REPORT TO
THE NEW ZEALAND MINISTRY OF TRANSPORT

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ADAPTIVE INVESTMENT MANAGEMENT

USING A REAL OPTIONS APPROACH IN
TRANSPORT PLANNING

C O N T E N T S

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Introduction

Real options provide a framework for planning and decision-making in the face of uncertainty. It is of most value where there is both uncertainty and flexibility to adapt a project to manage risks and respond to potential opportunities. It is an important supplement to traditional cost-benefit analysis in that it recognises the value of flexibility, and helps to avoid committing unnecessarily to large fixed costs which may be later regretted.

Real options analysis is particularly useful in probing uncertainties and identifying potential strategies to manage those uncertainties – in some cases, even to exploit those uncertainties to deliver greater value. It also provides a rigorous framework for valuing projects, although in our view much of the value of real options lies in the former, i.e. thinking through the uncertainties, their implications and the way in which they are best managed.

This report provides an explanation of real options analysis: the role of real options in planning and assessment frameworks, the insights it provides, and the different approaches that can be used to apply real options (with a particular emphasis on decision trees). The paper also provides an illustrative application to ports planning in NZ.

Real options analysis had its origins in finance, with the development of a methodology for valuing put and call financial options by Merton, Black and Scholes. Real options emerged as a formal discipline in the late 1970s, with Myers being the first apply real options to corporate strategic planning.

Real options, as distinct from financial options, take the form of capabilities to defer or abandon, ramp up or scale down, to introduce staging, to switch technologies, or invest in additional information prior to commitment of a project – along with soundly based principles to guide decisions on whether and when to use these capabilities. Many of the concepts will be familiar to transport planners, although they may not have been termed "real options".

The key steps in undertaking real options analysis are to:

⎯ Ensure that the real need is identified
⎯ Identify the nature and sequence of the key uncertainties
⎯ Probe the scope for adding value by building in or exploiting flexibility

Worked examples

The paper begins by explaining real options and illustrates its application by working through some simple examples. The first example considers the potential benefit of delaying a decision to invest in order to gain information regarding future revenues from the project. It shows that under a traditional analysis, where the decision on whether or not to invest is made prior to the resolution of the uncertainty, the expected value of the project would fail to cover its costs and the decision would be made not to invest. However by recognising and resolving the uncertainty, the optimal decision (to invest or to not invest) can be made in the light of outturn events – opening the possibility of a valuable project proceeding.

The second example considers the possibility of staging a project if there is uncertainty over the final level of demand, allowing an upgrade to capacity only if it is warranted. If only low demand emerges, then the amount of loss is minimised. If high demand emerges, then an expansion of capacity allows the upside opportunity to be grasped. Although it would have been cheaper to build the bigger plant initially, this would have been at the risk of incurring significant losses in the event of low growth.An adaptive strategy allows this risk to be avoided, and results in both a higher expected net value for the project and a lower downside risk.

Range of techniques

The paper explains the range of real options techniques that can be applied, including the Black-Scholes model (which was originally developed for financial options and later adapted to real options), numerical techniques and decision analysis.

To demonstrate the use of decision tree analysis, we use the software package TreeAge to develop a decision tree for the first of our simple examples, showing the decision-points and uncertainties and how the value of the project can be increased by managing the uncertainties.

Although the example is heavily stylised, it demonstrates how deterministic analysis, where decisions are taken in dis-regard of potential flexibilities and adaptive strategies, can be seriously biased. The typical "go/don't go" approach forces a harsh trade-off between upside opportunity and downside risk, a trade-off that is not necessary if there is flexibility to adapt the strategy in the light of how key uncertainties play out.

Decision trees can provide a powerful real options tool, as they encapsulate the key information in an intuitive manner, and allow a systematic statement and probing of the uncertainties and options. They also provide a useful means of communicating the key insights. Thus decision tree analysis:

— Structures the problem in a way that is intuitively understandable
— Is able to deal with multiple sources of uncertainty
— Defines optimal choices based on the consideration of the probabilities and outcomes of each choice
— Identifies an 'optimal' strategy over many periods of time.

Stylised ports example

To demonstrate how real options theory can be applied, the paper uses the example of planning landside transport links for New Zealand's ports. Recent years have seen a trend towards the use of bigger ships by shipping lines, with a resultant increase in transhipment and the need for increased capacity in landside links. However it is not clear to what extent this trend will continue, to what extent there will be continued increase in transhipment whether or not ship sizes continue to increase, and how the pattern of traffic will affect individual ports.

The paper illustrates the application of decision tree analysis by examining a decision whether to invest in upgraded road links for a hypothetical Port X, which is in competition with Port Y. The key uncertainties can be characterised as follows (to which we attach broad probabilities):

— Whether there will further increases in ship sizes
    – If yes, whether this will imply more transhipment
    – If no, whether transhipment will increase anyway

—— Whether there will be any rebalancing of transhipment traffic between road and rail

—— Whether Port Y will gain traffic at the expense of Port X

We also make assumptions regarding the cost of reinforcing the road link to Port X, the cost of incremental rail reinforcement, and the cost of congestion in the event that the road link to Port X is not upgraded. These various costs can be compared against the value of increased trade, to determine the strategy with the greatest net benefit to New Zealand.

Using this highly stylised model and parameter assumptions, we conclude that the strategy of allowing congestion to build up is preferable to pre-emptive investment in a road link, before likely traffic patterns have been established. However this conclusion is dependent on the likely cost attaching to congestion: if the costs of congestion are greater, then a point is reached where the optimal decision switches in favour of building the road link up front.

The paper then considers whether there are any strategies available which might be used to relax the constraints facing planners. Such a strategy would seek to avoid or mitigate the potential cost of congestion, while gaining the additional information needed for a robust decision to be made. Typically such strategies involve incurring higher operating/variable costs in order to minimise or delay commitment to large fixed costs. One such strategy might be to encourage the use of coastal shipping or rail for transhipment and so reduce the potential cost of road congestion while providing new information for planning investment – information in the form of revealed demand for services ahead of the need to commit to high capital investment. Such encouragement provides an option to hedge against the risk of a subsidy being given to importers and exporters (via over-investment in road and rail capacity).

More generally, the example also demonstrates the way that reformulating a problem within a real options framework can, for sound reasons, turn conventional thinking about appropriate economic and policy measures on its head.

Insights from real options

Real options can add value to investment planning and management by:

—— Limiting the risk both of locking into costs that later prove to be regretted and of underinvesting in ways that prove later to be very costly

—— Lowering the risk premium attaching to financing costs if and when that commitment is made

—— Building into the strategy greater flexibility and investing in gaining earlier information

Often real options can justify investment in a project where, under conventional analysis, the benefits appear to fall short of the costs. Real options analysis does this by constraining the downside and taking better advantage of upsides with low probabilities but potentially high value. Real options can be applied to any investment, but the approach is most valuable when there is substantial uncertainty combined with scope to vary the investment strategy.

In reality, business planners almost always plan for flexibility. The main problems arise from the way that strategies are compared. If project assessments do not adequately reflect the value of flexibility, then less flexible investment will be favoured over more flexible ones, and planners will face less incentive to develop proposals that embed greater flexibility. The real options approach addresses both of these concerns. Sometimes this will involve greater complexity, because the real investment challenge is itself complex and more complex than the standard analysis allows. At the same time, however, there is often less need for precise estimates than with standard analyses. For this reason, real options can provide

credible guidance, even where there are wide margins of error involved and a standard discounted cash flow analysis is not feasible or would lack credibility.

The final section of the paper offers a brief commentary on the perspectives on real options provided by NZ real options papers supplied by the Ministry.

1   Explanation of real options

1.1   Introduction

Real options provides a powerful framework for planning and decision making in the face of uncertainty, which emphasise adaptability and the value of flexibility and insurance. The framework enables improved planning processes, with information (known and unknown) and decision choices being identified and structured in ways that best manage uncertainty, and this is where much of the benefit of real option thinking lies.

