Decision Support Methods for Climate Change Adaption

4

Real Options Analysis

Summary of Methods and Case Study Examples from the MEDIATION Project

Key Messages

- There is increasing interest in the appraisal of options, as adaptation moves from theory to practice. In response, a number of existing and new decision support tools are being considered, including methods that address uncertainty.

- The FP7 MEDIATION project has undertaken a detailed review of these tools, and has tested them in a series of case studies. It has assessed their applicability for adaptation and analysed how they consider uncertainty. The findings have been used to provide information and guidance for the MEDIATION Adaptation Platform and are summarised in a set of policy briefing notes.

- One of the tools recommended for adaptation is **Real Options Analysis (ROA)**. Options analysis derives from the financial markets, where it has been used to assess the valuation of financial options and risk transfer. The same insights are also useful when there is risk or uncertainty involved with investment in physical assets, hence 'real' options

- Real Options Analysis quantifies the investment risk associated with uncertain future outcomes. It is particularly useful when considering the value of flexibility of investments. This includes the flexibility over the timing of the capital investment, but also the flexibility to adjust the investment as it progresses over time, i.e. allowing a project to adapt, expand or scale-back in response to unfolding events. The approach can therefore assess whether it is better to invest now or to wait – or whether it is better to invest in options that offer greater flexibility in the future.

- ROA has considerable potential for adaptation, and aligns with the concepts of iterative adaptive (risk) management, providing a means to undertake economic appraisal of future option values the value of information and learning, and the value of flexibility, under conditions of uncertainty. It can therefore justify options (or decisions) that would not be taken forward under a conventional economic analysis.

- The application to adaptation has often used dynamic programming, which is an extension of decision-tree analysis. This defines possible outcomes and decision points, and assigns probabilities and estimates expected values.

- The review has considered the strengths and weakness of ROA for adaptation. The key strength of the approach is the information it provides on large investment decisions, allowing economic analysis of the benefits of information and flexibility under conditions of uncertainty. The use of decision trees also provides a useful way to visualise the context of adaptive management. The main disadvantage relates to the complexity of the formal economic approach, which is likely to need expert application and significant resources, and the need to input probabilities and multiple risk points for climate change.

- Previous applications of ROA for adaptation have been reviewed, and adaptation case studies are summarised. The majority of applications to date have been for large coastal protection projects, though there is also an application for large water projects.

- The review and case studies provide useful information on the types of adaptation problem types where ROA might be appropriate, as well as data needs, resource requirements and good practice lessons. This identifies that ROA is most useful for large capital investments (project level), especially where there is a large adaptation deficit or a significant potential for learning or flexibility. It also requires good quality data on climate risks and cost/benefit components. Given the high resource requirements, the review also identifies the potential for more informal application of ROA, e.g. through the use of decision trees and more qualitative analysis of information and flexibility.

Introduction

There is increasing policy interest in the appraisal of options, as adaptation moves from theory to practice. At the same time, it is recognised that the appraisal of climate change adaptation involves a number of major challenges, particularly the consideration of uncertainty. In response, a number of existing and new decision support tools are being considered for adaptation.

The European Commission FP7 funded MEDIATION project (Methodology for Effective Decision-making on Impacts and AdaptaTION) is looking at adaptation decision support tools, in line with its objectives to advance the analysis of impacts, vulnerability and adaptation, and to promote knowledge sharing through a MEDIATION Adaptation Platform (http://www.mediation-project.eu/platform/). To complement the information on the Platform, a series of Policy Briefing Notes have been produced on *Decision Support Methods for Climate Change Adaptation*.

