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Climate Adaptation for **Decision-makers**

Evaluating investment projects under risk and uncertainty

Policy Brief

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Key points

- The timing of investment for infrastructure projects, and the payoffs or costs from delaying these projects, are important. Waiting to invest in a project means planners can improve their ability to learn about likely payoffs in a situation where these payoffs are initially imperfectly known. Irreversible investment commitments must clear more stringent net benefit hurdles to be undertaken immediately than is the case using standard cost-benefit analysis.
- Climate change presents particular challenges for investments that depend on climate related inputs, such as rainfall, because it adds additional uncertainty.
- Given possible value of waiting increases as learning about payoffs increases, there can be a case for deferring a project even if the current net expected benefits from the project are positive because there is an option value placed on improved information that can be gained in the future.
- If this option value is ignored, implementing standard cost–benefit approaches can lead to overinvestment in infrastructure because the full benefits may never be realised. However, there is an inherent trade-off between the enhanced flexibility from delaying a large project and the certainty gained from early implementation. Society is generally risk-averse when it comes to water security, leading decision makers to prefer early implementation, even if there are significant financial implications.
- The case for delaying large water augmentation projects therefore needs to be strong, with reliable back-up water sources and management policies available in the interim.
- Using auxiliary policies, strategic planning or modular design options can improve outcomes where there is risk and irreversibility, because:
  » Auxiliary policies can 'reduce the costs of waiting'. They include increasing the prices of commodities such as water when they are in low supply to reduce demand to lengthen their availability;
  » Strategic phasing for large investment projects can reduce implementation time and costs when the future investment decision is made; and
  » Modular design options that can allow smaller initial infrastructure investments to be built and then possibly scaled up as the future situation becomes clear.
- Introducing risk aversion into project evaluation modelling changes the analysis markedly. If failing to deliver an infrastructure project could result in severe social losses or, equivalently, if decision-makers were judged to be highly risk-averse.
- Real option approaches can improve on traditional cost–benefit analysis for analysing risky irreversible investments.

Introduction

The Enhancing Water Infrastructure Provision with Climate Change Uncertainty project investigated the use of alternative economic models for evaluating large public infrastructure investment projects (e.g. a desalination plant) when there is risk and uncertainty, and assesses appropriate policy options for water utilities, regulators and other government agencies. This brief presents a portion of the research relating to project evaluation. Insights can improve decisions relating to investment in water-supply infrastructure by accounting explicitly for climate variability and for prospective climate change. These insights can be applied to other capital-intensive long-term investment projects undertaken by government.

Real options analysis can change the way planners think about evaluating investments in infrastructure under conditions of risk. This approach targets irreversibility, risk and risk aversion. These are typically very practical considerations. This Policy Brief draws out the key insights from these theories and illustrates the main ideas by taking the example of building a desalination plant for urban water supply. Risk and irreversibility coupled with learning provide a case for more caution and delay even where conventional cost–benefit analysis might not suggest this.

Real option approaches typically assume risk neutrality, therefore decision-makers seek to maximise the expected value of investments. However, high risk-aversion can create a case for decisive early investment.

> Imperfect knowledge can be characterised in several ways. **Risk** describes situations where decision makers know all the possible outcomes that can occur and can assign probabilities to the various events. **Uncertainty** describes situations where the outcomes are known but the probabilities attached to these outcomes are entirely unknown. **Gross ignorance** describes situations where there are "unknown unknowns" – where outcomes can occur that were not even initially envisaged.

Real options analysis requires probability information and hence is based on situations of known risk. This probability information may not be readily available so it is also important to consider techniques for **dealing with** situations of uncertainty and gross ignorance.

When to consider real options techniques

Irreversibility, risk and the possibility of learning about such risks are key factors motivating use of a real options approach to evaluating investment decisions. They are described below:

- **Irreversibility**
  An investment is irreversible if, once capital is invested, it cannot easily be redirected to an alternative use. This characterises most infrastructure investments. Roads, highways, bridges, dams, airports, water supply facilities and train lines have very limited possible alternative uses beyond the purpose for which they were originally designed.