Real options is a form of cost-benefit analysis, in that it allows the comparison of costs and benefits across alternative projects or portfolios of projects, and favours strategies in which benefits are high in relation to costs. Conventional cost benefit is a special case of real options, namely where there is no flexibility or no cost-effective way to exploit flexibility (or, far less probably, no uncertainty). In these circumstances, a conventional CBA will yield similar conclusions to a real options analysis. However where there is uncertainty, combined with an ability to provide cost-effective flexibility to adapt to new information as it emerges, then application of a standard CBA analysis, with no consideration of how a large-scale infrastructure project might be adapted, can provide seriously misleading results.

This is because traditional cost benefit analyses (CBA) analysis, when used on its own, is prone to both failing to attribute adequate value to the flexibility that a project proposal offers, and to discouraging the development of alternative proposals that incorporate additional, cost-effective flexibility. By failing to adequately value flexibility, it is prone to underestimating investment value and, as a consequence, risks killing off project concepts that could in fact proceed cost effectively with careful design for flexibility and risk management. Where traditional CBA does support a project proceeding, it is commonly a project with unnecessarily high costs and unnecessary exposure to the risks of a project delivering scale, form and timing that does not align well with actual needs.

For example, instead of a rigid project designed and sized to meet 'expected' future demand, an alternative project might involve initial modest investment, which can be scaled up if circumstances prove favourable or abandoned if not. The option value of the project lies in its ability to allow the upside opportunity to be exploited, while limiting the downside should events prove unfavourable. Real options provides a robust framework for valuing projects which incorporate such options for project adaptation, although in our view much of the value of real options is derived through the thinking through of uncertainties, their potential impact and ways to mitigate them by exploiting flexibility, rather than the application of formal valuation methodologies *per se* (although the latter may be needed to support the construction of detailed business cases). Of course, these two ways of looking at real options are not mutually exclusive – and are commonly highly complementary.

Real options provide practical ways of identifying and exploiting flexibility, by examining questions such as:

— Could the project be delayed long enough to resolve the uncertainty first, or at least to significantly reduce the uncertainty? Would this entail other costs that would outweigh the value of the option that would be gained?

⸻ Is there a practical way of reducing the uncertainty early, to reduce the needed delay and its costs, through investment in market research, demand modelling etc.? Could this be cost effective?

⸻ Would it be possible to commit only to the front end costs of the project, or to the costs of a smaller but scalable version of the project, ahead of the uncertainty being resolved, delivering options to later avoid some of the costs or to ramp up to pursue the upside opportunity?

1.2   Origins and application to investment planning

Formal option theory was first developed in the context of financial markets, with financial options involving the right to buy and sell assets. A call option provides the holder with the right to buy a specified quantity of an asset at a fixed price (called the exercise price) at or until the expiration of the contract[1]. It will be profitable to exercise the option should the asset price rise above the exercise price at a time when the contract allows the option to be exercised. As long as there is a non-zero chance that this situation will emerge, then the option has value – in the same way that a lottery ticket has value before the result of the draw is known.

Equivalently, a put option gives the buyer an option to sell an underlying asset at a fixed price at a given date (or under other agreed conditions) in the future. The holder of the put option will exercise it if the asset price falls below the exercise price, with the pay-off being the difference between the price of the asset and the exercise price. Again, the option has value if there is a non-zero chance that the future asset price will favour the option being exercised.

More complex forms of options can be constructed. Compound options derive their value from other options rather than an underlying asset[2]. Rainbow options derive their value from two or more sources of uncertainty. Barrier options arise when the payoff on an option depends on whether the price of the underlying asset reaches a certain level by a specified time period. All involve the *capability* to force a particular financial transaction, and the *right to choose* whether or not to do so, based on what is known at the time, rather than what is known at the time the options contract is agreed.

Real options emerged as a formal investment planning discipline in the late 1970s, being used particularly in decisions concerning the exploration of oil and gas fields. Myers first applied the term real options to corporate strategic planning (as against physical assets) in 1984.

"Real" options (as distinct from financial options) take the form of decisions to defer or abandon, ramp up or scale down, to introduce flexible staging in a project, to switch technologies or change platform/capability. Importantly real options also include the option to invest in additional flexibility or in additional information before committing to an irreversible decision. Thus real options include:

1. Options to *delay* some or all of an irreversible commitment to a project or part of project.

    – The emergence of desalination technologies made it viable, and safe, to delay committing to the costs of new facility that would not be needed should the drought break. The shorter lead times involved, and the greater certainty of supply enabled

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1 American options can be exercised at any time within the term of the contract. European contracts can only be exercised at the end of the contract: there is no ability to exercise early.

2 There are four forms of compound options: a call on a call, a call on a put, a put on a call and a put on a put.

the delay, and so reduced the risk of overinvesting in capacity. The traditional approach to dealing with drought risk, building and filling dams ahead of the drought, afforded no such flexibility

2. *Information options*, that provide access to information that may reduce key uncertainties which are constraining the value of the strategy. Additional information allows the project to be more tightly optimised around the way the future is actually going to be, rather than the way it was first assumed it would be.

   – These can arise naturally out of delay options – for example delay in commissioning construction of a desalination plant has the potential to allow the drought to break and so enable commitment to the new plant to be avoided completely.

   – They can also emerge from proactively commissioned investments which gain access to better information – for example, through mineral exploration, through commissioning of detailed studies of demographic trends near an area being considered for development, or through other forms of investment in R&D.

   However, for the real options approach to add value to the decision-making process, either the information uncertainties must be resolvable prior to the investment being made or it must be possible to manage the investment so that it can adapt as uncertainties are resolved and outcomes emerge.

3. Options to *expand capacity or supply* rapidly or cost effectively in response to higher than expected demand

   – Peaking power stations afford access to the capacity to ramp generation up rapidly, to respond to peaks in demand, allowing high value opportunities to be tapped to satisfy system demand.

   – Making provision for transport corridors that allow for greater than expected future demand, for oversizing the pipes on gas or water infrastructure investments etc. can all enable lower cost future expansion in capacity.

4. Options to *reduce supply* in response to a drop in demand or the value of marginal supply

   – Sydney's desalination plant can be scaled back, through switching off modules, or turned off entirely in the event that its dams fill and start to overflow, allowing wasteful operating costs and environmental impacts to be avoided

5. Options to *switch* the way a demand is met

   – Dual petrol/LPG cars have options to switch between fuels to exploit shifts in relative prices or availability of fuels

   – Options for dual fuel generating plant are more expensive, but allow advantage to be taken of future changes in relative fuel prices

In all cases, the types of calculations involved in a conventional CBA are likely to be required to determine the net impacts of each of the alternative expansion or contraction options which are taken into account under the real option analysis.

Transport planners have traditionally worked with many of these concepts – although they may not have been termed "real options", and they may not have been assessed using modern real options methods. Thus real option principles support the sorts of decisions commonly made by planners to:

— Purchase/retain a land corridor which is wider than needed initially to allow for future road-widening

— Preserve an unused rail corridor, and using it for an alternative use temporarily or indefinitely, such as a bus route

— Pilot new technology, such as new signalling or train controls

1.3 Elements of real options analysis

Real option analysis involves three steps:

— Ensuring that the real need is identified

— Identifying the nature and sequence of the key uncertainties

— Probing the scope for adding value by building in or exploiting flexibility.

1.3.1 Meeting the real need

When ensuring that the real need is identified, it is crucial to ensure that the right question is being asked. For example, during the recent drought in Australia, the need for water security was, in important cases, not identified separately from the need for additional water to serve growth in water demand. Traditional planning led to a large desalination plant being built in Melbourne, which if it had been run continuously would have delivered relatively inexpensive "manufactured" water. However the flexibilities inherent in desalination, in terms of providing a capability that could be introduced in stages, with expansion only occurring in the event of the drought continuing, was not incorporated into the design of the system. With the breaking of the drought the large scale of the Melbourne plant is now widely regretted. Broadly analogous failure to allow adequately for flexibility had earlier led to proposals for a very large, continuous operation desalination plant in Sydney. However, application of real options principles there did result in substantial modification of the strategy, to allow for delayed, and then staged, construction and intermittent operation.