An overview of all the decision support tools reviewed is provided in *Policy Briefing Note 1: Method Overview*, which summarises each method, discusses the potential relevance for adaptation and provides guidance on their potential applicability. The methods considered include existing appraisal tools (cost-benefit analysis, cost-effectiveness analysis and multi-criteria analysis), as well as techniques that more fully address uncertainty (real options analysis, robust decision making, portfolio analysis and iterative risk (adaptive) management). It also includes complementary tools that can assist in adaptation assessment, including analytical hierarchic processes, social network analysis and adaptation turning points. Additional information on each method is presented in a separate *Policy Briefing Notes (2 – 10)*.

This *Policy Brief (Note 3)* provides a summary of **real options analysis**. It provides a brief synthesis of the approach, its strengths and weaknesses, the relevance for adaptation, how it considers uncertainty, and presents case study examples. It is stressed that this note only provides an overview: more detailed information is available in MEDIATION deliverables, and sources and links on the MEDIATION Adaptation Platform.

Description of the Method

The concepts of real options analysis lie originally in the financial markets. A financial option gives the investor the right, but not the obligation, to acquire a financial asset in the future, allowing them to observe how market conditions play out before deciding whether to exercise the option. This transfers risk from the buyer to the seller, making the option a valuable commodity. Options analysis quantifies this value based on how much such a risk transfer is worth (Black and Scholes, 1973).

The same insights are also useful for investment in physical assets (hence 'real' options), in cases where there is risk/uncertainty (McDonald and Siegel, 1986). Real options analysis (ROA) quantifies the investment risk associated with uncertain future outcomes. It is particularly useful when considering the value of flexibility of investments. This might be for example flexibility over the timing of the original capital investment, or the flexibility to adjust the investment as it progresses over a number of stages, allowing decision-makers to adapt, expand or scale-back the project in response to unfolding events.

ROA typically gives two types of result that set it apart from traditional economic analysis. The first affects projects that are cost-efficient under a deterministic analysis. ROA shows that sometimes it makes more sense to wait for the outcome of new information, rather than investing immediately. Conversely, the second type of result affects projects which may fail a deterministic test of cost-efficiency. Under conditions of uncertainty, it may make financial sense to start the initial stages of the project where these are needed to keep the overall project alive, in case its fortunes change at a later date and it starts to look like an attractive investment option.

ROA has been applied quite widely in the energy sector, including analysis of mitigation options, and there are examples in the literature looking at the uncertainty of investment under climate change policy (e.g. Hlouskova et al. 2005: Fuss et al, 2009; Szolgayova et al 2011). As further examples, Rothwell (2006) examined returns on investment in nuclear plant with uncertainty over carbon prices, while Laurikka and Koljonen

(2006) looked at investment uncertainty with future emissions trading.

Such studies show that ROA can provide useful information to help decisions in cases of three key conditions:

- First, the investment decision is irreversible once taken;

- Second, the decision-maker has some flexibility when to carry out the investment (either in a single step, or in stages);

- Third, the decision-maker faces uncertain conditions and by waiting to invest they are able to gain new valuable information regarding the success of the investment.

The formal application of the approach (e.g. Dixit and Pindyck, 1994) is rather complex, but the intuition of the method can be described relatively easily.

For a simple one-off investment opportunity which faces uncertain outcomes, it may be worth waiting to invest at a later date when more information is gained about the likelihood of different outcomes. Waiting can help the decision-maker to avoid costly mistakes by allowing them to decide not to proceed with an investment if they find themselves facing poor investment conditions.

For waiting to be worthwhile, the decision-maker must reasonably expect to gain valuable information. The value of waiting will then be higher (lower) if:

- The degree of uncertainty regarding the cost-effectiveness of the project is greater (smaller)

- The duration of the period of waiting before information is gained is shorter (longer)

The value of waiting needs to be balanced against the cost of waiting (see box), because during the period of waiting, the project will not be delivering the goods, services or other benefits it set out to achieve.

ROA therefore provides decision-makers with a new investment criterion that takes account of uncertainty. Projects should proceed if the project overall seems cost-efficient and if the

cumulative lost value of these benefits during the waiting time exceeds the value of waiting.