- **Risk**
  The long time horizon of many infrastructure investments means that decisions are made in the context of recognised risks about future costs and benefits. We do not know for certain how the construction and other associated costs will be subject to the weather and other factors. These include labour costs, technological improvements and efficiencies, and future energy pricing during its operation. We do have the knowledge and capability to model these through time to assist our decision making.

The value of learning

For policy makers to be able to derive advantage from using a real options approach, information about the risks associated with a project must improve over time. The rate of this learning needs to be commensurate with the timing of future decision points.

For example, in the case of a desalination plant, the benefits from the project will depend on the future value of the water sold, which will in turn depend on the evolution of the demand for water, the availability of water from sources such as dams and aquifers and the feasibility and cost of purchasing water from other sources or users. Future aggregate water demands will also depend on demographic factors such as population size and age structure and water consumption characteristics. Future values are by their nature highly uncertain but these values become generally better known as the future unfolds.

For climate-related variables, investment in research could result in better understanding of historical climate variability or greater confidence in the capacity to predict future conditions.

Reducing the costs of waiting

While waiting for better information, there are a range of approaches that can be considered before committing to full investment. These measures improve the flexibility of investment decision-making by enhancing the capacity to delay project initiation. See Clarke (2014).

- **Auxiliary policies**
  Auxiliary policies can reduce the costs of waiting and improve the economics of the investment. For example, an auxiliary policy for urban water supply might price water higher when water storages are low ("scarcity pricing"), hence reducing water demand and thereby enabling the postponement of major capital investment. Other options might include integrated water cycle management or investment in research and development on water consumption and efficiency measures.

- **Modular design**
  Modular design can replace all-or-nothing construction decisions for large-scale investment projects. For example, a smaller scale facility can be built to be scaled-up if future conditions require it. This may mean that potential economies of scale are not realised. Pilot-scale plants can provide cost information, which may be particularly important if facilities that are being contemplated have no similar local/ national comparison projects constructed in Australia.

- **Strategic phasing**
  Where possible, the implementation of large capital investment projects should be phased into discrete standalone components with those generating the highest overall benefit to society being implemented first. By way of example, before fully investing in a large scale infrastructure development such as carbon-capture and storage (CCS) technology, it might be more cost-effective to first investigate and develop a new regulatory and legislative framework that is required for CCS. Even if the full investment does not proceed in the short-term, the benefit of this work will reduce the costs of undertaking CCS for future decision makers or if there is later private sector interest.

When to defer investment

A crucial component of the real options approach is that planners learn more accurately about the future state of the world as time proceeds. Thus, if an investment is deferred, planners may be in a better position to make such judgements about the true state of the world. The benefits from such delays need to be assessed against the costs of not gaining immediate output benefits from the project.

In the desalination plant example, this might mean that over time we obtain better information on how climate change is associated with worsening droughts. Typically, for urban water planning, if we wait to invest there will also be better knowledge of variables such as demographic changes and the success of water conservation efforts — and hence of aggregate water demands.

Predicting future water availability in a changing climate is particularly challenging. On a continental basis, rainfall trends have high inter-annual variability so that that isolating the effects of gradual climate change might be statistically difficult. The confidence around projections for local areas is also lower than for larger regional areas.

Risk does not need to be completely resolved for learning to delay the final decision to proceed with the investment. However, if a planner is confronted with exactly the same risk assessment in the future as today, then there is no benefit from waiting or investing in learning.

The decision can be made immediately on the basis of expected returns.

The most important issues are whether the project should be started now or deferred, and the desired project scale. For the investment to proceed, the calculated expected benefits, of the project must exceed the expected costs. Otherwise, it would always make sense to defer. Thus, the investment decision is whether it makes sense to defer, even though expected net benefits are positive. When should construction begin immediately?

The key insight of the 'real options' approach is that there can be a case for deferring a project even if the net expected benefits from the project, calculated now, are positive, because under uncertainty there is a benefit to waiting to gather further information.

Intuitively, because embarking on the investment is irreversible, there are unavoidable ongoing costs. However, not starting the project now is a decision that can be reversed. If say, in some future time period, improved or stronger evidence is forthcoming, then the initial decision not to build the plant can be reversed and construction can proceed. If present expected benefits from proceeding are significantly greater than expected costs, then waiting to access new information may be worth less than proceeding now.