In both cases, the initial planning proceeded on the assumption that the need was for additional water to be sourced as cheaply as possible. However, this was not the need – in both cases the need was for system security – for insurance against the risk of the system being unable to meet demand for water. It turned out that the most cost effective insurance involved a very different strategy from that which would deliver the cheapest additional water (even after the drought broke).

It is also important to consider the project both as a stand-alone project and as part of a portfolio of projects which in total meets the requirements placed on the system. Thus water supply planning in NSW no longer considers the next least costly source of water supply in isolation. Rather it examines the portfolio of future supply options that could be implemented, covering expansion of recycled and desalination capacity, augmentation of smaller dams, pipelines to secure water from a different geographic area (to spread climate-specific risk), demand management as well the next major dam if a suitable site is available. The performance of the portfolio against the requirements for sufficient water, sufficiently secure water and other environmental objectives such as river water quality can then be assessed.

The addition of "manufactured water" such as recycling or desalination may be expensive in project unit cost terms of water delivered, but if operated flexibly can improve the security of supply of the system on a cost-effective basis. Importantly, manufactured water projects commonly offer the flexibility to delay any commitment to building new plant until the system is deep in drought – a flexibility not offered by most dam-based water supply projects – and this value can make such strategies highly cost competitive.

It is also important to not confuse means with ends. The statement of need should not be bundled with assumptions on how that need should be met. In the above discussion, the assertion that there was a need for additional water involved just such confusion – it was water security, not water, that was the real need. The focus on delivering more water diverted attention from strategies that could deliver greater water security without the need to lock into the costs of delivering more water – i.e. from strategies that embedded flexibility to delay commitment to high costs. Often a completely different approach to meeting a challenge will provide the most cost-effective solution – such as introducing flexible desalination capacity that can be utilised during periods of drought.

In short, to determine whether there is a real need, analysts need to ask the following types of questions:

⸺ Why do we need the investment?

⸺ What are the size and scope of the impacts of not investing?

⸺ Is the investment required now? Or in the future?

⸺ Is the project standalone or part of a portfolio?

1.3.2   The nature of uncertainties

The second key step is the careful probing of uncertainty. These uncertainties may be internal to the project, such as ground conditions or construction cost rates. Or they may be external to the project, such as influences on the demand for services or unpredictable climate changes.

Projects with large sunk costs tend to be vulnerable to changes in demand, and hence have the potential for regret should initial assumptions on future growth in demand prove misplaced. There can also be regret that greater capacity was not built, in the event that actual demand proves greater than was expected.

In addition it is necessary to understand how the sequence of events may pan out. In other words, we need to understand which decision is dependent on which uncertainty and in which order. The sequential order of uncertainties can sometimes result in different preferred investment strategies. One common approach to determining the nature and sequence of uncertainties is to work through the possible scenarios with a focus group. This process is also useful for confirming the problem definitions, the need to invest and the real options available. The development of a decision tree, as a representation of the structure of the available choices, also requires explicit consideration of the sequencing and interdependencies – and provides powerful tools for ensuring that this is done sensibly.

1.3.3   The scope for adding value through flexibility

For projects with large sunk costs, the scope for later regret can often be minimised by building in or preserving flexibility. Such flexibility might involve the incorporation of stages in a project, which allow high-cost elements to proceed later, more slowly or not at all should the anticipated demand not materialise.

Similarly, different approaches might be available that deliver different degrees of flexibility. For example, ICT, non asset approaches and R&D investments can often embed greater flexibility. Traditional transport infrastructure – roads, bridges, rail lines etc – tends to be reasonably rigid in the maximum capacities provided by a particular investment. In comparison, fixed copper wire telecommunications infrastructure has proven incredibly flexible as a platform for rolling out totally new communications technologies (such as the internet and streaming video), and for upgrading existing services for much greater speed and capacity. It is not necessary to script how flexibility will be used in the future to

recognise that wired and wireless communications infrastructure supports potentially high value options for future new uses, and for adapting rapidly to emerging demands and technologies.

Of course, transport infrastructure can embed significant flexibility. Engineering roads with capacity in excess of expected demands does just this – usually at a significant up-front cost. Provisioning for later road upgrade, but also for modifying lane directions to accommodate demands that vary with time of day are proven uses of inherent flexibility.

A potentially important point is that some uncertainty, even uncertainty external to the project, can sometimes be reduced dramatically as a result of information that the project will itself generate. For example, the first stage of a proposed road system, one designed with options to later broaden the road to accommodate higher demands, will itself start to deliver real data on service demands and trends in demand. The data emerging from the first stage of the project – including resultant changes in residential and commercial land use patterns that will feed later demand – can all contribute to a much sounder assessment of likely forward demand than can modelling based on broadly analogous experience.

If a project can be designed to deliver better and earlier reductions in critical uncertainties, this can in itself deliver substantially greater flexibility to adapt strategy cost effectively. New information can support high option value, by allowing other forms of flexibility to be used more effectively. This new information might come from R&D directed at external trends – but it can and commonly does include information that can be sourced from the early stages of an adaptive investment strategy.

Therefore, the key part of an adaptive investment strategy is to build in flexibility by considering all possible outcomes when selecting options for investigation. All of the potential responses to the identified outcomes need to be assessed (using traditional tools such as the net present value calculations commonly undertaken using a conventional assessment framework). The potential responses then need to be expressed in terms of a strategy which can be adapted as outcomes emerge.

1.4   The role of real options

The role of real options analysis is to provide access to choice, which limits the cost of actions which prove inappropriate with the benefit of hindsight. It aims to provide flexibility and assist in gaining the knowledge needed to guide decisions.

A real options approach seeks to minimise the risk that an investment will be regretted. It cannot eliminate the chance of regret – rather it limits the extent of the regret as far as possible, or as far as is cost justifiable. In doing so, real options may entail higher costs up front, in the way that car insurance involves higher costs than no insurance provided you don't have an accident. And, as with car insurance, different forms of options can entail a different mix between up-front costs and value in the event that an option needs to be exercised. Insurance with a high excess, in the event of a claim, is often securable at lower upfront cost. In the same way, real options may be obtainable at low upfront cost – in some cases it may be worth spending more to provide better risk management later.

Real options analysis, and the types of investment strategies it favours, commonly offer much lower **expected** costs (when correctly measured). Options to abandon an investment, or to delay it further pending external conditions improving, will typically have the effect of lowering the future expected cost of the project. It will also often allow upside benefits to be exploited, including in circumstances when the upside benefits might be inaccessible to a more deterministic project concept.

Under some circumstances real options may usefully add to expected costs, correctly measured, but only if there is a more than compensating increase in expected benefits. What is common in real options planning is for the project to be restructured so that the circumstances in which high costs will arise are closely correlated with the circumstances in which high benefits will flow. Costs will be kept low unless and until spending more emerges as cost effective. In effect, the project is being restructured to 'self-hedge', so the costs and benefits are more closely correlated. As result the distribution of net value has less downside and greater upside. Thus real options is not focused on reducing expected costs per se, but rather on reducing the exposure of the costs.

Peaking power stations, which can be turned on and off relatively easily, are an example of infrastructure that provides options. Similarly desalination capacity provides additional flexibility that can be used in the depths of a drought. In other contexts, R&D also can be used to provide options – for example much medical research is justified by the area being seen as "promising" and benefiting from good researchers who might develop a strong commercial or public health prospect, rather than there being a well-defined object from the research. Basic research is substantially justifiable not on the value of scripted outcomes, but because of the track record of well-managed basic research as an input to high value later developments – it can offer high option value even in the absence of a scripted commercial target. Reservation of transport corridors, or corridors wider than expected needs, can also underpin (at a price) potentially valuable expansion options.

In providing access to choice, real options plays several complementary roles:

⎯ In developing a sound statement of the investment challenge (including key uncertainties and possible flexibility)
⎯ In guiding the identification and assessment of possible investment strategies to increase value and lower risk
⎯ In providing soundly-based formal estimates of the value of key options, and of a strategy that embeds options.

