Notes on applying 'real options' to climate change adaptation measures, with examples from Vietnam

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NOTES ON APPLYING 'REAL OPTIONS' TO CLIMATE CHANGE ADAPTATION MEASURES, WITH EXAMPLES FROM VIETNAM

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Abstract

A factor common to all adaptation measures is the uncertainty that is the hallmark of climate change. The timing, intensity and location of climate change impacts is not known to any degree of precision. Because most deterministic analyses and policy prescriptions ignore this uncertainty, their recommendations are likely to waste community resources. Except by chance, adaptation measures will either be over-engineered, or they will be inadequate and result in harm. Applying real options thinking allows an incremental and flexible approach. Adaptation measures are implemented only as better knowledge becomes available over time. Several examples are given of real options in the Mekong Delta, with a comparison of net present values of two housing alternatives. It is essential to undertake net present value calculations when comparing different projects to ensure that the value of any options is weighed against other costs and benefits.

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It is generally recognised that adaptation[1] to climate change is likely to take many forms. Cultural, geographic and climatic differences between countries and regions will ensure that both the type of adaptation and its method of implementation will differ to some degree in each locality.

However, the factor common to all adaptation measures is the uncertainty that is the hallmark of climate change. In particular, it is not clear at this stage how much change will occur, its precise nature, or the timing of any specific change. Climate models reflect this lack of knowledge because simulations can yield very divergent, even contradictory results.

Despite the uncertainty, and local differences, many technical analyses recommend specific, deterministic action in response to expected climate change. However, they do not generally shed any useful light on the ideal timing or strength of a proposed response. It is this lack of a trigger mechanism or decision criterion that nullifies the utility of many such deterministic analyses.

For example, building sea walls or dikes today because of expected intensification of storm surges at some unknown date in the future may commit resources sooner than required. Where the resources could have been used for other socially beneficial purposes such as education or the health sector, an opportunity cost will be incurred by the community. Similarly, leaving adaptation measures too late can also incur costs due to pain and damage inflicted on people and property.

Policy approaches to climate change therefore need to be formulated in a way that minimises the use of scarce resources in order to maximise the welfare of society. Even though adaptation to climate change may well become a high social priority in future, governments will also continue to be faced with many other competing priorities such as education, health or defence. The whole gamut of social priorities needs to be considered on the basis of a coherent and common decision-making criterion. Social cost-benefit analysis provides a ready-made and rigorous means of doing so.

Importantly, social cost-benefit analysis readily incorporates uncertainty, especially through the 'real options' approach. The approach is analogous to investment decisions that are routinely made in the face of uncertainty about expected future flows of financial returns.

During a field visits to Vietnam and China in the first half of 2010 as part of a World Bank project, it became clear from discussions with government officials, researchers, and aid agencies that the focus of thinking is still largely deterministic. In Vietnam, for example, the construction of sea walls in central coastal provinces, and dikes in the Mekong Delta, appear to attract the most interest. But the 'real options' framework appears not to have been explored to any noticeable degree in either country, despite the fact that it could potentially generate positive fiscal outcomes.

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[1] Adaptation refers to deliberate efforts to obviate or ameliorate the bio-physical effects of a changing climate. For example, the installation of air conditioners to deal with a hotter climate. Adaptation does not refer to structural adjustment to mitigation measures such as carbon taxes. That is, adaptation does not refer to lower consumption of fossil fuels due to higher petrol prices instituted by governments. The term 'mitigation' is generally used to mean reductions in the emission of greenhouse gases from anthropogenic sources such as power stations or agricultural production. Its primary aim is to mitigate or reduce the contribution of anthropogenic greenhouse emissions to their total atmospheric concentrations.

This note builds on Dobes (2008) and Dobes (2010) which propose that the 'real options' approach is ideally suited to addressing the climatic uncertainty associated with adaptation measures. A more detailed study of potential real options for adaptation to climate change in both developed and developing countries would be highly worthwhile in generating new lines of thought. This paper is intended only to indicate a way forward.

1. THE 'REAL OPTIONS' APPROACH

A financial option provides an investor with a right (but no obligation) to purchase a financial asset such as a share in the future for an agreed exercise price. The investor can decide whether or not to buy the share itself at any time before (American call option) or on (European call option) the date specified in the option contract.

If the market price of the share rises above the exercise price specified in the option contract, then the investor can buy it at the contracted price. Because its price in the market is greater, it can be resold immediately at a profit. If the market value of the share has fallen below the option contract price, then the investor will probably avoid exercising his or her right to purchase the share at the contracted price because it can be bought more cheaply on the open market. Where the share price has fallen, the investor loses only the value of the financial option that he or she purchased. A rough analogy is that of a lottery ticket: if the ticket wins, it can be cashed in, but if it does not win it will likely be discarded, and its cost forgone.

In the realm of 'real' (i.e. physical, rather than financial) capital, it is often possible to identify or create options when investing. An everyday example given in Dobes (2008, p. 62) is that of a couple buying a house, but uncertain about their future needs:

> 'Buying a large house immediately could be unnecessarily costly if they remain childless, or if they delay starting a family for a significant time. But they could buy a smaller, cheaper house on a suitable block of land and extend it later, as required. The smaller house in effect 'embeds' an option to extend, but there is no obligation to do so if the family remains small. The couple can thus delay a final decision on the size (and hence the full cost) of the house until better information becomes available regarding specific family size.'