However, projects are usually more complex than a simple one-off investment, and ROA can add to the understanding of how project value evolves during the various stages of project development.

There will often be flexibility to adapt the project as it proceeds through these stages, for example to expand, contract, or even stop the project altogether if it appears unlikely to be successful.

Standard economic appraisal normally assesses the performance of the project over its whole lifecycle without taking account of the value of this flexibility. Averaging the outcomes across multiple scenarios will tend to undervalue projects, because it does not take account of the ways in which projects can be adapted to adjust as these various scenarios arise over time. The advantage of ROA is that it can incorporate the value of this flexibility, and can therefore lead to better decision making (HMT, 2007).

ROA can be carried out in a variety of ways. The most relevant to adaptation is an approach called dynamic programming which is essentially an extension of decision-tree analysis. This defines possible outcomes, and assigns probabilities to these.

The decision-tree defines how a decision-maker responds to resolution of uncertainty at each branching point in the tree. Quantifying the value of these decision options then proceeds by assessing all the branches. ROA calculates option value based on the expected value over all branches contingent on making the optimal choice being taken at each decision-point.

The optimal decision in turn is evaluated based on all the possible outcomes downstream of that decision in the tree. This ROA value can be compared to a normal economic (cost-benefit) calculation that would simply be a probability-weighted average of the outcomes along each possible branch in the tree.

Box 1: The Concepts of Real Options Analysis

The example below shows a simplified investment example, showing the expected gross margin over time, with annuitized capital costs shown as a blue shaded area. Uncertainty is represented as an anticipated shock or an information event that occurs in the future (Tp) which will affect the project's cash flow either adversely (the red line) or favourably (the green line). In case A (top) – the normal positive NPV criterion – a decision has to be made at time t=0 on whether or not to invest. In this case, there is not the option to wait. The expected 'best guess' (the central orange line) is the average of the upper and lower estimate of the outcome of the price shock, noting in this case, risks are symmetrical, and cancel out such that the expected value of project will continue to be profitable (and thus the decision maker should proceed with the investment). In Case B (bottom), there is the opportunity to wait until time Tp before making the investment. This allows it to avoid the potential loss that might occur if conditions turn out worse than expected (the red dashed area), but this must be traded off against the opportunity costs of waiting (the orange dashed area).
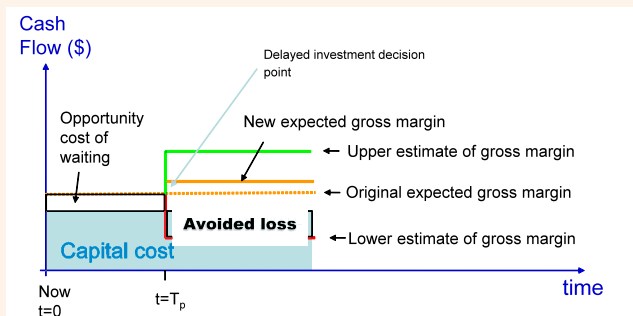
Case A:
"Now or never" investment option at t=0
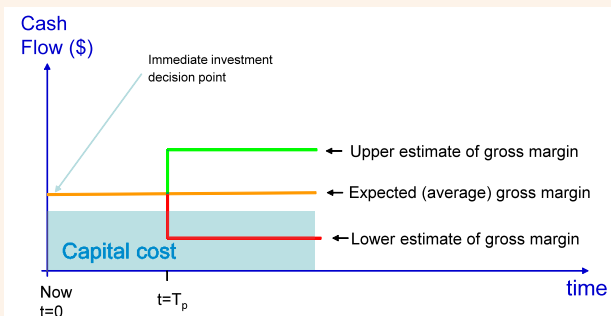
Case B:
Option to wait until after t=Tp, the expected time of policy change that affects the investment