1.5 Insights to be gained from real options planning

Real options analysis offers an approach to the planning, assessment and management of investments, especially investments of long planned duration. While in principle real options analysis is applicable to any investment planning and management, it comes into its own in comparison with more traditional approaches where there is a combination of two factors:

⎯ Substantial uncertainty of a kind where, were it possible to resolve the uncertainty before the investment is made, could have important implications for whether, when and how the investment is actually made. We term such uncertainty *strategy-relevant*.
  – Whether it will rain today is relevant to whether we should invest energy in carrying an umbrella; whether it will rain at the other side of the country is not.
⎯ Scope for varying the investment strategy – i.e. flexibility – in order to offset the damage caused by the possible ways in which uncertainty may play out or, equally importantly, in order to take advantage of emerging opportunities thrown up by the particular way the uncertainties are playing out.
  – Carrying an umbrella affords the *option* to put the umbrella up, should it start to rain, and therefore reduce the harm; the umbrella provides the capability to erect a mobile shelter, and this capability brings with it the option to do so if that would be useful.

If either of these conditions is absent, the real options approach will converge onto a more deterministic, NPV-based project assessment, very similar to the traditional cost-benefit

approach widely used now. That suggests that where large infrastructure projects are involved, with large sunk costs and hence the possibility of significant regret, that the nature of uncertainties and extent of flexibilities be probed carefully. If it is the case that there is no scope to incorporate a flexible approach into the planning then there is no advantage to be gained from applying a real options approach as it would not be able to add any further insights compared to a standard NPV analysis.

In that case, application of full of real options analysis would not be required to gain an unbiased assessment of the project. However, at the start of investigation into any potential project, it is important to test whether a real options approach would add value. This requires probing and characterising the uncertainties surrounding the project, and exploring whether alternative approaches could be used to add, or to better use, flexibility.

Real options adds value to investment planning and management by:

— Limiting the risk of locking into costs that prove later to have been unnecessary or cost ineffective. Often this is done by delaying commitment; investing strategically in reducing uncertainty earlier; or choosing a structure for investment that is more robust in dealing with the plausible range of ways the uncertainties will play out

— Lowering the risk premium attaching to financing costs if and when that commitment is made, by shifting the timing of major commitments to cost beyond the point at which uncertainties will be reduced

— Building into the strategy greater flexibility, and investing in gaining earlier information, to enable greater or more cost effective access to the upside opportunities associated with the project.

Often real options analysis can justify investment in a project where, using conventional analysis, the benefits appear to fall short of the costs. This is because real options serves to lower expected costs by constraining the downside. It also enables more advantage to be taken of upsides with low probabilities.

By contrast, deterministic planning processes often favour the worst case. The classic example is the traditional water engineering approach of planning water resource augmentation through additional dam storage, based on ensuring security of supply under a "worst case" scenario. Additional dam storage does not provide flexibility during a period of drought: it needs to be built and filled well in advance of drought conditions materialising. The emergence of desalination technologies has fundamentally changed the way planning can be conducted. It is possible to start building a desalination plant well into a drought and have it operating in time to secure supply. Moreover, it can be worth delaying the commitment to expenditure as late as possible, to allow for the significant chance that the drought might break – in which case the desalination plant would no longer be needed. Indeed, this period of delay can be extended by employing "readiness" strategies, such as purchasing the land, obtaining the environmental approvals, setting out the design requirements etc, which would enable the build to be mobilised rapidly once the need is confirmed.

In reality, planners almost always plan for flexibility. Scenario-based planning is common, projects are commonly staged in ways that almost always delivers options to delay and to scale up. Planners will commonly expect that the strategy will, in practice, be managed flexibly and, indeed, it often will. The main problems arise from the way that alternative strategies are compared. If comparisons are done using a method that does not adequate reflect the value of the flexibility in strategy, it will be prone to bias. Most commonly, this bias will favour less flexible strategies over more flexible ones (assuming there is a cost attached to the flexibility) and will favour not undertaking a project over undertaking it. In

failing to value flexibility, the assessments bias the estimated benefits, and net benefits, downwards. Many fundamentally good proposals have failed to receive funding as a result of these serious biases in assessment.

A flow on effect from this weakness in the assessment process is that it weakens the incentives for planners to invest extra effort in developing proposals that embed even more valuable flexible, which could deliver even better outcomes. The process is distorted towards project specifications that will perform well under the applicable assessment processes – even where these are flawed. Opportunities are missed even before they are thought of.

Greater use of real options methods could address both these concerns head on. Sometimes this will involve greater complexity – though mainly because the real investment challenge is more complex than the standard analysis allows. Quite often, however, real options methods provide a firm basis for commencing an investment much earlier and more easily than would more traditional methods. Because it allows for flexibility and adaptation, there is not the same need for precision in estimation, and the real options approach can prove tractable in circumstances when through-life discounted cash flow analysis is not feasible.

1.6 Two simple examples

The following examples illustrate some key aspects of real options analysis, and the way it overcomes the bias that can arise from considering only one deterministic option.

1.6.1 Example 1: Introducing an option to delay

The first example considers an investment which would cost $1.0bn to undertake. For simplicity we assume that there are two possible outcomes with respect to the level of future demand for the product produced, each with equal probabilities of emerging. If demand is high, the cumulative present value of future revenues will be $1.5bn. If low demand eventuates then the present value of future revenues will be $400m. (To keep the example simple, we assume no operating costs and abstract from discounting issues).

Under the standard approach to project assessment, the structure of the decision and possible outcomes would be as shown in Figure 1.

Figure 1 **Decision structure for investment with uncertain demand**
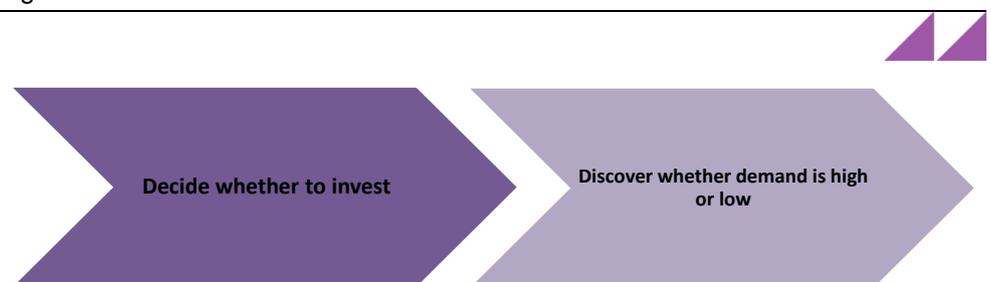
Table 1 shows the calculations that would be undertaken under a traditional NPV calculation to assess the value of the project and whether to invest. There are two possible outcomes of investing: high revenues of $1,500m or low revenues of $400m. If they have an equal probability of occurring, expected revenues are $1,500m x 0.5 + $400m x 0.5 = $950m. The expected future returns would be compared with the initial investment cost of $1bn to give

an overall project value of -$50m, supporting a decision not to proceed. This is shown in Part B of the table.

Table 1   **Investment project with uncertain revenue**

	Yr 0 Investment	Yr 1 Investment	Future revenues	Probability
A. Assumptions	$m	$m	$m	
Possible future revenues high			1500	0.5
Possible future revenues low			400	0.5
Investment cost	-1000			
B Cashflow: undertake in period 0				
Expected profit			950	
Investment cost	-1000			
Total NPV	-50			
C Cashflow: wait and invest if demand is high				
Expected profit =1500 x 0.5 +0 x 0.5			750	
Expected investment cost = 1000 x 0.5 + 0 x 0.5		-500		
Total NPV	250			

However suppose the decision structure is altered slightly, to allow the decision-maker to discover whether demand is high or low before committing to the investment (i.e. to create an option but not a commitment to invest). The adjusted decision structure is shown in Figure 2.