Dobes (2008, 2009) provides a number of other examples relevant to adaptation to future climate change. These include the following:

'Fitted for but not with'

Designers of military equipment often use a concept analogous to real options. Weapons platforms such as ships or aircraft, for example, may be 'fitted for but not with' the capability of being equipped in the future with missiles. Immediate fitting of a specific missile (that is immediate exercise of the option) may not be warranted because of the significant uncertainty about the type of missile that might be required in the future. Because the type of conflict, the specific combatants, and the missile countermeasures available to a potential future enemy are unknown, it is preferable to wait until more information becomes available before exercising the option of installing a particular missile system. Trains and buses can similarly be 'fitted for but not with' stronger air conditioning units by designing space for future installation.

Airport runways

If the climate becomes significantly hotter, planes will need a longer take-off to develop sufficient lift. (More powerful engines are an alternative, but they would also create more noise.) An airport owner considering the future might decide to build a longer runway now. But immediate construction would mean that the full cost would be incurred up-front and temperatures might ultimately not rise as fast or as high as expected on the basis of current knowledge.

In the face of uncertainty about the future, a better alternative for the airport owner might be to purchase or earmark additional land for a runway extension but to wait until temperatures increased significantly before undertaking its construction. An even better alternative would be to purchase a (financial) option to buy the land if temperatures rise by a specific date in the future.

Flooding in low-lying areas

Riparian flooding and coastal inundation due to rising sea levels are commonly cited effects of climate change. The popular prescription is to build sea walls or levee banks to protect nearby life and property. However, such advice is rarely if ever accompanied by advice on exactly how high a wall or levee bank should be, or when it should be built. In the absence of information on likelihood of occurrence, this is understandable, but the policy risk is that advice will default to planning for a worst-case scenario. But a worst-case scenario can be unnecessarily wasteful of community resources, and even worst-case scenarios change over time as more information about climate change becomes available.

In the absence of reliable information about future river or sea levels, a better alternative would be to build a solid base that is capable of supporting a high (worst-case or higher) wall, but only build a wall high enough to offer protection for current circumstances, or perhaps no wall at all. The wall can be raised later if the foundation is appropriately designed, or the base can just be used for sandbagging for the occasional flood or king tide. Inflatable flexible PVC tubes (the so-called Beaver flood barrier, *Engineers Australia*, February 2009, p. 69) that are filled with water and can be stacked on top of each other to provide a further option that is faster and easier to erect than sandbag barriers.

In other words, the option created by building only a base or low wall means that the full cost of a higher, worst-case wall is not incurred until it is actually required due to chronic or intensified flooding.

The floods in February 2009 that isolated Cairns from other coastal towns despite the recently upgraded Bruce Highway, saw calls for an even higher, ‘flood-proof’ highway, or an alternative inland route (e.g. editorial *The Cairns Post*, 11 February 2009, p. 12). A cheaper alternative that could have been used to alleviate the shortages of meat, milk and vegetables that were experienced by Cairns residents would have been to bring in more supplies by sea. However, a shortage of refrigerated containers along the coast apparently precluded this solution, and Brisbane-centric supply chains used by major retailers appear to have precluded use of local produce (*The Cairns Post*, 10 February 2009, p. 4). Nevertheless, it is clear that there are at least two real options (flexible local food purchasing arrangements and warehousing of 'spare' refrigerated sea-going containers) available as alternatives to immediate flood-proofing of the coastal highway.

Long-lived infrastructure

The real options approach is particularly relevant to long-lived infrastructure such as roads or railways. A decision to build may need to be taken today, but the infrastructure will last well beyond the often spuriously accurate time horizon of current predictions of climate change. We do not know, for example, how high the road should be above the surrounding land because we cannot forecast accurately the extent of any flooding along each section of the road.

A real option could be to set aside additional land adjoining a road or railway route to form a wider corridor. If required in future, the additional space can be used to build protective levee banks to protect the road or railway from flooding. Or gabions can be placed next to the road or railway to minimise damage from wave action, a solution that would be familiar in Queensland. And the costs of acquiring additional corridor space can be partly offset by leasing it to pipeline or telecommunications infrastructure providers.

Bushfires

At least some of the tragic loss of life and property might have been avoided through options such as better education of residents, installation of fire shelters near houses (ditches and bunkers covered with logs and earth were used in the nineteenth century but concrete pipes and brick rooms were used successfully in February 2009), or more frequent backburning of forest litter. All of these offer 'real option' alternatives to expensive construction of purpose-designed fire-proof (if such a things exists) houses now being proposed by some. Note the similarity of the bunker concept to the use of the concrete water tank as a cyclone shelter in the Mekong Delta in Figure 6 below.

Agriculture

Australian farmers have more than two centuries of experience with adaptation to extreme climatic conditions, and regularly employ the real options approach in their management of farm production. A farmer who has prepared land for a cotton crop, for example, is likely to keep in reserve the option of planting sorghum in a dry year.

The recent introduction of the South African Meat Merino (ABC, 2006) offers the option of producing meat or wool from the same animal, depending on weather and market conditions. And research into drought-tolerant grains continues to provide hope of adaptation through genetic engineering of crops.

Equally significantly, Australia's legendary cattle king, Sir Sidney Kidman, created real options for his herds by acquiring a string of contiguous properties north to south and east to west across the continent. Dry conditions on any one particular property could be overcome by moving cattle to other properties that had sufficient feed and water. With strategically located fattening properties, as well as holding properties near railheads to capital cities, he could maximise prices received for his cattle on the basis of intelligence obtained from a network of bushmen and indigenous contacts who telegraphed information about the movement of competing herds being driven to markets (Bowen, J. 2007, pp. 76-66). It is noteworthy that this large-scale adaptation to climatic conditions required no government involvement.

Other examples

The intuitively appealing strategic flexibility inherent in real options makes them an attractive proposition to many businesses. Management theorists often refer to them as 'strategic options'. Cuypers and Martin (2007) and Nerkar et al (2007) give joint ventures and business method patents as examples. A patent, for example, confers a right but not an obligation to profit from an invention or innovative business method in the future when it becomes clear that the time is propitious to exercise the option. Real options are not limited in application to adaptation measures: Lambie (2010), for example, applies the approach to an emissions trading scheme.