The standard rule of cost–benefit analysis is that a project should proceed when the expected, discounted benefits from a project (*EB*) exceed the expected costs (*EC*).

Desalination plant, Wonthaggi. Credit: Peter Bellingham

Real options theory shows that applying such rules can lead to less expected net present value when investments are irreversible and risky, and when a planner's knowledge of the risks can improve, through learning, with time. The rule for not delaying investment in the model outlined is:

$$EB > EC + QOV$$

where *QOV* is the 'quasi-option value', a positive number reflecting the expected value of the extra information obtained from waiting to invest. Since *QOV* is positive, this rule is stricter than using the standard approach of replacing random variables with their expected values. Clarke (2013) discusses calculating the *QOV* in a simple setting.

Insurance against climate change impacts

The standard real options model developed does not consider risk aversion. Planners may seek to avoid risks of extreme shortages for essential goods and services. They might seek to insure against such risks. For example, water customers might willingly pay a premium to reduce the likelihood and duration of water shortages.

Risk aversion

An example of risk aversion is the annual premium a householder pays to insure their home contents against theft. This is paid even though the cost per year of the policy exceeds the expected value of any possible theft. For example, in a low-crime neighbourhood with only a negligible (e.g 1 per cent) chance of a theft worth $80,000, the householder might still pay $1000 insurance because a loss of $80,000 would be extremely damaging for them.

The difference between the cost of the householder's policy and the expected claim is $200; this amount measures the insurance premium. The decision to insure generally depends on the insurance premium charged relative to the risk, the costs consequent to the risk and the householder's degree of risk aversion.

The same idea applies to infrastructure projects. The extent of risk aversion reflects the amount planners will pay to avoid critically low levels of water supply.

Project evaluation techniques can be adapted to assess risk aversion by attaching a relatively high value to assuring delivery of a commodity (e.g. water) if there is a risk that it might become scarce. This value might reflect the judgement of planners or the planners might infer it from the behaviour of consumers, who might be induced to pay extra to avoid low supply.

This leads to a distinctive way of thinking about the cost of a technology such as desalination. Water supplied by a desalination plant might be more expensive to deliver than water supplied by rain-fed dams. But rain-dependent water supplies are subject to drought risk, whereas desalinated water is not. Thus, by providing a rain-independent source of water a desalination plant can be considered akin to taking out insurance against the prospect of drought that threatens to leave a community severely short of water in the event of extended drought.

When might the insurance premium paid for desalination be too expensive? This is difficult to judge without knowing the risk attitudes of planners and the community they serve. Insuring against the risk of inadequate rain does not address risk aversion towards other possible risks, such as increased energy prices, which might bear substantially on a technology such as desalination. Such risks come into greater prominence when a rainfall-independent technology, such as desalination, is already in place.

Examining the extra cost that desalination options imposed on state economies over cheaper rain-dependent options gives indirect evidence on this issue. The Productivity Commission (2011) estimated that the extra cost Melbourne and Perth paid for desalination was $2.1 billion over 10 years. For current populations in these cities over 10 years, the average price is $38 per person per year. Considered in this way, depending on attitudes to risk and the concern over shortage, households (of four people) might willingly pay $152 per year for insurance against severe water shortages arising from future climate change. The Productivity Commission thought this extra cost was excessive, but it is an issue of judgement.

Other methods to include values for 'the willingness-to-pay' for security of service supply can be determined using approaches in environmental economics (Kolstad, 2011), which uses 'stated preference', 'contingent valuation' or 'experimental economics' techniques. Cooper et al. (2013) estimate the willingness-to-pay of different groups of consumers for reduced probabilities of facing water supply restrictions in Sydney and Melbourne.

Real option versus heuristic[1] approaches

Both real option and cost–benefit approaches have, at their core, the idea that probabilities can be attached to different possible 'states of the world' or future outcomes. Procedures then emerge for decision-making, based on maximising the expected payoffs from investments when risk is represented by such probabilities and when there is both learning and irreversibility.