Figure 2   **Decision structure under wait option**
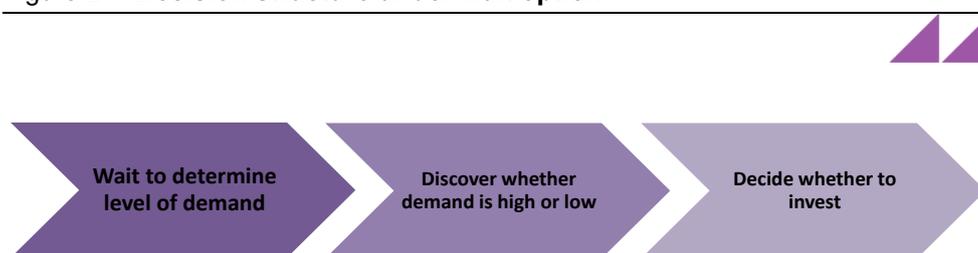
Part C of table 1 shows the value of waiting for one period before investing. If demand is high, the investment will be undertaken in period 1, in which case future revenues will be $1.50bn. If prices fall then the investment will not be undertaken, so that future revenues are zero. The discounted value of expected revenues are $1,500 x 0.5 + $0 x 0.5 = $750m. The discounted expected cost of the investment is $1000 x 0.5 + 0 x 0.5 = $500m, which gives an overall expected value for the project of $250m. Thus the option of waiting one period and then undertaking the investment is valuable.

Indeed, if these were the only uncertainties, then the analysis suggests that the maximum 'option fee' that it would be worth paying to secure the rights to the investment would be $250m.

Often the option of discovering additional information is not costless. In this simple example both the investment cost and the assumed future revenue stream were delayed one year

with the assumption that there was no cost imposed by the delay. In practice there is potential for delay to give rise to a variety of costs:

⎯ Cost might be imposed on users unable to access the product in that first year

⎯ There might be a shortening of the period over which revenues and profits can be earned if there is a fixed time period involved, or a likelihood of rapid obsolescence

⎯ There might be costs involved in the process of obtaining the information awaited

⎯ The loss of first-mover advantage could result in a significant reduction in forecast revenues and profits.

In this very simple example, the source of uncertainty was clear, and the action needed to gain additional information (i.e. wait one period) was also very clear. The indicated strategy is very much a real options strategy – you exercise the option to delay and you exploit the extra information that becomes available before committing to full project costs. However in real-world examples, the source of inflexibility and the means of reducing the impact of irreversible costs are often far from obvious. In such circumstances option analysis can be used to add value to a project through a clear understanding of the uncertainties involved and the strategic options available.

1.6.2   Example 2: A scalable investment

Another example of how options can be used is provided by the ability to invest in a scalable project rather than committing to a large scale investment in the presence of uncertain growth. In this example, we assume that there is a residential development being planned, which requires a local water treatment plant. It is not possible to simply wait and determine whether demand will be high or low – some initial investment is needed for the development to go ahead. It is uncertain the extent to which the development will grow over the foreseeable future however, with future revenues being either $1,500m or $400m

We assume that a treatment plant costing $1,000m would be sufficient to cover all future growth in demand. Alternatively, a smaller plant could be built, which provides half of the capacity, but at a slightly higher unit cost of $600m. If the probabilities of high and low growth are equal at 50%, the expected value of installing the large plant is -$50m as can be seen from Part B of Table 2.

Table 2　**Investment in scalable plant**

Period	Investment	Future revenues	Probability
A. Assumptions	$m	$m	
High growth development, revenues up		1500	0.5
Low growth development, revenues down		400	0.5
Investment cost large plant	-1000		
Investment cost small plant	-600		
B Cashflow: invest in large plant upfront			
Investment cost	-1000		
Expected revenues		950	
Total NPV	-50		
C Invest in small plant and upgrade if needed			
Investment cost small plant	-600		
Possible outcomes:			
High growth, second investment needed	-600	1500	0.5
Low growth, no second plant needed	0	400	0.5
Total NPV	50.00		

Part C of the table shows how building a scalable plant allows future costs to be better matched to future revenues. If high demand materialised, revenues would be $1,500m less investment costs of $1,200m, giving a project value of $300m. If low demand emerges, revenues of $400m less investment cost of $600m gives a net value of -$200m. Since the two outcomes are equally likely, the overall expected value of the project is $50m.

The option of building a smaller plant initially guards against the large loss that would arise if the development sustains only low growth and the large plant is built. At the same time, it enables high future growth to be accommodated, by building a second plant or treatment module. If the high growth situation emerges, then with hindsight it would have been cheaper to build the bigger plant initially. But that would have been at the risk of incurring significant losses in the event that low growth materialises (a 50:50 risk). The additional flexibility provided by the scalable plant comes at a cost, but a cost that serves to lower expected costs, and in particular eliminate the risk of a very major loss.

2 Different approaches to the application of real options

As shown above, much of the benefit of real options thinking can emerge just from the process of probing the nature of key uncertainties and flexibilities. Real options analysis helps focus the questions being asked, understand how uncertainty impacts on the ability to deliver the best decisions, and then explore how to create and exploit flexibility to reduce threats and increase access to opportunities.

As the complexity of problems rises, there can be great advantage in tapping into some specific tools for setting out the investment possibilities in a structured way. A range of techniques are available to guide both the identification of potentially valuable options and to support the assessment of alternative investment strategies.

This is not a 'one size fits all' approach. Depending on the nature of the uncertainties and the investment possibilities, some tools will perform better than others. In some cases, ACIL Allen has found it appropriate to develop a new set of tools tailored to the specifics of a problem. The following discussion indicates the range approaches available, which fall broadly into the categories of Black-Scholes models, numerical techniques, simulation and decision trees.

2.1 The Black-Scholes model and application to real options

The pivotal insight into valuing financial options was made by Black and Scholes (1972). Their insight was that options can be valued using a continuously replicating portfolio of the underlying asset and borrowing/lending. Since an option can always be replicated by such a portfolio, the principles of arbitrage mean that the value of the option must equal the value of the replicating portfolio. This means that the valuation of an option can be divorced from the risk preferences of individuals.

Black and Scholes derived a formula to value European options which are dividend protected[3], and this formula has been applied widely to financial options. The formula was derived using a continuous time model, assuming that share prices follow a Geometric Brownian Motion and that share price is the only source of uncertainty[4].

The result that Black-Scholes derived stated that[5]:

The value of a call option[6] $(C) = S\, e^{-yt}\, N(d_1) - K\, e^{-rt}\, N(d_2)$

Where

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[3] Merton (1973) subsequently elaborated the formulae to take account of dividend payments, which serve to reduce the value of holding the option.

[4] Other authors have derived analogous (more complicated) formulae for when the distribution of prices follow an alternative motion, such as a Markov process, or when there are multiple sources of uncertainties.

[5] As modified by Merton for the presence of dividends.

[6] An equivalent formula was also derived for put options.

$$d_1 = [\ln(S/K) + (r\text{-}y + \sigma^2/2) \, t] \div \sigma\sqrt{t}$$

$$d_2 = d_1 - \sigma\sqrt{t}$$

and S = the share price
     X = the exercise price
     y = dividends
     r = the risk free rate
     σ^2 = variance in the ln(value) of the share price
     t = time to expiry, and
     N(d) = the cumulative normal distribution function.

$N(d_1)$ is the proportion of shares required to replicate the call option, and $N(d_2)$ is the probability that the call option will be exercised on expiry.

Thus the formula calculates the value of a financial option, given a number of parameters. These parameters include the share price, the exercise price of the option, the risk free rate, the variance of the share price and the time until expiry of the option.

Myers (1987) was the first to suggest that options pricing could be used to value investments with operating or strategic options. Since then, numerous authors have developed the application of options to real investments (see for example Dixit and Pindyk (1994)). Table 3 indicates the interpretation of the Black-Scholes parameters when applied to a real options project.