2 REAL OPTIONS AND COST-BENEFIT ANALYSIS

Dixit & Pindyck (1994, pp. 3-4) list a number of common characteristics that most investment decisions share, including:

- the investment is partially or completely irreversible. That is, at least part of the initial cost is 'sunk' because it cannot be recovered even if the rest of the investment process does not proceed. If all costs were recoverable, there would be no value in delaying the full implementation of the investment.
- there is uncertainty over the future rewards or payoffs from the investment.
- there exists the ability or opportunity to delay the timing of the investment, at least partially.
- more information about potential rewards or payoffs (but never complete certainty) becomes available during any procrastination.

Dixit and Pindyck (1994) show that it is possible to include the value of real options in a cost-benefit context to take account of uncertainty about the future values of costs and/or benefits. Often, projects may appear to be unviable (NPV < 0) using a conventional, but dated approach to cost-benefit analysis where it is assumed that full investment resources must be committed immediately, or not at all. However, a partial investment that creates the option (but not an obligation) of a fuller investment commitment later, when more information becomes available, may well yield a positive net present value.

Dixit and Pindyck (1994, pp. 15-16) give the example of American firms in mid-1993 not hiring permanent workers in the face of uncertain economic conditions. At the same time, the firms in question 'were willing to pay wage premiums for overtime work and to use agencies that supplied temporary workers and charged fees of 25 percent or more of the wage'. The option to expand output when conditions improved was maintained, but without committing fully and immediately to the cost of hiring a larger permanent workforce.

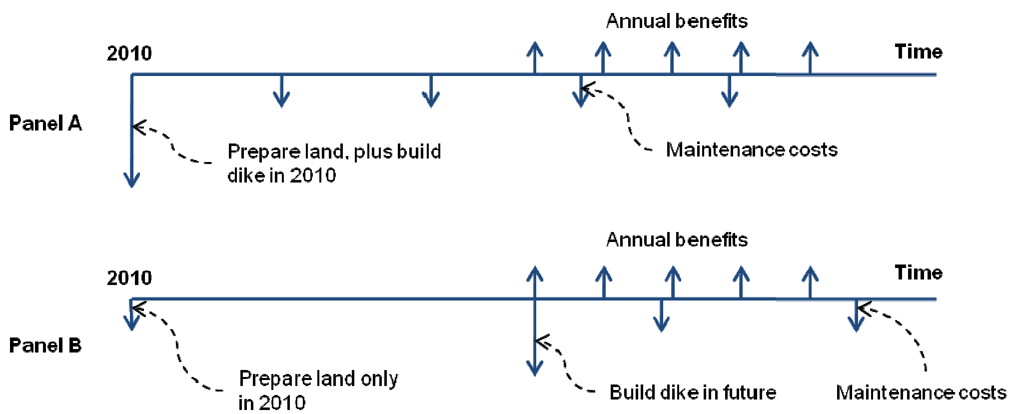
Adam (1996) discusses the 'embedding' of options in projects, while Wang and de Neufville (2005) distinguish between options 'in' and 'on' projects. An example of an option embedded within a project is evident from a report by Gesner & Jardim (1998) about the construction of a bridge over the Tagus River at Lisbon where the original bridge was built to be strong enough to carry a second level, if required in the future. The 'Portuguese government exercised the option in the mid-1990s, building a second deck for a suburban railroad line' (p. 5) above the road deck.

3 THE FISCAL IMPLICATIONS OF REAL OPTIONS FOR GOVERNMENTS

The flexibility of real options is particularly advantageous for budget-constrained governments. Expenditure on climate-relevant projects can be spread out, to be made when required over time. This aspect makes 'real options' analogous to a 'just-in-time' technology. Because budgets can be spread out more efficiently over time, a greater number and a greater range of climate-relevant projects and other government functions can be funded over time. The benefits for fiscal policy are obvious.

Panels A and B of Figure 1 below provide an illustration of a 'real options' approach to constructing a dike or a sea wall intended to prevent future inundation resulting from more intense, or more frequent, riparian floods or storm surges and sea rise due to climate change.

Figure 1 Two different approaches to building a dike or a sea wall to respond to flooding risk



It is, of course, possible to build a dike or a sea wall immediately (along the lines of the popular 'precautionary principle') perhaps to a height that will provide protection against a devastating 1 in 100,000 year flood. Panel A illustrates this case. The full cost of construction is incurred immediately, with regular maintenance costs thereafter, but the benefits are realised only at some uncertain time in the future.

The alternative shown in panel B is to expend only a relatively small amount today on surveying or preparing the land[2] on which a future dike could be built. This amount – smaller than the full cost of a dike – is analogous to the price paid to acquire a financial option,

[2] In market economies, it might also be necessary for a government to purchase (or compulsorily acquire with appropriate compensation) the land to provide greater certainty of being able to build the dike when it may be required. An even cheaper alternative would be to only purchase options from landowners to acquire their land in the future.

because it establishes the opportunity, but not an obligation, to invest in the full asset when required.

It would be incumbent on the decision-maker in panel B to continually monitor, and regularly re-evaluate the estimates of costs and benefits arising from climate change impacts after 2010. A full investment in a dike can be made when the present value of the benefits of countering the effects of climate change exceed the present value of the future costs[3]. The net present value of the panel B approach is higher than that in panel A, irrespective of the discount rate used.

The 'real options' framework is particularly attractive analytically because it can be readily incorporated into a social cost-benefit framework (Dixit & Pindyck 1994). However, even the 'real options' alternative project shown in panel B needs to meet the conventional cost-benefit test of a positive net present value if the welfare of society is to be increased. In a budget-constrained situation, priority should be given to projects with greater net present values, irrespective of whether they are 'adaptation' projects, or some alternative such as national defence, or spending on health or education.

