Introduction

Concern over global warming consequences has intensified over the last two decades as severe natural disasters become more frequent. Higher frequency of disasters is believed to be a direct consequence of global warming. Global warming raises the energy level within the climate system and makes catastrophic events such as floods, storms, droughts and bushfires more likely to happen. While climate change mitigation can help to treat the problem at its root, mitigation initiatives may take a long time to show their impacts due to the inertia inherent in the global climate system. Even if substantial emission reduction is committed, the global temperature is going to increase before it stabilizes (IPCC, 2007). The risks, related to catastrophic events, are expected to increase regardless of mitigation efforts, making climate change adaptation essential.

Most of adaptation decisions to mitigate catastrophic losses require significant investment, the benefits of which scatter among various stakeholders and spread over a long time horizon. To help policy makers make sound investment decisions, a thorough analysis of the costs and benefits of different adaptation strategies is needed. This is not a simple task, requiring the assessment of all the impacts of the project and then attaching monetary values to these impacts. Impact assessment often requires multi-disciplinary approaches and impact monetization sometimes requires complex modeling when markets for some products of the project do not exist. A large number of studies have focused on analysing the cost and benefits of adaptation projects, if the project is to be invested immediately (Brouwer and van Ek, 2004; Suarez et al., 2005; Michael, 2007; Kirshen et al., 2008; Symes et al., 2009a). In these studies, after the present values of expected costs and expected benefits of the project have been found, they are aggregated to give an expected net present value (ENPV). As a general decision rule, the project is invested if the ENPV is positive and not, otherwise.

The ENPV criterion, however, ignores an important aspect of investment. By evaluating the project based on an immediate investment decision, the possibility that the project investment can be deferred to a future time is not considered. Such analysis ignores the optimal timing of investments and takes away the flexibility to defer the investment decision and reconsider it at another time. For an adaptation project, this flexibility is important for two reasons. First, because catastrophic risks increase over time and the value at risk may be expected to increase over time, by delaying the investment, the capital cost of investment in initial years, when the benefits of the project are low, can be avoided. Second, because significant uncertainty is inherent in climate change projections, deferring investment to future periods gives the investor an opportunity to revise the estimation of the project values based on new information on climate change. If the impacts of climate change are not significant, the project is not invested and the expensive investment cost is avoided. Otherwise, the project is invested and only the benefit of the project over the deferral period is lost. Therefore, the investment flexibility helps the investor to avoid the downside risk (to the value of the project) and benefit from the upside risk.

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In this paper, we provide a framework to compute the optimal timing of adaptation strategies, taking into account investment flexibility under deterministic assumptions about the growth of the value at risk and the impacts of climate change on the probability that catastrophic events occur. The paper is structured as follows. In Section 1, previous studies on climate change adaptation will be reviewed. In Section 2, the modeling framework is outlined and applied for the exemplary case of an adaptation measure to bushfire risk in Kuringai council, NSW, Australia. The last Section concludes the paper.

1. Literature review

Climate change adaptation involves a wide range of investment decisions. For example, infrastructure upgrade or replacement, land use planning as well as coastline and flood defense projects are highly researched topics (Hallegatte, 2009). In most adaptation studies, climate change impacts are carefully estimated, while investment choices are analysed, based on the simple ENPV criterion.

To provide a prediction of climate change, adaptation studies often assume a certain global emission scenario to generate a global emission rate. The emission rate is then used as an input to a general circulation model (GCM) to provide forecasts on the future global climate (Kirshen et al., 2008, Ermolieva and Sergienko, 2008, Jones et al., 2007). The climate projections generated by GCMs and the economic scenarios for the examined region are then combined to examine the optimal adaptation strategies. In some studies, instead of assuming an exogenous global emission rate, an integrated assessment model (IAM) is used to generate global emission rates (Kuik et al., 2006). Although, adaptation may alter the emission rate at the global level when many regions are considered, as pointed out by Kuik et al. (2006), no study so far has incorporated the feedback from adapation scenarios on emission rates. Once the global climate projections have been obtained, the correlation between the global weather and the local weather can be used to generate local climate projections.

Regarding investment analysis at the local level, most adaptation studies adopt a static framework, ignoring the flexibility of investment decisions (West et al., 2001; Brouwer and van Ek, 2004; Suarez et al., 2005; Kousky et al., 2006; Michael, 2007; Kirshen et al., 2008). The majority of these studies use insurance models to provide detailed modeling of catastrophic risk at the local level.