The associated decision tree for this example is shown below. The 'risk event' represents an event in which a variable which was previously uncertain is resolved. In this example, there are only two equivalent outcomes, a high revenue scenario and a low revenue scenario, noting in practice, there may be many outcomes, with different probabilities.
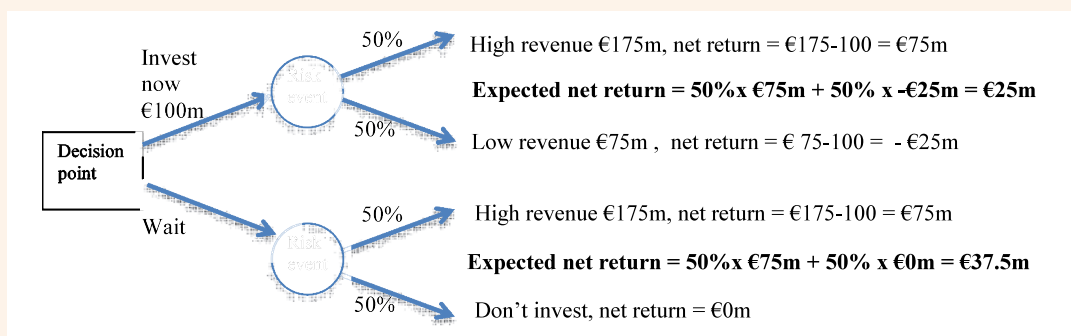
To make a direct comparison between the 'invest now' and the 'wait' options, the expected net returns (the probability weighted mean) is expressed in present value terms, since the decision-maker needs to compare the relative value of the two options in the current time period of the decision. Under the 'invest now' branch, the expected net return in present value terms is €25m, since revenue starts to flow immediately. Under the 'wait' branch, the expected net returns of €37.5m needs to be discounted. If the duration of the wait was 3 years, and a discount rate of 7% is used, then the present value would be €30.6m. In this case, the decision-maker would better off waiting. If the duration of the wait was 8 years, at 7% discount rate, the present value of the investment option would be €22m, so the decision-maker in this case would be better off to invest immediately, and take the future downside risk when it occurs.

The Application to Adaptation

ROA has been widely cited as a possible decision support tool for adaptation as it aligns closely with the concept of iterative decision making. The MEDIATION project has reviewed the application of ROA to adaptation.

A key value of ROA is that it provides an economic analysis of investing now versus waiting, and the economic value of flexibility, which allows a comparison of the additional marginal cost (or lower initial benefits) of added flexibility and future learning.

ROA can also be used to support initial enabling steps to help secure projects for future development, even if they are not expected to be cost-efficient on the basis of traditional, static CBA/CEA appraisal.

In considering the application to adaptation, the ROA investment framework is most likely to be supportive of projects that have some combination of substantial near-term benefits, and the ability to scale-up or down in line with learning regarding potential upside benefits or downside risks. This will be the case for example when there is an existing adaptation deficit that the immediate investment can reduce, such as current flood risks. It is also relevant to adaptation in situations where projects proceed on a similar timescale over which information will be gained about likely climate impacts (and therefore benefits of different project options).

However, the framework will tend to suggest that there is value in delaying projects that are focussed on long-term benefits with highly uncertain outcomes, given the expectation of valuable information arising over coming years and decades regarding climate impacts.

The approach is most relevant to large, capital intensive investments such as dyke flood protection or dam-based water storage. Capacity building, no-regret or soft options are generally only likely to be evaluated in ROA to the extent they are necessary initial steps in keeping open possible future investment options.

The theoretical basis for the application to adaptation has been outlined (e.g. HMT, 2009) but the application to real world decisions is complex (see box).