In some cases it may be possible to determine or delimit probabilities using evidence. For example, historical records on rainfall and stream-flow data can help characterise future water supply. Even then the future water market is difficult to pin down, as the effects of climate change and water demands are driven by as-yet unspecified population policies. Urban water markets are characterised by uncertainties that are difficult to define using probabilities. For example, CSIRO (2008) estimates of climate change impacts on rainfall in the Murray–Darling Basin are highly uncertain — the report forecasts that future precipitation may fall within a range from 70 per cent higher to 70 per cent lower.

[1]Heuristic – a procedure for resolving decision problems using approaches that are plausible although not necessarily optimal.

Given that option pricing approaches are data- and technique-intensive, are there less-data intensive frameworks that can help decision-makers think through infrastructure investment planning?

Uncertainty

Where planners know the possible outcomes that can emerge but do not have even subjective probability information about the likelihood of these states, heuristics based on classical decision rules are useful. For example, application of the 'minimax criterion'[2] will result in an investment if it avoids the worst possible outcome imaginable - for example a city running out of water. This approach is related to the well-known "Precautionary Principle" (Chisholm and Clarke, 1993) often used to guide natural resource management.

Moreover, the minimax rule dictates not taking a decision if, in one state of the world, costly policy action would be ineffective. Policy in this situation would never be implemented because the worst outcome is that the adverse outcome occurs along with a costly failed policy. Unless the possibility of policy failure can be ruled-out the minimax criterion is implausible since it always involves recommending inaction.

'Minimax regret'[3] is an alternative heuristic. This involves calculating, for each possible investment option, the "regret" experienced defined as the difference between the cost incurred when undertaking an investment and the cost a decision maker would seek to incur once the outcome is observed. It suggests undertaking a policy when that action can avoid catastrophic consequences at relatively low potential cost.

This is the basis of the Intergovernmental Panel on Climate Change's (IPCC) case for global action to address climate change. Action should be taken because there are potentially catastrophic consequences of climate change (with trillions of dollars of consequent costs) and these can possibly be averted at relatively low cost (e.g. a small per cent loss of gross domestic product (GDP)).

This approach has appeal — it avoids very costly possible situations if this can be done at low cost. However, an implicit assumption is that the probabilities of the catastrophic events are not negligible, which invites arbitrariness.

[2] Minimax criterion - minimizing the maximum possible loss that could conceivably occur.
[3]Minimax regret - difference between the actual payoff and the payoff that would have been obtained if actual future outcome had been observed.

The minimax regret criterion has the attractive feature of focusing on extreme risks, for example, the (non-negligible) possibility that a city may have highly-restricted water supply. The criterion then seeks to consider inexpensive ways of avoiding such situations.

Since both the minimax and minimax regret heuristics do not use probability information they cannot involve any attempt to incorporate improved learning about such probabilities.

Gross ignorance

The most realistic situation to consider is the decision–problem where neither subjective probabilities nor an exhaustive understanding of other possible states of the world can be described. This is described as 'gross ignorance'. This situation is realistic though problematic. Therefore, it is important to anticipate that non-envisaged outcomes may occur, to avoid tunnel-vision theorising in making investment decisions and to adapt when making development plans by being prepared to reconsider plans that show evidence of being unsuccessful. This is difficult for large, individual public investment projects. It is therefore wise to consider scenarios where climate change is much more and much less severe than anticipated and to also consider situations where, as above, a policy failure may occur.

In these situations scenario-based approaches are a valuable tool for decision making. These support a shift from 'enhanced prediction' to 'robust decision making' under a range of potential future conditions. To maximise benefits of this approach, there needs to be a clear linkage between the scenario analysis and specific policy and program decisions. See more at: http://www.vcccar.org.au/adaptation-resources-for-decision-makers#sthash.LGGj60iW.dpuf

Conclusion

Learning with time or through experience is fundamental to the assessment of risky, irreversible investment projects under climate change uncertainty. Quasi-option values measure the extent to which planners should be conservative when assessing such prospects in situations when decision-makers are only concerned about expected returns. With risk neutrality, there is a case for making more cautious judgements than standard cost–benefit analysis suggests. If decision-makers are risk-averse then measures of their risk aversion provide the basis for quantitatively determining how much they will pay to avoid such risks. There could be a shift towards much less caution when undertaking investments.

In situations of uncertainty a number of heuristic decision rules can incorporate a focus on the issue of policy failure.

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