A key question raised by panels A and B is how a cost-benefit analysis is to be performed in practice. Uncertainty about climate change precludes specification of actual dates when benefits from a dike or a sea wall will begin to flow. Provided that we are prepared to approximate the future by a suite of climate models and/or projections, the application of Monte Carlo analysis to the results of climate modelling can provide some guidance to the analyst: see sections 7 and 8 below.

The key feature of the 'real options' approach illustrated in panel B is its incorporation of flexibility. As time goes by, it may be found that climate change is occurring less quickly than originally anticipated, perhaps due to reduced global emissions. Unlike the situation in panel A, where the dike has already been built at the outset, the option remains in panel B to delay construction further, based on new information. It is also possible to abandon the dike construction project entirely in the future if little discernible climatic change occurs. Conversely, if climate change occurs faster than expected, it may become cost-beneficial at some time in the future to commence construction sooner than originally expected.

By waiting until better information becomes available, a dike can be built, and extended, to a height that more closely matches the actual impacts of the climate at any particular point in the future.

4 FLOOD-PRONE HOUSING IN VIETNAM: AN EXAMPLE OF REAL OPTIONS

Houses on wooden stilts are a traditional form of construction in the Mekong Delta. Figure 2 shows Mekong Delta houses in An Giang Province built on concrete and wooden stilts to avoid damage from seasonal floods.

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[3] For simplicity, the cost of monitoring climate change, and periodically re-evaluating the cost and benefits of construction from 2010, is not shown in panel B.

Figure 2: Traditional design stilt houses in the Mekong Delta.

concrete stilts (Mekong Delta)

Source: Nguyen Van Kien

wooden stilts(Mekong Delta)

Source: Leo Dobes

The traditional stilt construction has provided a tried and true means of accommodation by farmers to seasonal flooding. However, the fixed nature of the construction means that adaptation to any increase in flood height that may result from future climate change is likely to be difficult and expensive. Platforms can be built inside such structures to allow continued habitation during higher-than-expected floods, but the scope for doing so is obviously limited by the nature of the structure.

Similar problems exist in towns where houses are built at ground level in areas that have not previously been significantly affected by flooding. Residents of Can Tho city (the capital of Can Tho Province) in the Mekong Delta are reported by Birkmann et al (2010, p. 198) to have experienced intensified flooding over the last decade or so, both in magnitude and frequency. Over 70 per cent of respondents to a survey stated that their houses or the floors had been raised at least once in the last 50 years. Elevation of the floor is the most common technique and is accomplished through use of infill, including clay, sand, gravel, concrete and tiles.

The traditional approach to accommodating regular flooding is sometimes replicated in more modern structures. For example, the concept has been applied in coastal areas of Indonesia on the basis of a new housing design introduced by the Indonesian Ministry of Marine Affairs and Fisheries (Asian Development Bank, 2009, p. 113). Shown in Figure 3, the design is reportedly intended to meet future threats of inundation by raising houses 160cm above the ground.

While it would represent a sensible solution to a known and quantifiable threat, the Indonesian solution also lacks flexibility to respond to emerging risks that may not have been foreseen at the time of implementation. The house is evidently solidly built, but it would be difficult to raise its floor height, or to move it elsewhere, if required. In this sense, it is similar to the Vietnamese houses that have concrete or wooden stilts (Figure 2), but would almost certainly be more expensive to construct or relocate.

Figure 3: New housing design in coastal areas in Indonesia

Source: Asian Development Bank (2009), Figure 6.7, p. 113.

However, it is possible to embed the flexibility of real options into traditional designs. An example is shown in Figure 4 of prefabricated houses with steel frames that are manufactured in Vietnam by Bluescope Buildings. The construction can be completed in one day, essentially relying on the use of a spanner to tighten the nuts and bolts that fasten steel beams and joists to each other.

Discussion with Mr Tran Hong Quan, National Sales Manager, Bluescope Buildings in Hanoi in July 2010 revealed the existence of at least three embedded options. The most important option in terms of potential increases in flood heights in a future climate-affected world is the possibility of easily raising the floor level without rebuilding the house. A second option is available in the cladding. Traditional bamboo or wood cladding can be used, but could be upgraded later to tin or concrete or some other material. Should future flood levels or riverine salinity prove to be excessive, it would be relatively easy to dismantle the house, transport it to a new location using a boat or even the ubiquitous motorcycle, and reassemble it.

The dwellings in figures 2, 4 and 5 are not identical in terms of their accommodation characteristics. The two examples shown in Figure 2 are larger than the two Bluescope[4] Buildings examples shown in Figure 4, or the Red Cross version shown in Figure 5. Both the steel-framed Bluescope Buildings and wooden-framed Red Cross houses are intended to replace the low-income type of dwelling shown in Figure 5, so they are more comparable.

[4] The terms "Bluescope" and "Red Cross" are used here for convenience. In fact, "Bluescope" houses have also been supplied to the Red Cross and Red Crescent Societies in Vietnam to relocate and house low income families subject to flooding.

Figure 4: 'Real options' in Vietnamese housing: a "Bluescope" house

Bluescope steel frame, wood cladding

Source: BlueScope Buildings (Vietnam)

Bluescope steel frame house in Mekong flood area

Source: North Sullivan (Sydney)

Figure 5: Mekong Delta: house provided by Red Cross and low income rural dwelling

"Red Cross" house

Source: Nguyen Van Kien

low income rural dwelling

Source: Bluescope Buildings (Vietnam) Ltd

5 LAND EASEMENTS AS A REAL OPTION FOR FUTURE EXTENSIONS OF DIKES

The potential of applying a real options approach in rural Vietnam is not limited to the housing sector.