Box 2: Moving to practical applications of real option analysis

An example of how complex real option analysis can be in practice is demonstrated with the study of Jeuland and Whittington (2013), who applied real option analysis for a water resource planning case study in Ethiopia along the Blue Nile, looking at the planning of new water resources infrastructure investments (for five large dams, each with different relative characteristics) and their operating strategies in a world of climate change uncertainty. Their analysis considered flexibility in design and operating decisions over the selection, sizing, and sequencing of new dams, as well as reservoir operating rules, using a simulation model that included linkages between climate change and system hydrology, with testing of the economic outcomes of investments in new dams.

This required three linked models for stochastic runoff generation, hydrological routing, and Monte Carlo simulation of economic outcomes for the different project alternatives (looking at 7,350 simulation experiments comprised of 350 planning alternatives × 7 runoff scenarios × 3 water withdrawal assumptions). For each of these a separate hundred-year sequences of stochastic inflows were passed through the system. The 100 resulting sets of physical outcomes were then used as inputs to a cost-benefit model in which 5,000 Monte Carlo trials were applied to yield distributions of net present value (NPV) for each experiment. The results indicated that there was no single investment plan that performed best across a range of plausible future climate conditions. The value of the real options framework was its use in identifying dam configurations that were both robust to poor outcomes and sufficiently flexible to capture high upside benefits should favourable future climate and hydrological conditions arise.

Strengths and Weaknesses

A key part of the MEDIATION project has been to identify the strengths and weaknesses of different approaches. A summary of some of the key strengths and weakness of the approach is presented below.

The key strength of ROA is the information it provides on major investment decisions, providing a way to assess in quantitative and economic terms the relative benefits of implementing now versus waiting, and so incorporating uncertainty into the heart of the analysis.

It also provides a way to value the economic benefits of flexibility, i.e. to allow an economic appraisal of whether the additional marginal cost of this flexibility (or the lower early benefits from a more flexible project) are offset by the option value for future learning, i.e. for uncertainty resolution. The decision trees used in the method also provide a way to conceptualise the context of adaptive management – indeed this is probably a significant strength of the approach and the transferability for wider application.

The potential weaknesses relate to the need to define probabilities in the decision-tree, which may narrow the potential application of the technique, noting the poorer the estimates of probability, the less accurate will be the results. Strictly speaking ROA considers risk, where

probability is defined, rather than uncertainty, where it is impossible to attach probabilities to outcomes (see HMT, 2007).

The approach also requires quantitative information and valuation of all elements of costs and benefits, which may limit the approach to sectors that have non-market components. Since such probabilistic data is not yet available, and quantitative impact data is limited in many sectors, the scope for the practical application of ROA is more limited than often thought.

There is also a need to consider multiple risk points for climate change, and define these in a way that match to the available climate information (e.g. climate averaging periods). Finally, the complexity of the formal economic approach is likely to require expert application and involves significant resources.

However, many of these issues can be addressed through a more informal application of ROA, e.g. through the use of decision trees and more qualitative analysis of information and flexibility.

Case Studies

The MEDIATION study has reviewed existing literature examples that have applied ROA to a number of adaptation case studies. A number of these case studies are summarised in the box below.

Key strengths

Quantitative and economic analysis of the value of flexibility, learning and iterative adaptive management.

Decision trees provide a useful and understandable way to conceptualise and visualise the concept of adaptive management and to frame analysis.

Potential for informal application of ROA, e.g. through the use of decision trees and more qualitative analysis of information and flexibility.

Potential weaknesses

Data and resource intensive, with high complexity often requiring expert input. Data constraints a potential barrier, especially the need for probabilistic climate information and quantitative impact data.

Requirement for quantitative and economic information on costs and benefits likely to limit for non-market sectors or elements.