Suarez et al. (2005) evaluate the productivity loss in the Boston metrololitan area due to lack of transportation in flood events caused by climate change. An empirical flood insurance model is used together with a set of development assumptions regarding spatial patterns of population, economic activities and development patterns for the future years to estimate the flood cost in the case of no climate change. The impacts of climate change on the sea level and on the local weather are evaluated using a global climate model (GCM). The cost, imposed by climate change, is then the difference between the flood cost in the climate change scenario and the flood cost in the no climate change scenario. Suarez et al. (2005) found that the flood cost is significantly increased by climate change. However, no adaptation is considered in their study.

Kirshen et al. (2008) evaluate adaptation strategies to reduce the loss from increased storm surge flooding in metropolitan Boston. Sea levels are assumed to rise at a constant rate, which increases storm surge heights and results in more severe property damage. Examined adaptation strategies include no adaptation, property floodproofing, building coastal protection structures such as seawalls and retreating inland. They found that it is optimal to use expensive structural protection in areas that are highly developed and less structural approaches such as: floodproofing and limiting or removing development in less developed or environmental sensitive areas. Although it is claimed to be a unique study that considers various adaptation actions, these actions are evaluated separately. The strategies are considered using the ENPV criterion, ignoring the value of the option to delay the investment.

Symes et al. (2009b) examine land retreat strategies in South East Queensland to avoid losses from storm surges. Using an empirical insurance model and the assumption that the sea level will rise by 0.3m by 2050, they estimate the water level for the whole region when the highest storm surge occurs. The results are used to divide the region into high risk and low risk areas with high risk areas being the ones in which the highest water level is above 1 m.

Brouwer and van Ek (2004) investigate the increased risk due to the expected impact of climate change and the increasing economic value of the protected properties. They evaluate the benefits and costs of a floodplain restoration (i.e., widening and deepening floodplain) strategy to increase the resilience of water systems to reduce the risks and damages associated with flooding in the Netherlands. It is argued that floodplain restoration provides environmental benefits in terms of creating new wildlife habitats, recreational amenities in addition to reducing flooding risk. Brouwer and van Ek use a combination of modelling and expert judgement methods to evaluate the expected consequences of protection measures. Non-monetary benefits are monetised, using results from stated preference studies. They found that the ENPV of floodplain restoration is positive and the investment is desirable, but cautioned that the exact size and value of the predicted impacts of the strategy is highly uncertain.

In summary, static studies not taking into account the optimal timing of investments into adaptation strategies seem to dominate the literature. Using empirical insurance models, these studies can provide quite accurate forecasts for the near future. These studies, however, ignore the value of the option to delay the investment. For adaptation strategies that involve a long time horizon, ignoring the option value, may result in significant losses or suboptimal invesment decisions.

2. Modeling framework

In this Section, we will provide a framework for the analysis of climate change adaptation options with respect to risk from catastrophic events and finding the optimal adaptation strategy. In a first step we suggest an approach for quantifying potential losses from extreme events like storms, droughts or bushfires that might be further increased in frequency and severity due to climate change impacts. We recommend the use of the so-called loss distribution approach (LDA) that is quite popular in the financial industry for modeling insurance claims and losses, arising from operational risks in the banking industry (see Klugman et al., 1998; or Bank of International Settlement, 2001). The LDA involves the estimation of an adequate frequency and severity distribution for the considered extreme events. The aggregate loss distribution for the hazard is then computed by combining these two distributions such that expected annual loss and the loss at any arbitrary confidence level α can be computed. In the second step, using the calculated figures of the aggregate loss distribution for each year in combination with cost estimates for adaptation strategies it is then possible to apply the real option theory to compute the optimal strategy.

2.1. The loss distribution approach. The LDA is a statistical approach for generating an aggregate loss distribution. To compute the probability distribution of the aggregate loss over a one year time horizon, we need to estimate the probability distribution function of the single event loss and its frequency. For a natural or climate-impact related hazard, this means that we have to determine a probability distribution for the number of events per time period as well as a severity distribution for potential losses from the events. Then it is possible to compute the cumulative losses for each time period.

Generally, a stochastic process $(S_t, t \geq 0)$ is assumed describing the cumulative catastrophic losses faced over the time interval [0, *t*]. The process $(S_t, t \geq 0)$ is modeled by a compound Poisson process of the form:

$$S_t = \sum_{k=0}^{N_t} X_k, \quad X_k \overset{i.i.d.}{\sim} F, \tag{1}$$

where F denotes the distribution function for the severity of the losses, N_t denotes a homogenous Poisson process with intensity $\lambda > 0$, and N_t is assumed to be independent from X_k.