For example, a real option implemented in a commune that was visited in Cho Moi district of An Giang Province in July 2010 relates to the expected future raising of the height of a dike. The commune authorities have decreed that electricity power lines must be located away from the existing dike, and have banned the planting of eucalypts and melaleuca (so-called 'permanent' trees) next to the existing dike.

These measures will ensure quick exercise of the option of raising the height of the dike, once a decision has been taken on the timing of implementation. But because farmers incur an opportunity cost in terms of loss of benefit from harvesting of wood, as well as the cost of relocating power lines, they effectively pay a premium for the option of raising the height of the dike in the future.

On the other hand, the same commune has made provision to place only a limited number of sluice gates (to allow irrigation from a nearby canal) in the raised dike, based on existing farmer land allocations. There is therefore no embedded flexibility to readily change future irrigation patterns if land use within the dike area changes.

6 WATER TANKS AS A REAL OPTION ON A PERMANENT CYCLONE SHELTER

The effect of natural hazards can often be ameliorated through the establishment of suitable shelters. Examples include underground tornado shelters on farms in the American mid-West, and below ground bushfire bunker shelters used in Australia.

Conceptually, relatively cheap shelters can be considered as expansion options. They are useful for protection from infrequent hazard events. However, if hazards should become more frequent, or last longer due to climate change, then the construction of more permanent shelters, perhaps at a communal level, might become justifiable on a cost-benefit basis. Alternatively, interim shelters may be considered as put options that facilitate personal survival in highly adverse circumstances. The (presumably high) benefit of personal survival is obtained in return for the premium of the cost of construction.

An interesting example of a hazard amelioration option is shown in Figure 6. The concrete tank at the corner of the house is normally used to collect fresh rainwater throughout the year. In the event of a (wet season) cyclone, however, it can be pushed over onto its side and used by the inhabitants of the house as an emergency shelter. The net present value of the concrete tank is therefore greater than that obtained from its manufacture and use for collecting water alone. Should the frequency or intensity of cyclones increase, or the number of inhabitants of the house increase, an expansion option might be to obtain a second tank, or to build a more permanent communal shelter.

Figure 6: Water tank as an optional cyclone shelter

This rural house in Ben Tre Province uses a concrete tank to collect fresh rainwater. The tank doubles as a cyclone shelter during the wet season because it is the only structure solid enough to provide sufficient protection against hard objects carried by the wind: *pers. comm.* October 2010, Nguyen Van Kien

Photo: Nguyen Van Kien

7 COMPARING ALTERNATIVES: THE MEKONG DELTA HOUSES AGAIN

Despite its intuitive appeal, the real options approach may not always be justified as a solution to alternative investment strategies. In the example of the dike in Figure 1, the bulk of the expenditure was deferred in panel B, so that it follows that the Net Present Value is greater. In the case of two different assets, however, the value of an embedded option may not always outweigh costs associated with an alternative asset. An instructive example is the comparison between the construction costs of the various houses presented in section 4 above.

While acknowledging the difference in housing quality and characteristics of the different house types, a comparison is presented in terms of their estimated construction costs in Table 1. The Bluescope house is significantly more expensive than the traditional house on wooden stilts in Figure 2 and the Red Cross house in Figure 5. Comparison with the house on concrete stilts is difficult because of the range of prices shown, but the Bluescope house would probably be more expensive, for a given size.

Given the differences in characteristics of the various houses, direct price comparisons are obviously difficult. In particular, it would be difficult to adjust for the larger size of the houses in Figure 3 to enable quality-adjusted comparisons. However, it is at least arguable that the Bluescope house in Figure 4 and the Red Cross house in Figure 5 are reasonably comparable except for the wall cladding, and the price difference between them is in the order of $US600-700. Because the wood-frame Red Cross house is built on rock stilts rather than wooden ones, it is assumed here that its life is at least equivalent to the steel-frame Bluescope house.

Assuming that a direct comparison between the Red Cross and Bluescope houses is reasonably valid, it can be hypothesised that the difference in price is attributable to the flexibility offered by the three embedded options that are available in the steel-framed house. On the basis of this hypothesis, it is possible to apply basic net present value analysis.

Table 1: comparison of estimated house construction costs in the Mekong Delta

house	VND	$US	source*
wooden stilts	20 million	1,025	Figure 3
concrete stilts	30-40 million	1,540 to 2,050	Figure 3
Bluescope Building, steel frame	33 million	1,700	Figure 4
Red Cross, tin cladding	22 million	1,130	Figure 5

**Sources*:

- Price of Bluescope Buildings house ex factory gate: *pers. comm*., 8 October 2010, Trinh Anh Duc, Regional Sales Manager, Bluescope Buildings Vietnam Ltd, Ho Chi Minh City. Quoted in $US, excluding Value Added Tax.
- Prices of other houses in Vietnamese Dong (VND): *pers. comm*., 13 September 2010, Nguyen Van Kien, Faculty of Agriculture and Natural Resources, An Giang University, and the Australian National University.

Notes:

- The Bluescope Buildings house in Figure 4 includes steel frame, purlins and girts, Zincalume roofing sheets, ridge capping and gutters. It excludes walling, foundations, floor decking, and installation.
- Currency conversion $US 1 = VND 19,500 as at 13 October 2010.