Identification of decision points complex for (dynamic) aspects of climate change, and need to match these decision points to equivalent climate data.
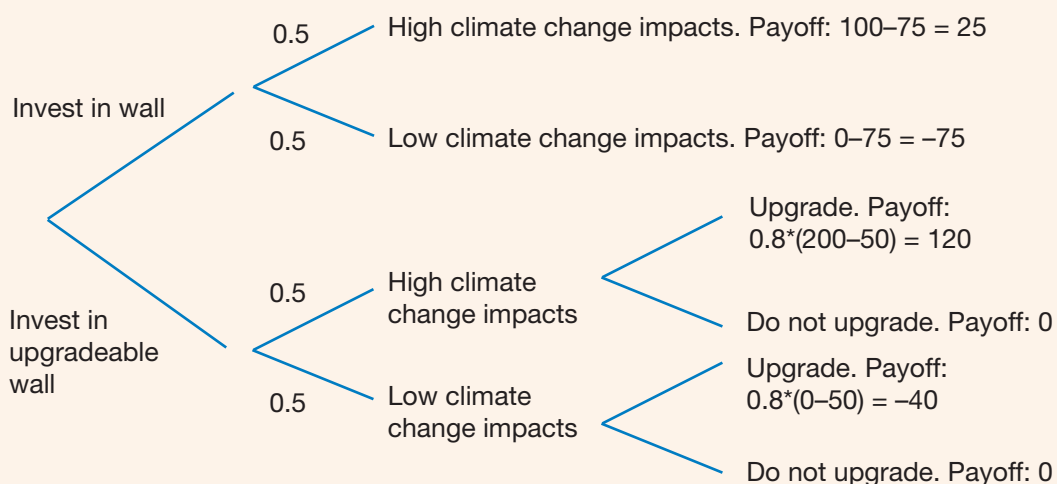
Case Study 1: Real Options Analysis – Generic Guidance

The practical application of ROA to adaptation is limited, with only a few examples to date.

HMT (2009) provides a simplified theoretical example, which is incorporated into supplementary Government guidance on economic appraisal for adaptation. This recognises that there may be activities (or options) with the flexibility to upgrade in the future, and that these provide an option to deal with more (or less) severe climate change in light of information from learning or research. It presents an example using sea wall defence and sets out the use of decision trees to understand the sequence of actions and decision points. Similar to the simplified example above, it uses two alternative options: investing now in a large sea wall defence versus investing a wall which has the potential to be upgraded in the future. The NPV of these investments is assessed under low and high future sea level rise scenarios (hypothetical), estimating the expected value and assuming equal chance of low and high climate change. The analysis can therefore compare a standard investment against an upgradeable wall, the latter with the flexibility to be upgraded in the future if higher levels of sea level rise emerge.

In the example, the standard wall costs 75, and has benefits of 100 from avoided flooding. The upgradeable wall costs 50, the upgrade costs 50 and would give benefits of 200 from avoided flooding. For the standard investment, the NPV is -25 (=0.5*25 + 0.5*-75), which suggests the investment should not proceed. For the upgradable wall, then an extended decision tree is considered. If the impacts of climate change are high enough to warrant upgrading, then the value of the investment is 120. If the impacts are low, then upgrading is not justified as the payoff is negative (-40), but since the investment costs of the upgrade are not needed in practice in the low outcome, they are not incorporated into the NPV. The expected value of investing now with the option to upgrade in the future is therefore +10 (=0.5*(120) – 50). Comparing the two options shows an NPV of -25 for the standard wall, and +10 for the flexible wall, thus flexibility to upgrade in the future is reflected in the higher NPV, and switches the investment decision.

This figure redrawn!

Invest in wall
- 0.5 — High climate change impacts. Payoff: 100–75 = 25
- 0.5 — Low climate change impacts. Payoff: 0–75 = –75

Invest in upgradeable wall
- 0.5 — High climate change impacts
  - Upgrade. Payoff: 0.8*(200–50) = 120
  - Do not upgrade. Payoff: 0
- 0.5 — Low climate change impacts
  - Upgrade. Payoff: 0.8*(0–50) = –40
  - Do not upgrade. Payoff: 0

Source HMT (2009).