The compound Poisson process in equation (1) has parameters that do not change through time. In contrast, in considering potential losses under climate change scenarios, it is more realistic to assume that the frequency and severity distribution may change continuously through time. To apply the LDA to the climate change adaptation problem, we use T compound Poisson processes, each representing the aggregate loss occuring in one time period, where T is the lifetime of the project. Let λ_t and F_t be the parameters of the compound Poisson process in period t. A property of the compound process in equation (1) is that the expected aggregate loss, $E(S_t)$, is equal to the product of the expected number of events λ_t and the expected individual loss:

$$E(S_t) = E(N_t) \times E(X_t) = \lambda_t E(X_t). \tag{2}$$

2.2. Investment model. In this Section, we consider an adaptation project that reduces the probability of the property at risk being damaged when a catastrophic event occurs. As in many previous studies (West et al., 2001; Brouwer and van Ek, 2004; Suarez et al., 2005; Michael, 2007; Zhu et al., 2007; Kirshen et al., 2008), we assume that the investor is risk neutral. This assumption is reasonable for investment projects, funded by government, since catastrophic risks in different regions are independent and the government can pool these risks such that only the expected values are relevant (Kousky et al., 2006).

Suppose that the project reduces the probability of the property at risk being damaged when a catastrophic event occurs by a proportion *k*. With the project in place, the number of damaging events in period *t* follows a Poisson process with intensity $k\lambda_t$, and the expected benefit of the project in period *t* is $k\lambda_t E(X_t)$.

We assume that the investment decision can be deferred forever, but once the project is invested, a new project will be invested whenever the old one is fully depreciated. These are standard assumptions in real option studies (Dixit and Pindyck, 1994). Then, investment provides a cash flow of $k\lambda_t E(X_t)$ for each period from the time it is invested to the infinity and the investment cost is the present value of a flow of investment cost per project that occurs every T years. Specifically, the investment cost can be calculated as follows. Let I_T be the estimated investment cost for a project that lasts T years and A be the annuity of the investment cost, i.e:

$$A + \frac{A}{1+r} + ... + \frac{A}{(1+r)^T} = A\frac{1-\beta^{T+1}}{1-\beta} = I_T,$$

where $\beta = \frac{1}{1+r}$ is the discount factor. In other words:

$$A = I_T \frac{1-\beta}{1-\beta^{T+1}}.$$

Then, the investment cost over the infinite time horizon is:

$$I = A(1+r)/r. \quad (3)$$

The investment problem is then to find the investment time τ so that the ENPV of the investment is maximised:

$$\max_{\tau} \sum_{\tau=0}^{\infty} e^{-rt} k\lambda_t E(X_t) - I, \quad (4)$$

where I is calculated using in the equation (3).

2.3. Empirical results. *2.3.1. Baseline analysis.* The model is applied to the case of bushfire management in Ku-ring-gai Council Local area (in New South Wales, Australia), where residential properties are in close proximity to bushfire risk areas. Assume that as an adaptation strategy, the risk of house damage could be reduced by constructing a fire trail that breaks wild fire transition and allows more time for fire brigades to respond bushfires. To investigate the reduction of the risk for residential properties, expert opinions could be used to calibrate the parameters of the loss distributions before and after implementing this adaptation measure.

Under a changed climate with a tendency to have hotter temperatures, the frequency of bushfires is likely to increase. The estimation of the bushfire frequency distribution is based on the assumption that the stock of greenhouse gases will significantly increase over the next decades and continue this increasing trend until the year 2100, when it stabilises at a constant level. In order to quantify the frequency distribution, we apply an expert guess stating that for the considered Ku-ring-gai area it is expected that the frequency of bushfires will approximately double until 2050. Based on these forecasts, we further make the assumption that the intensity of bushfires, λ_t, is assumed to increase linearly until the time when the climate system stabilises, i.e., the year 2100. With the intensity in year 2010, estimated by the expert to be 0.02, the bushfire intensity is estimated to increase to a level of 0.04 by 2050. With a continuing linear increase of the intensity until 2100, we assume that the intensity reaches a level of 0.065 by 2100 and remains at that level for subsequent years (Table 1). We acknowledge that the choice of the frequency parameter for our case study is rather based on an expert estimate than a climate model, however, given the difficulties of such models with respect to downscaling predictions to the local scale, we consider our approach still as a feasible alternative.