Table 3   **Interpretation of parameters in financial vs real option valuations**

S	Share price	The present value of the cashflows expected from the investment opportunity
X	Exercise price	Fixed investment required for the project
R	Risk free rate of interest	Risk free rate of interest
Y	Dividends	The value lost by delay
σ^2	Variance of stock price movements	Variability of the cash flows associated with the project
T	Time to expiry	The period for which the investment opportunity is available

Given appropriate parameters, the application of the Black-Scholes formula is straight-forward in a mechanical sense. However, in our view it is less applicable to a real options framework, given the strong assumptions required for its derivation. The key concerns are:

— The premise that a continuously replicating portfolio can be created using the underlying asset and riskless lending or borrowing is not defensible when the underlying asset is not traded;

— The Black-Scholes model[7] assumes that the price process of the underlying asset is continuous. However, in practice many of the important risks in an investment project are discrete in nature – for example a sudden technological change can cause a step jump in the value of a project;

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[7] And other partial differential equation approaches

⸺ The variance of returns is unlikely to be known and constant. While this assumption may be reasonable for financial options, the variance for real projects is usually both difficult to estimate and varies over time.

⸺ When market data is used to estimate the variance of returns, there is often only a poor correlation between these returns and the returns on the investment project concerned; while

⸺ The use of subjective data to estimate the variance is inconsistent with the approach's reliance on a replicating portfolio and market data.

In broad terms, investment proposals where key uncertainties are big and lumpy, and their impacts are reasonably well understood, tend to play to the strengths of decision trees relative to Black-Scholes. On the other hand, when uncertainty involves market determined prices and values moving progressively in response to a myriad of ill-understood uncertainties, which can be encapsulated by the specification of a probability distribution or random process, this tends to play to the strengths of the Black-Scholes approach. Stock market prices often exhibit something approaching a 'random walk' driven by tens of thousands of individually small effects, with occasional major shocks. Modelling that sort of volatility tends to be harder using a decision tree.

2.2 Numerical techniques

Numeric approaches can be used to estimate the value of options when the application of formulaic approaches, such as Black-Scholes, is too difficult.

2.2.1 Binomial trees

The most commonly used numerical procedure is the binomial method, whereby binomial trees are used to approximate the behaviour of the underlying asset. The binomial trees assume that in each period the value of the asset moves up or down by a given percentage movement. These up and down movements and their corresponding probabilities are determined on a risk-neutral basis – ie so that the expected return of holding the asset is equal to the risk free rate. The option price is then calculated by starting at the end of the binomial tree and rolling the tree backwards, discounting value at the risk free rate.

Following the exposition in Copeland and Antikarov (2001), this approach is sometimes referred to as the Marketed Asset Disclaimer (MAD) approach. It assumes that the present value of cashflows is the best unbiased estimate of the market value of the project were it a traded asset. Asset prices are assumed to follow the Geometric Brownian Motion on the basis that changes in asset values follow a random walk.

The volatility of the cashflows is determined subjectively (ie without reference to market traded data) – often using a Monte-Carlo simulation[8] of the inputs to estimate the volatility. This volatility is then used to model a binomial process over time.

Borison (2003) identifies the lack of market-traded data as the major problem with this approach. While the calculations may be internally consistent, no effort is made to tie these assessments to market valuations. Thus while the underlying asset and the option may be priced consistently, both may be mispriced relative to the market.

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[8] Monte Carlo simulation relies on repeated random sampling from a defined distribution of the unknown variable.

2.2.2   Simulation

The other numerical method commonly used is simulation, whereby a Monte-Carlo simulation is used to sample the different paths that an asset value may follow. For each path the option payoff is calculated and discounted at the risk free rate. The arithmetic average of the discounted payoffs is the estimated value of the asset. See Juan et al (2002) for a simulation methodology applied to a harbour investment problem.

The disadvantage of a simulation approach is that, unlike decision tree analysis, it is not easy to identify the optimal decision path for a project, or indeed the states of the uncertain variable(s) that leads to a given project value. While it is easy to calculate expected values for cashflows given a specific policy for all decisions, it is difficult to determine the policies that maximize expected value given the information available at the time. This makes the simulation approach less useful for project decision-making, although simulation can form a useful adjunct to a decision tree approach in testing sensitivities.

2.3 Decision analysis

2.3.1   Overview of decision trees

A decision tree maps the sequence of decisions which define the project together with the key sources of uncertainty. Decision trees can provide a powerful real options tool, as they encapsulate the key information in an intuitive manner, and allow a systematic statement and probing of the uncertainties and options. Decision trees are supported by off-the-shelf software and provide a useful means of communicating the key insights.

Decision tree analysis:

— Structures the problem in a way that is intuitively understandable

— Is able to deal with multiple sources of uncertainty

— Defines optimal choices based on the consideration of the probabilities and outcomes of each choice

— Identifies an 'optimal' strategy over many periods of time.

The discipline of identifying the different states of the world and the key decision points is valuable in developing an understanding of the project. By attempting to identify flexibilities and constraints, it is often possible identify new options and strategies. By contrast, under a classic 'Black-Scholes' type of approach to real options it can be hard to identify the states of the uncertain variable that leads to a given asset value (especially when there is more than one source of uncertainty). This "slurring" of sources of uncertainty hinders the ability of Black-Scholes analysis to prompt better design of options and other risk management strategies.

Within a decision tree, the decisions emanating from a decision node represent the options available to the decision maker. The chance nodes identify where an external event will influence the project, and assign probabilities to each outcome. These outcomes need to be specified as discrete possibilities even if this means approximating a continuous outcome. For example, a price outcome within a range might be approximated by two or more 'representative' prices, each with a specified probability.

2.3.2   Simple example decision tree

Figure 3 takes the simple example shown above (Section 1.5) and structures it into a formal decision tree, using the TreeAge software package. First we consider the situation where the decision is being made to invest upfront, i.e. not waiting for the additional information on

future revenues and profitability. The tree shows the initial decision of whether or not to invest and the subsequent resolution of uncertainty regarding the future level of demand and operating profits.

The decision to invest incurs the initial investment cost of $1bn, with the level of outturn revenues determined by whether high or low demand eventuates. The decision not invest incurs no costs or revenues/profits. (In this example, we have input all of the model parameters into the decision tree, so that the decision tree software is able to identify the optimal choice given the probabilities of different outcomes. However it is also possible to use the TreeAge software combined with an Excel front-end, which allows sophisticated modelling of the costs and benefits to sit alongside the decision tree analysis).

Figure 3   **Decide up front - decision tree structure**
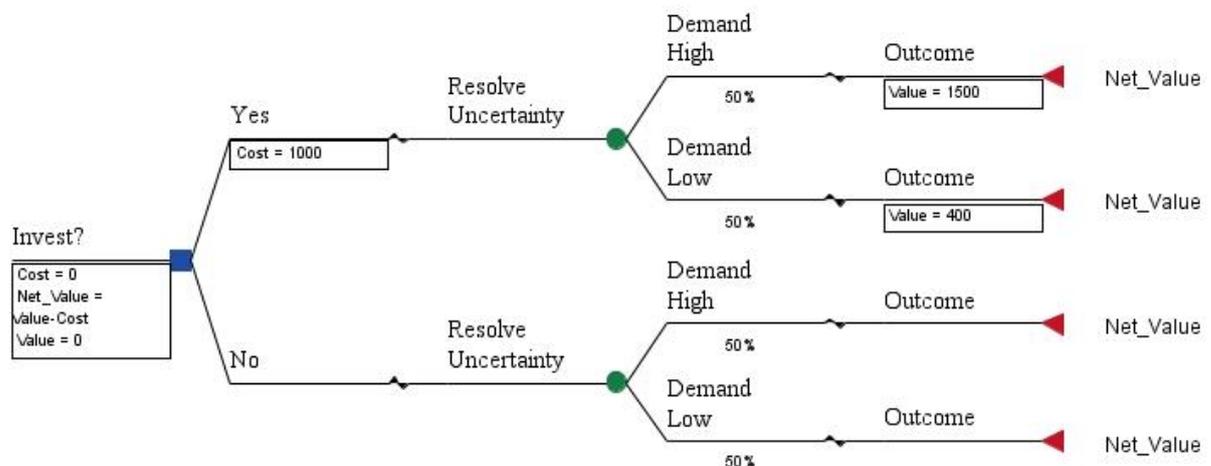
Once the tree has been laid out, decision analysis solves the tree from right to left, working back down each branch to find the best possible decision at each point. One decision rule commonly used is to select the decision which offers the best expected value, with the present values weighted by their probabilities[9].