In practice, this example does not reflect the complexity or challenges involved with real world decisions, e.g. the complex uncertainty over sea level rise scenarios (including changes in storm surge risks), the level of detail on costs and the quantitative and economic analysis of benefits.

Case Study 2: Real Options Guidance – Moving to Practice

The previous example is relatively straightforward to solve because: only four investment options are considered, either invest in a standard/upgradeable wall, with one sequential decision to upgrade; there are only two decision points, i.e.: at t0, and at the upgrading moment; only two possible uncertain future states of the world can be realised, either 'high', or 'low' climate change impacts; the timing of learning is known; and at this time, uncertainty is fully resolved. A more realistic case study looking at the optimal dike height under uncertainty with learning about climate change impacts is therefore presented below.

Dike heightening is expensive, and economically efficient investment is therefore important. Van Dantzig (1956) described that dike investment is a cost minimisation problem, after a large flooding in the Netherlands in 1953. In essence, higher dikes reduce expected damage costs, but investment costs increase exponentially with dike height. A balance has to be found between expected damages and costs of dike construction over time, noting decisions on dike height are recurrent for a number of reasons (e.g. economic growth, climate change impacts on water levels, or soil subsidence). On the one hand, it is not optimal to build a dike once and for all because that would result in excessive investment costs with only little benefits. On the other hand, dike heightening, like most large investment, has fixed costs, and therefore, yearly investment is not optimal but rather a solution where a dike is revised at longer time intervals, for example, half a century.

Crucial to determine optimal dike height over time are water level observations. With these observations return periods of different water levels can be estimated. Water defences protecting land from large-scale flooding events typically offer protection against events with long return periods (e.g. 10000 years or even more), but these events are extremely rare, though they will become less rare in the future due to climate change.

With climate change, sea levels are expected to rise, and peak river discharges are expected to increase. These future scenarios have been projected, but are insufficient to be valuable for a cost-benefit approach, as they require information on possible future states of the world and also probabilities of these states. In the Bayesian literature these probabilities are called informed priors, or subjective probabilities. So far, subjective probability distributions are lacking for the rate of sea level rise or the increase in peak discharges although that it is clear to some scenarios are much less likely than others. A second problem is that we poorly understand how / what / when we will learn about climate change impacts. Some sources of uncertainty are likely to be reduced: water level observations will grow, reducing statistical uncertainty, and model structure uncertainty is likely to be reduced over time with research. If we know that better information will be available in the future, this may have implications for current dike heightening decisions. As explained previously, information has expected value: once we know better dike heightening strategy can be adapted to reduce total expected costs.

Nonetheless, with some prior distribution about the rate of the structural water level increase, that is the speed with which the relative water level is structurally increasing, and assumptions about the learning process, it is possible to investigate the problem of optimal dike height, and how valuable it is to obtain better knowledge on climate change impacts for the dike heightening problem: that is the expected costs savings that can be obtained by anticipating new information, and by changing the dike heightening strategy once information has been received. Furthermore, early information is more valuable than late information because future costs are discounted. For this case study, we introduce a special case of learning: perfect learning, which we assume to be a probabilistic event following a survival model. The decision variable is the dike increment , u_t, the amount with which the dike is heightened, at any time t. The problem is discretised in small time steps , t_k, and the decision space is discretised as well, u_{t_k}, $E\{0, \Delta u, 2\Delta u ,.., umax\}$. The left panel of Fig.1 shows a decision tree with