Different from bushfire frequency, bushfire severity in future years depend on the physical strength of bushfires and the value of the risk-prone properties. Although the weather under a changed climate may make bushfires more fierce, the fuel load can be expected to be lower due to more frequent bushfires. Therefore, we assume that the physical strength of bushfires in the future will be same as the current level. In contrast, the value of the risk-prone properties depends on the number of additional houses in the region and the future costs of reconstructing houses after a fire occurs. The census data for Ku-ring-gai indicates that the number of houses in this area has reached a stable level and in future years, it is unlikely that new houses will be constructed (Hatzvi and Otto, 2008). The number of damaged houses, when a fire occurs, is therefore assumed to be constant in the future years and equal to 30 houses as estimated by the expert for year 2010. For the future costs of house reconstruction, we use the estimation by ABCB (2008) for the year 2010 construction cost and calculating the real growth rate of house construction by subtracting the inflation rate from the nominal growth rate of construction estimated cost using the price index of materials used in house building for NSW over the period of 1967-2009 (ABS, 2010). The construction cost is estimated to increase at a rate of 0.1% per year from the level of $320,000 per house in 2010. The discount rate is assumed to be the social discount rate since the considered project is invested by the public sector. It is assumed to be 1% (see Gollier (2008) for the discussion on social discount rate under climate change).

Table 1. Estimated values of parameters

Parameters	Value
Current damage risk, λ_{2010}	0.02
Damage risk in year 2100, λ_{2100}	0.065
Expected number of houses damaged per event	30
Current construction cost per house	$320,000
Real growth rate of construction cost	0.1%/year
Risk reduction proportion by project, k	20%
Lifetime of the project, T	50 years
Investment cost per project	$1.5 million
Project maintenance cost	$50,000
Real interest rate	1%

The model in equation (4) is solved using an Excel spreadsheet. The ENPVs of the project (dependent on the time when the investment is made) in the base case is depicted in Figure 1. As shown, the maximal value of the investment project is achieved if the project is invested in 58 years' time, even though investing immediately would give a positive ENPV. The difference between the ENPV when investment time is optimised and the current ENPV of the project is the value of investment flexibility. For the investigated base case, this value is nearly 50% of the true value of the project such that immediate investment, despite a positive ENPV would result in a suboptimal outcome in comparison to the potential economic benefit of the adaptation strategy under the optimal investment time.

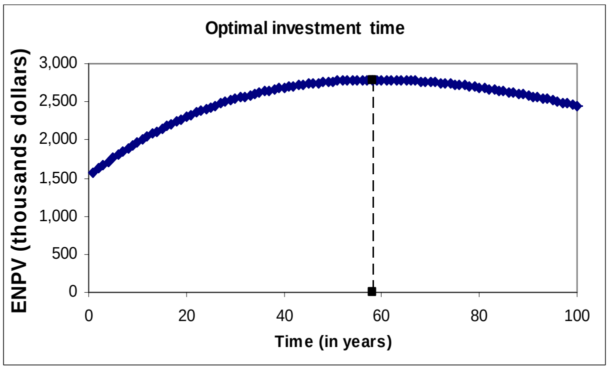
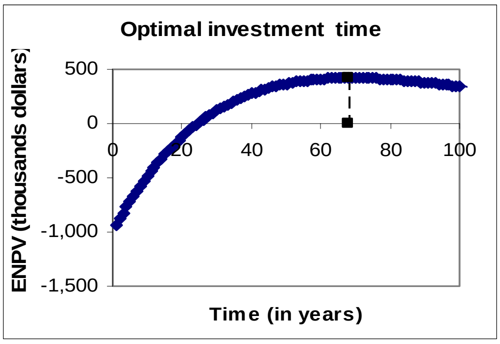


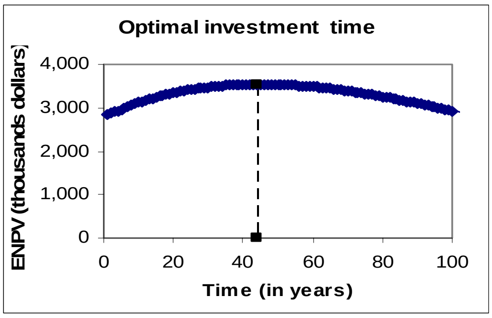
Fig. 1. Optimal investment time for baseline case

2.3.2. Sensitivity analysis. To examine the robustness of the empirical results, we carry out sensitivity analysis on the discount rate, the investment cost, the growth rate of the value at risk, and the growth rate of catastrophic risk.