In general, the net present value (NPV) of constructing a house that takes into account the need to protect its inhabitants against flooding will have the following form:

$$NPV = PV(benefits_t – costs_t) + OV - I_0$$

where:

- PV is the present value, calculated a some specified discount rate, of future benefits and costs
- $benefits_t$ are primarily those that arise in each year due to avoidance of flooding inside the house. Ideally, benefits would be estimated using willingness to pay rather than flood damage costs avoided.
- $costs_t$ can include a range of private costs, but principally maintenance. Unless significant externalities are associated with the house, the private costs will approximate social costs. A fuller analysis might include the cost of raising a house built on fixed stilts if flood levels rise due to climate change. For the Bluescope house, there will also be costs associated with monitoring flood levels and exercising options such as raising the floor level or relocating the house.
- I_0 is the cost of constructing the house at time t = 0
- OV is the option value embedded in the house with respect to flooding

In the case of the Red Cross (R) house, the capital cost I_{0R} = $US1,130. The Option Value (OV_R) is assumed to be zero, implying that there is no flexibility in responding to significantly higher flooding, and therefore no future cost due to raising the house by replacing existing stilts with higher ones[5]. There is nothing to be gained in delaying a decision whether to build the Red Cross house immediately, because it will be built to a predetermined, fixed floor height. By implication, if future climate-induced flooding is greater than expected, a replacement house will need to be built on higher stilts.

So $NPV_R = PV(benefits_t – costs_t)_R + 0 - \$1130$

The floor height of the more flexible Bluescope house, by contrast, can be adjusted in future to cope with higher-than-expected flood levels. Is construction cost I_{0B} = $US1700, and the Option Value (OV_B) will probably be some positive amount.

Thus $NPV_B = PV(benefits_t – costs_t)_B + OV_B - \$1700$

Assuming that the Red Cross and Bluescope houses are the only alternatives available, and the price difference between them reflects only the degree of flexibility in adjusting the floor level, the option value OV_B can be estimated by comparing NPV_R and NPV_B under identical

[5] In reality, of course, there may be some degree of flexibility or reversibility of investment that would generate an option value. For example, some traditional houses may be light enough to be lifted manually while higher stilts are inserted underneath, or they may be dismantled relatively easily, with most of the material available for relocation to another site. Where this is the case, the option value OV_R would be greater than zero.

conditions of uncertainty. Dixit & Pindyck (1994, chapter 2) illustrate the approach[6] using several straightforward examples.

Estimates of the future cost and benefits of avoiding flooding due to climate change are not readily available for the two housing types, although a putative methodology is presented in section 8 below. It is therefore not possible to estimate the option value of the Bluescope house directly.

Nevertheless, it may still be possible to say something about choices between the two houses. If benefits are estimated on the basis of willingness to pay to avoid climate-induced flooding – as they ideally should be – rather than on the more restricted but commonly used basis of damage costs avoided, then the benefits of avoiding flooding will be approximately identical for the inhabitants of both houses. If we also assume that future costs are primarily due to regular maintenance of the two houses, and that they are not too dissimilar, the costs involved will also be similar for the two houses.

That is, $PV(benefits_t - costs_t)_R = PV(benefits_t - costs_t)_B$

So that $NPV_B - NPV_R = -\$1700 + \$1130 + OV_B = OV_B - \$570$

Because we do not have data about future benefits, we cannot estimate the option value of the Bluescope house, OV_B. However, it is likely to be larger the longer the time period under consideration and the greater the uncertainty about the likely future impact of climate change on flood levels.

Moreover, there are two possibilities in terms of the construction of the Red Cross house:

1) The Red Cross house may have been built on stilts that include an especially large safety margin (freeboard) against potential future flood heights. For example, it may have been built with a freeboard of 5 metres greater than the most severe historical flood. If this were the case, it is unlikely that it would suffer any future flood damage, assuming sufficiently strong foundations, etc. The sole difference then between the Red Cross and the Bluescope houses would be the flexibility generated by the option. The combined value of the three options would need to be greater than $570 – the difference in construction price between the two houses – if the Bluescope house were to be preferred. However, $570 is roughly one third of the capital cost of the Bluescope house, so that it could be argued that an option value of this magnitude would be unlikely.

2) Alternatively, the Red Cross house may have been built with only 1 metre freeboard[7]. If it becomes subject to frequent, climate-induced flooding before the expiry of its design life, it may need to be replaced by a house with higher stilts. For example, if it needed to be replaced in 30 years time, then an additional present value of $466 in cost would be incurred, representing its current replacement value of $1130,

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[6] Although Dixit and Pindyck (1994) do not appear to say so explicitly, the approach of comparing otherwise identical houses has strong parallels in the hedonic pricing methods used in conventional cost-benefit analysis.
[7] According to Nguyen Van Kien, *pers. comm.*, 1 November 2010, it is common practice in the Mekong Delta to allow freeboard of 1 metre above the previously highest flood when a new house is constructed. In fact, the flood in the year 2000 reached a level about 1 metre below the floor of the Red Cross house in Figure 5.

discounted at 3 per cent per annum. But the Red Cross house would still be preferred, unless the Bluescope house generated an option value of at least $104 ($570 – $466).

8 ESTIMATION OF FUTURE BENEFITS IN THE FACE OF UNCERTAINTY

Knowledge is lacking – particularly at the local level – as to both the intensity and the timing of future climate change. Much work on adaptation has been based on mean projected values, but adaptation, by its very nature, requires consideration of extremes. The intensity of future weather events might remain much as it is today, or change along a spectrum that includes both the benign and the catastrophic. The timing of any additional intensity is equally uncertain.

A particular advantage of the cost-benefit framework is that it allows readily for consideration of uncertainty in several ways. The 'real options' approach and the use of Expected Values within a decision-tree framework are two methods. Of themselves, however, both require exogenous estimates of probabilities to portray uncertainty. But any estimate of probability associated with climate change implies a degree of certainty in our knowledge of the future. Monte Carlo analysis permits probability modeling of combinations of stochastic variables used in an analysis, and is readily incorporated within a cost-benefit framework.