Figure 4 shows this process of rolling back the decision tree to determine the optimal initial decision. The outcomes of the decision to invest are an overall profit of $500m or a loss of $600m (shown in boxes), with an expected value of -$50m (shown in a box at the decision point). As this is less than the expected value of the decision not to invest, the Yes option is crossed out (with two lines through the path). The decision not to invest is shown in pink, indicating it is the preferred decision. The No decision forgoes the upside possibility, as the price of avoiding the downside.

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[9]   Another rule used is to take account of the risk attitudes of the user/firm, and build a risk-adjusted objective function.

Figure 4 **Decide up front - decision tree rollback**
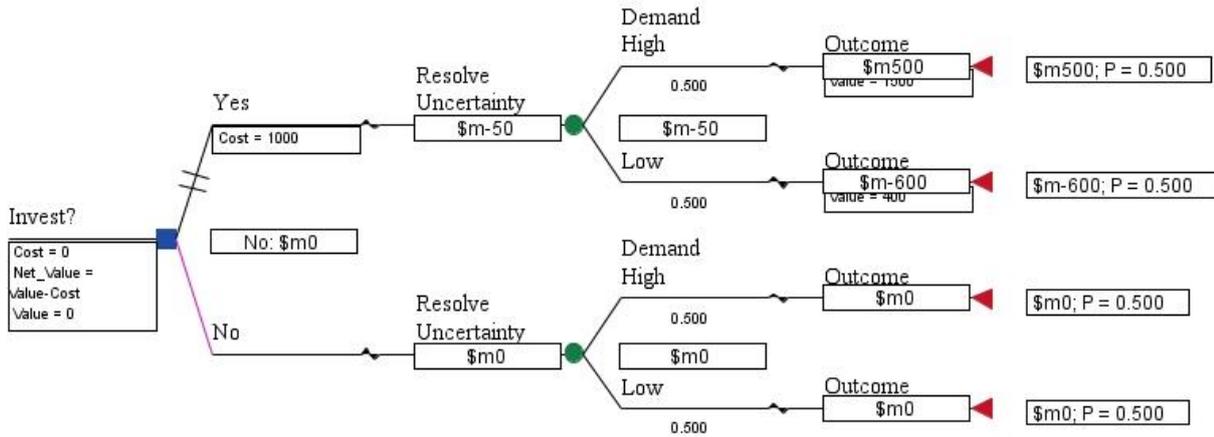
The following two figures show the decision process if the decision to invest is made <u>after</u> the uncertainty is resolved. The same cost and value assumptions have been used, but with the assumption of a one period delay to enable information about future demand to emerge.

Figure 5 **Wait to decide - decision tree structure**
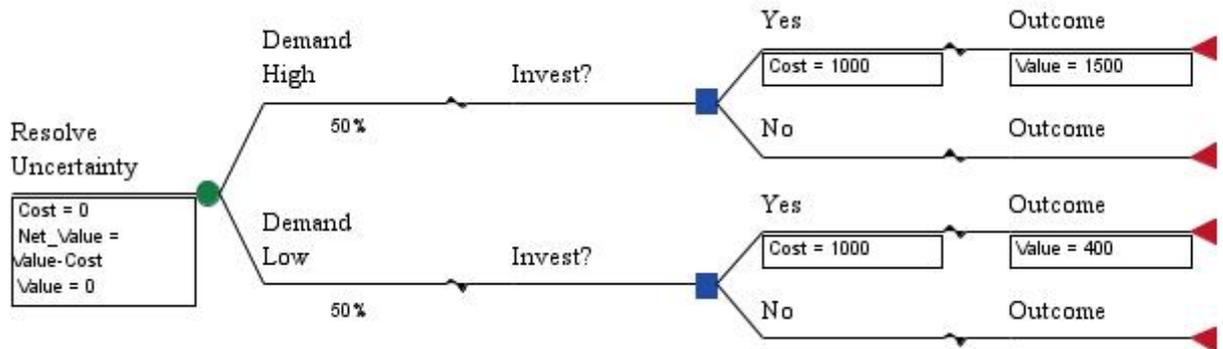
The implication of the change in decision structure is clear from the rollback in Figure 6. In this case two decisions are rejected: the choice of not investing when demand is high, and of investing when demand is low. Taking the expected value of the two possible outcomes gives an expected value of $250m, reproducing the result shown earlier in Table 1.

Figure 6   **Wait to decide - decision tree rollback**
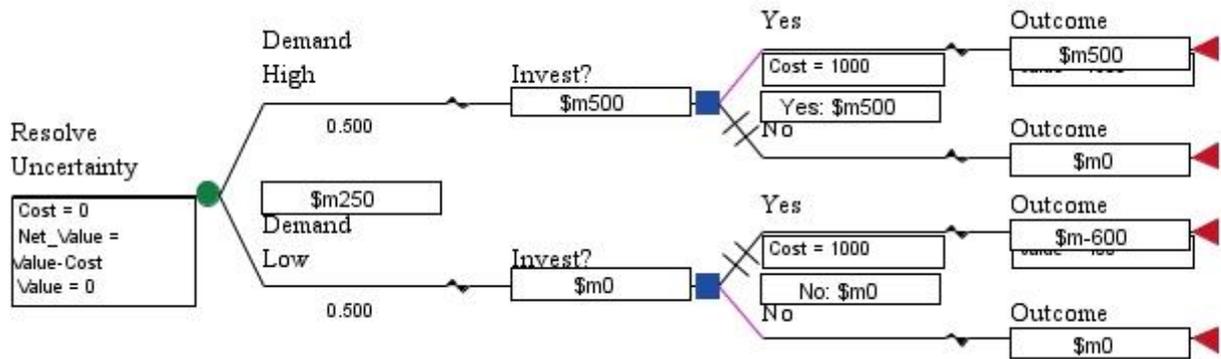
In this stylised example there is no downside risk, yet all of the upside opportunity has been retained. The need to trade-off upside opportunity to avoid downside risk has been circumvented, by a strategy that invests first in resolving the uncertainty, and then responds flexibly to the new information.

Lastly, we consider the situation where delay can achieve a significant reduction in uncertainty, although some uncertainty remains. Thus instead of certain high demand arising with a 50% probability, we assume that there is a 50% of high demand being likely: i.e. high demand will emerge with 75% probability but there is still a 25% probability of low demand emerging. Concomitantly, instead of certain low demand, we assume that there is a 75% probability of low demand and a 25% probability of high demand. While still stylised, this two-step structure for the uncertainty more closely approximates the manner in which uncertainties commonly reduce through time.

It is straightforward to introduce this residual uncertainty into the decision, by introducing two tiers of uncertainty resolution. Following the initial resolution of whether high or low demand is more likely, we replace the certain outcome following the decision of whether or not to invest with the 75%/25% and 25%/75% probability outcomes.

The overall probability of high demand remains at 50 per cent, but by the time of the decision to invest, additional information has allowed the probabilities to be revised to either 75% or 25%: 75% if the outcome is expected to be high demand, in which case there is scope for proceeding, and 25% if the outcome is expected to be low demand, in which case the expected profit is insufficient to justify the cost.

The decision tree is shown in Figure 7 below, and the rolled back version which solves the tree is shown in Figure 8.