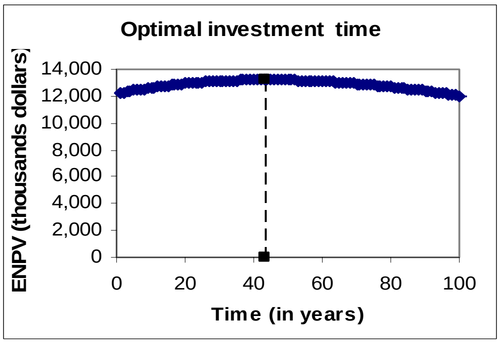
1. *Discount rates.* The debate on a choice between a social discount rate and a market discount rate is yet to be settled in the literature (Kuik et al., 2006). In the case of using a market discount rate, the discount rate will be significantly higher than in the base case scenario. Under a higher discount rate, the capital cost, avoided by deferring the investment, increases. As a result, the value of flexibility and waiting time increase as illustrated in Figure 2a. This result holds as long as the discount rate does not increase excessively and drive the current ENPV of the project below zero. When the current ENPV of the project becomes negative, the flexibility value is equal to the value of the project when investment time is optimised.
The results, when the discount rate is increased to 3%, are shown in Figure 2a. The ENPV of the project is negative if it is invested immediately, but positive if investment is deferred by 68 years. Using the ENPV criterion would turn down valuable projects. However, the value lost, due to the usage of the ENPV criterion, is lower when the discount rate is higher.
2. *Investment costs.* The impacts of the initial investment costs are similar to the impacts of the discount rate. As the investment costs decrease, also the capital cost avoided by investment delay decreases. Therefore, the benefit of delaying the investment decreases and the waiting time is shortened. As shown in Figure 2b, when the investment cost is reduced by one third, the waiting time is reduced from 58 years to 44 years. Note that, under the given scenario, when the investment cost is reduced to a sufficiently low level (e.g., $50,000), it is optimal to invest in the project immediately instead of postponing the investment to a later point in time.
3. *Growth rate of value at risk.* We examine the impacts of an increase in the growth rate of the value at risk – in our example the expected number of houses that will be damaged times the reconstruction cost per house – by increasing the growth rate of the construction cost from 0.1% to 1%. With a higher growth of the value at risk, the annual benefit of the project in a later period is higher. The cost of wating increases and the value of investment flexibility and the waiting time are decreased, as shown in Figure 2c.
4. *Growth rate of catastrophic risk.* Modeling results, when the growth rate of catastrophic risk is doubled, is presented in Figure 2d. Although the role of catastrophic risk and the role of construction cost are the same, the role of the growth rate of risk is different from that of construction cost. The former is assumed to stabilised in year 2100, while the latter is not. However, the impacts of a higher growth rate of risk estimated by the model are the same as that of the growth rate of the value at risk. With a higher growth rate of risk, the investment flexibility value and the waiting time are reduced.



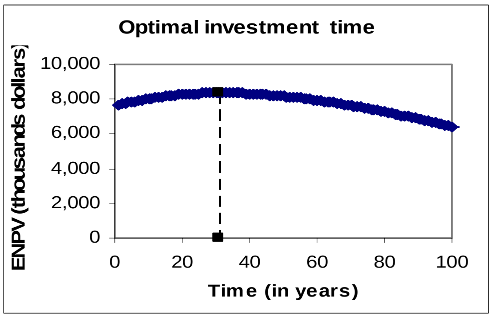
a. Impacts of a higher discount rate



b. Impacts of a lower investment cost



c. Impacts of a higher growth in VaR



d. Impacts of a higher growth in risk

Fig. 2. Sensitivity analysis results

Conclusion

In this paper, we have outlined a framework to quantify the risk of catastrophic events and to evaluate optimal adaptation strategy incorporating the value of investment flexibility. The application of the framework has been demonstrated for the case of bushfire management in the Ku-ring-gai area, NSW, Australia. For a stylized example, we have illustrated that immediate investment into an adaptation measure to climate change might provide a positive economic value, but deferring the investment to a later point in time can provide even a greater economic benefit. A large number of previous studies have focused on evaluating whether an adaptation project creates positive values to the society, ignoring the value of flexibility in investing. The results in this paper demonstrate that in evaluating adaptation projects, it is important not only to cover all the impacts of adaptation projects, but also to consider the choices an investor has in terms of optimal timing of the adaptation strategy.

A limitation of the framework outlined in this paper is that no uncertainty has been considered. In reality, the uncertainty relating to the estimation of costs and benefits of adaptation projects is vast. Therefore, deferring the investment will enable the investor to gain more accurate climate change impact assessments. The value of information will enhance the value of investment flexibility and it is even more important to incorporate the value of investment flexibility in the cost benefit analysis. The extension of the framework to allow for uncertainty about the growth of value at risk and the impacts of climate change on catastrophic risks is left for future research.

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