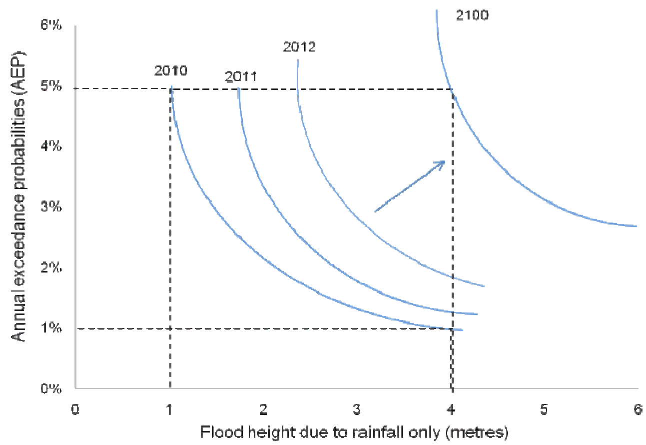
Extreme value distributions and Monte Carlo methods

Most economies have sufficient historical data to generate models based on extreme value distributions. Because historical data are used, they effectively represent a 'basecase' scenario of extreme events.

Figure 7 illustrates an extreme value distribution for flood-inducing rainfall now and in the future. It plots the Annual Exceedance Probability (AEP) for various flood heights. Only the 'fat tail' of the distribution[8] is shown because minor flooding (less than 1 metre in Figure 7) is assumed to be internalized by the local population. Figure 7 also shows that a 5 percent AEP (1 in 20 year flood) is associated in 2010 with flood heights of about 1 metre. Floods that occur once in a hundred years (AEP = 1%) are obviously less frequent, but cause more damage because they may reach heights of around 4 metres. An extreme value distribution such as the Gumbel or Weibull can be estimated from this information (see Box 1).

[8] Gaussian distributions such as the Normal are not particularly suited to modelling extreme events because the tails of the distributions rapidly approach zero probability. The tails of distributions with greater kurtosis, such as the Cauchy, are said to be 'fat' or 'heavy' because they indicate higher probabilities of occurrence of very low or very high values compared to the Normal distribution.

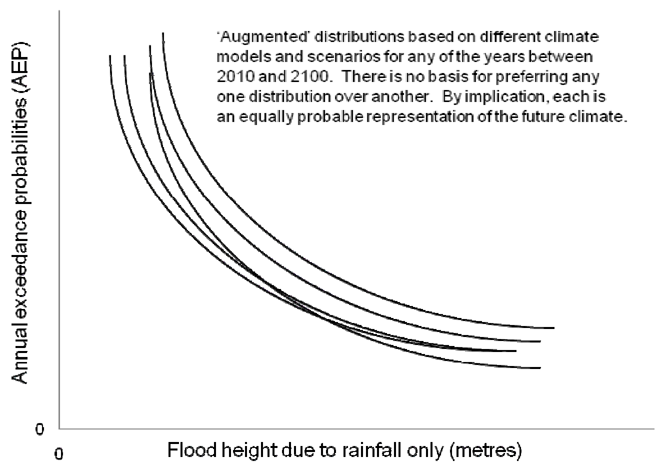
Figure 7: Illustration of annual exceedance probabilities (AEP) for rainfall and floods



The basecase 'extreme value' probability distribution for 2010 can be 'augmented' to take into account climate change over the coming century by shifting it to the right on the basis of predictions obtained from physical climate models. In Figure 7, for example, the current 1-in-20 year flood may be expected by the year 2100 to be 4 metres high, a level experienced only once in a hundred years in 2010. The approach as described so far is suggested by Repetto and Easton (2009) for hurricane losses, and by World Bank/IBRD (2010, Section 3.1.3). While useful, it does not take into account the fact that physical climate models will provide different, often contradictory results. Further, climate models may assume significantly different scenarios about greenhouse emissions.

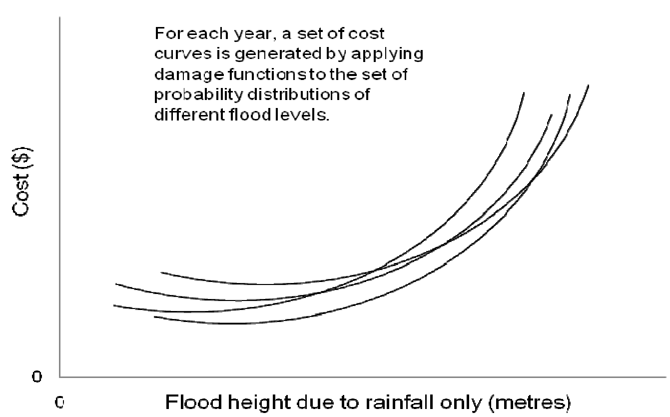
The uncertainty surrounding climate change can be incorporated into the 'augmented' extreme value distributions by using a series of climate models to generate a series of distributions for each year or period under examination. Each of the distributions shown in Figure 8 illustrates the results of simulating climate change for a single year with different models, or using different scenarios. (Only the extreme value distributions for one year are shown in Figure 8, for illustrative purposes.) The range of results indicated by the climate models reflects the uncertainty inherent in the knowledge of future climatic conditions.

Figure 8: Uncertainty illustrated by a range of distributions for each year under study



By applying a damage function to each of the 'augmented' probability distributions for each year between 2010 and 2100, a set of cost functions can be generated for each year. This is illustrated in Figure 8. Applying Monte Carlo analysis by generating random numbers to choose flood heights (from among the different distributions in Figure 8), a probability distribution of costs can then be generated for each year, giving a range of possible values of cost for each year, rather than single point estimates. This approach was applied in cost-benefit work commissioned by the Australian Department of Climate Change and Energy Efficiency (2010): see Box 1. World Bank/IBRD (2010, p. 22) also endorses this approach.