the various trajectories of dike heightening over time. The right panel in Fig.1 shows an event tree: at every time step it is possible that perfect information is received on the rate of the structural water level increase. Once perfect information has been received, we are back to an original deterministic problem setting, which has been studied by Eijgenraam et al. (2012).
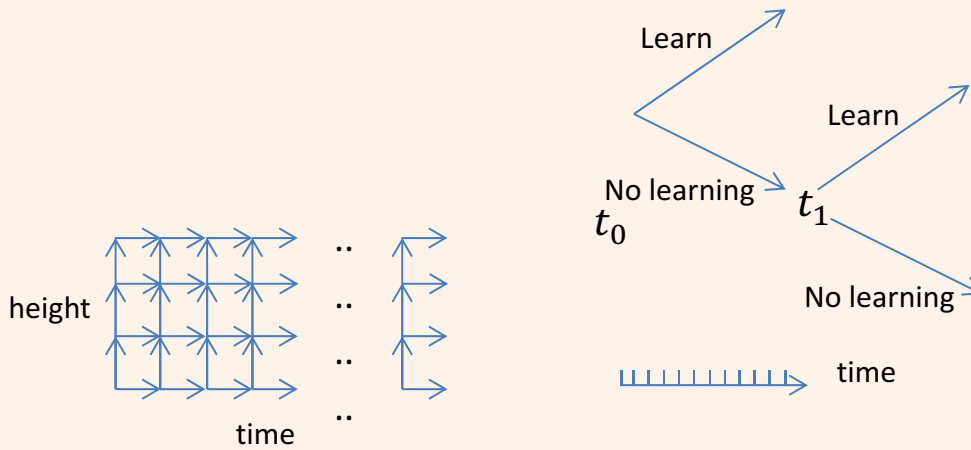

Figure 1: Dike height decisions over time graphically illustrated (left panel), and event tree showing probabilistic learning (right panel).

The above problem is solved with dynamic programming. The procedure is similar to the previous example: for every probability weighted state expected costs are calculated, and the optimal dike heightening strategy is found with in a backward-forward procedure.

Case results indicate that current and short-term dike heightening decisions are weakly affected by future learning. Perceptions about the likelihood of climate change impacts are very relevant for current decision making. Optimal dike heightening strategies change significantly if different priors for the rate of the structural water level increase are taken. The expected value of information can be substantial.

For more information, see:
- van der Pol, T.D., van Ierland, E.C. and Weikard, H.-P. (2013) Optimal Dike Investments under Uncertainty and Learning about Increasing Water Levels. *Journal of Flood Risk Management* (under review)

Discussion and Applicability

The review and case studies provide a number of practical lessons on the application of real options analysis to adaptation. They provide useful information on the types of adaptation problem types where ROA might be appropriate, as well as data needs, resource requirements and good practice.

In summary, ROA is considered most useful for project based investment analysis, for major irreversible capital investment, particularly where there is an existing adaptation deficit (because this involves a trade-off between acting now and waiting). It also has applications such as the second case study, where there is an existing maintenance backlog, and in cases where there is the possibility of receiving new information in the future. In general it is less useful for new projects that address future climate change, where benefits arise in the long-term only, especially if these are highly uncertain, because in such cases it will make more sense to wait.

It also has the potential to assess flexible versus conventional options, which is a particularly important component of iterative risk management. It can also be used to support initial enabling steps to help secure projects for future development, even if they are not expected to be cost-efficient on the basis of traditional, static CBA/CEA appraisal.

The application requires inputs related to probability or probabilistic assumptions for climate change and the identification of decision points. It is therefore less applicable under situations of (deep) uncertainty, where probabilistic information is low or missing. For such cases, alternative approaches, such as robust optimisation, may be considered (see briefing note 3). It also requires the analysis of quantitative data on costs and benefits, the latter which have to match to the decision trees and outcomes: this usually requires a linked modelling system or a large number of assessments, coupled with some form of sampling (e.g. Monte Carlo analysis). For this reason, the resources and level of expert knowledge needed to apply the approach are high. The focus of the approach on economic costs and benefits makes the application to non-market sectors more challenging.

Given the high resource requirements, the review also identifies the potential for more informal application of ROA, e.g. through the use of decision trees and more qualitative analysis of information and flexibility.

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Further Reading and Reference Sources

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Further information

To find out more about the MEDIATION project, please visit:
http://mediation-project.eu/

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