Figure 9: Illustration of cost functions generated from flood probability distributions



Box 1: Application of Monte Carlo analysis to adaptation to coastal inundation at Narrabeen Lagoon in Australia

Narrabeen Lagoon is one of about 70 intermittently closed and open lakes and lagoons (ICOLLs) along Australia's eastern coast. Storms can block ocean entrances to lagoons by depositing sand, but, in combination with flood waters from creeks that feed into a lagoon, they will occasionally also flush away deposits in the entrance. When its entrance is blocked, rain and floodwaters will generally fill a lagoon like a bathtub, and can therefore flood the land and houses around it. Because climate change is expected to increase the frequency and intensity of storms and rainfall in the Narrabeen catchment over the coming century, as well as raising sea levels, the Australian Department of Climate Change (2010) commissioned a study of the social costs and benefits to the community of adaptation measures such as levee banks to protect major access roads, widening the lagoon entrance, flood awareness programs, and planning controls.

Two observations on historical data (a one in 20 years rainfall extreme event and one in a hundred years) obtained from local authorities were used to estimate the two parameters of a Gumbel extreme value distribution for the year 2009. Eleven runs of climate model simulations supplied by CSIRO were used to generate sets of distributions of rainfall probabilities for the years 2055 and 2090 (like Figure 8), with intervening years estimated by interpolation. Probability distributions were transformed into cost functions using damage estimates for different flood heights.

Using readily available @*Risk* software, Monte Carlo analysis was applied by sampling from the 11 cost functions for each year from 2009 to 2010 to generate a single probability distribution for costs in each year. (An optimization model was also applied to assess the effect of interdependencies between different adaptation measures.)

The study found that a flood awareness program, increasing the minimum height of new buildings and a levee at one site next to the lagoon would generate benefits greater than costs if implemented immediately. However, the benefits of widening the lagoon entrance would not exceed the costs until 2035.

Source: Department of Climate Change and Energy Efficiency (2010). More information is available at http://www.climatechange.gov.au/~/media/publications/adaptation/coastal-flooding-narrabeen-lagoon.ashx

The methodology sketched out here would enable estimation of likely future costs of damages avoided due to climate change, taking into account the associated uncertainties. However, it would be feasible to extend this methodology to the estimation of willingness to pay. For example, insurance companies may be able to provide estimates of likely market premiums that would be commercially viable, both in terms of price and quantity demanded. Alternatively, some form of hedonic pricing, based on comparison with existing insurance policies in 'analogue' economies or regions, might be used.

Further refinement may be required of this outline approach to ensure that it is relevant to conditions in countries like Vietnam or China. For example, subsistence farmers who do not actually have access to insurance may be highly risk averse in order to ensure sufficient food for the next season. Rather than growing the most profitable crop, they may instead grow low risk and low yield crops. As their income grows over the course of the century, or if insurance becomes more readily available, perhaps in the form of micro-insurance, they may switch production patterns. Damage cost functions would also need to be altered to take this into account. Similarly, as their incomes grow, the general population may become willing to pay for environmental 'goods' (Stage, 2010).

Decision-making costs could be reduced if climate model-'augmented' extreme value distributions were produced for each economy, either by governments or aid agencies. Generation of augmented distributions such as those in Figure 8 requires considerable modeling expertise and information about each economy's climate. There would be a credible 'public good' argument for the production of such functions for major regions within each economy. Because analyses of adaptation projects would be able to draw on the data generated, cost savings would be realized at all levels of government in commissioning future cost-benefit studies.

9 SOME POLICY IMPLICATIONS

The 'real options' approach provides a useful framework for planners because it encourages consideration of flexible and creative alternatives to standard deterministic responses. However, its use has a number of policy implications.

1) Incorporation of real options in adaptation measures, although intuitively attractive in the face of uncertainty about the future impacts of climate change, still requires the application of rigorous cost-benefit analysis. Not all real options will generate superior net present values compared to less flexible alternatives.

2) Adaptation measures should not be seen as an end in themselves. The well-being of society depends on a range of considerations, not just the amelioration of adverse climatic events. Adaptation measures should therefore be compared on a cost-benefit basis with alternative social projects such as the provision of hospital or education services or other developmental projects. The real options approach can be applied to all sectors of the economy, not just adaptation measures.

3) If a real options approach is implemented for an adaptation measure, a monitoring regime also needs to be instituted. At some stage, the option may need to be exercised, or, in some cases, abandoned. It is therefore necessary to regularly re-evaluate the social costs and benefits of the measure as better information becomes available about future climate change. It may also be justifiable, on public good grounds, for governments to fund greater research into the effects of climate change at local levels.

4) A real options approach may well require changes to normal program management and funding arrangements. Conventional program funding is based on a relatively fixed timetable, with slippage from deadlines regarded as constituting under-

performance. The implementation of a project that embeds a real option, on the other hand, may favour delay until exercise of the option is warranted.

5) The principle of subsidiarity is a natural complement to a real options framework. Because climate change will differ from location to location, implementation of adaptation measures is best carried out at a level that has the most information about the effects of climate change as well as about credible alternative strategies that may incorporate real options. It may therefore be necessary to reconsider some existing jurisdictional arrangements between different levels of government. Similarly, more thought needs to be devoted to allocating responsibility for adaptation between the private and public sectors.

6) Finally, an important consideration is the presentation of a policy approach to adaptation. Use of terms such as 'real options' is unlikely to fire the public imagination. A term adopted by the Greater London Authority is 'Flexible Adaptation Pathways', referring to escalating responses to prevent flooding along the Thames. Its use is now apparently also being contemplated by New York City (Yohe and Leichenko, 2010).

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