Figure 7   **Partial reduction in uncertainty - decision tree structure**

ADAPTIVE INVESTMENT MANAGEMENT USING A REAL OPTIONS APPROACH IN TRANSPORT PLANNING
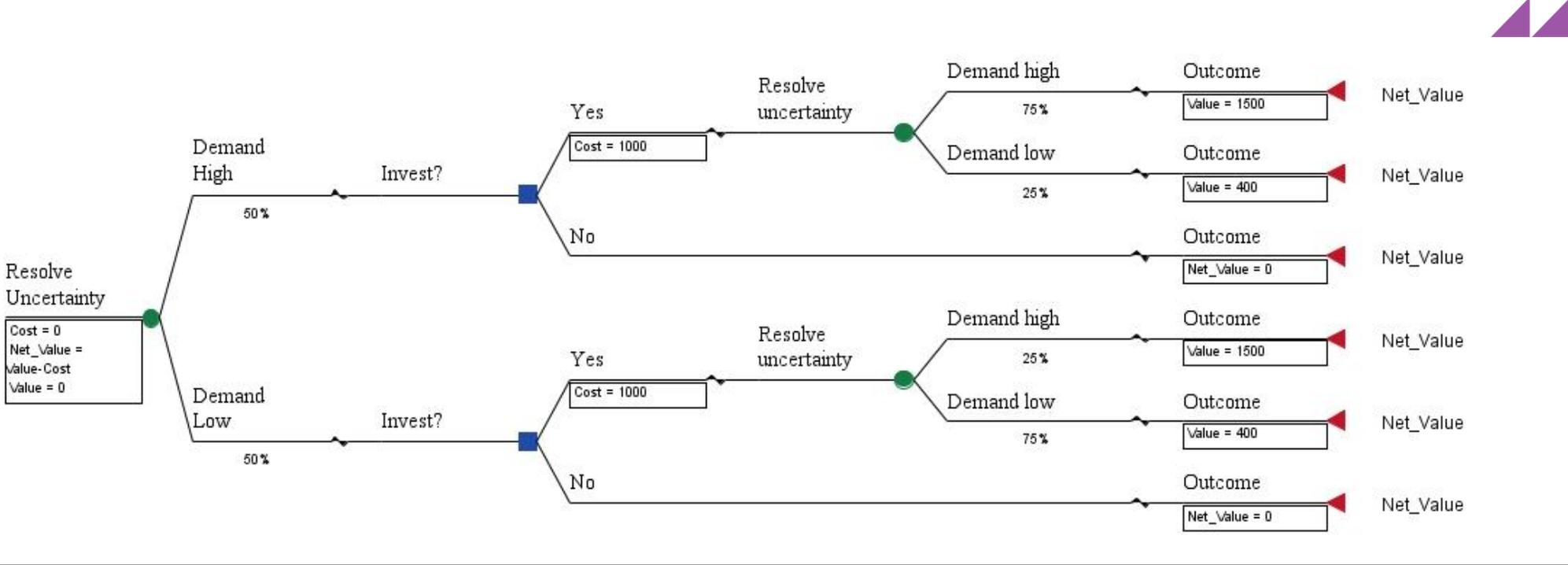
Figure 8 **Partial reduction in uncertainty - decision tree rollback**
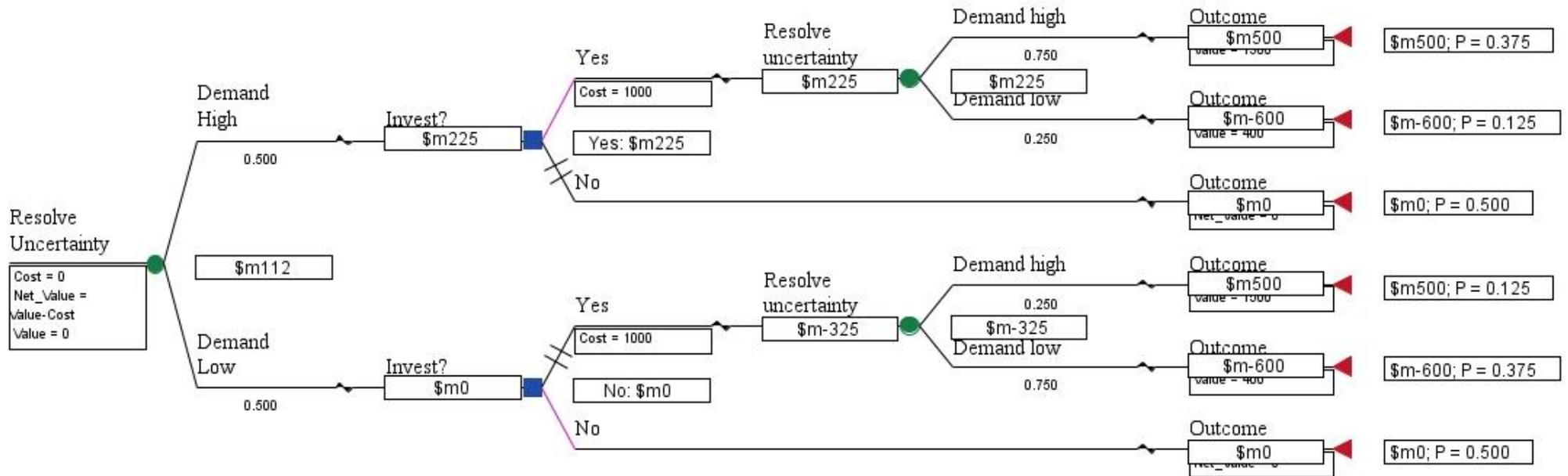
Not surprisingly, the outcomes under Figure 8 fall somewhat between the deterministic solution and the earlier costless resolution of the uncertainty.

— As we have seen, the deterministic solution kills the project, locking in a net return of zero, because otherwise there would be large downside and a negative expected return.

— The 'full information' solution (Figure 6) allows the project to proceed, with a 50 per cent likelihood, eliminating the downside risk and securing expected returns of $250m.

— This approach based on partial resolution still invests with a 50 per cent likelihood. The results suggest the project should proceed if the reduced uncertainty delivers a 75 per cent chance of high demand, but should not proceed if the probability of high return emerges as only 25 per cent.

– The expected net return falls half way between the deterministic and the full resolution versions. The value of the option to partially resolve the uncertainty before committing is $112m.

– Some downside risk re-emerges – because of the 25 per cent risk that the investment is made but the demand is actually low. The worst case scenario is a loss of $600m (as would have been the case had the project just been built without worrying about risk), but with a probability of 1 in 8 instead of 1 in 2. It is this greatly reduced likelihood of losses that suggests the risks are now defensible, given the potential upside.

Alternatively, if the decision-maker is risk averse (and this risk aversion is factored into the analysis), then the decision tree could still favour non-investment as a way of protecting against the 1:8 chance of a poor outcome.

Of course, the 1:8 risk would also encourage exploration of other options, including staging the initial investment as a smaller facility, better suited to the low demand outcome, while building in options to scale up later should the case for doing so emerge.

The decision trees show why the deterministic analysis first undertaken can be biased against an investment that could be highly valuable if it was more adaptive, and recognised as such when the analysis was done. The 'go/don't go' approach forces a harsh trade-off between upside opportunity and downside risk – a trade-off that is not necessary if there is some flexibility to adapt the strategy in the light of how the key uncertainty actually plays out. The value of the flexibility, and the value of the associated option to proceed or abandon the investment, is $250m (or $112m with residual uncertainty).

2.3.3 Using decision trees to probe the problem

In reality, the "full information" situation, where it is possible to delay and hence gain complete certainty as to the outcome, is unlikely. While it may be possible to gain some information by delaying, or by investing in gaining additional information, usually some level of uncertainty will remain.

In this situation, decision trees can be a powerful tool to aid the process of probing the uncertainties and potential responses. This involves looking for practical ways of tapping into at least some of the value of flexibility, by examining questions such as whether the uncertainty can be resolved ahead of commitment to the project (such as delaying the project or investing in additional information), or whether it would it be possible to commit only to the front end costs of the project, or to the costs of a smaller but scalable version of the project, ahead of the uncertainty being resolved.

Setting up a decision tree requires that probabilities be specified for each of the possible outcomes at a chance node. The assessment of such probabilities can be based on evidence from other jurisdictions or comparable situations, if such information is available. For example, if the underlying distribution of the factors giving rise to the uncertainty is known, then probabilities can be estimated by simulating the range of likely outcomes. Often, however, it is necessary to rely on qualitative judgements as to the likelihood of different outcomes.

However decision trees can provide powerful insights even where precise knowledge of probabilities is lacking. A crude representation of the probabilities can be a lot more accurate than using an approach that effectively ignores the uncertainty. Furthermore, starting with crude estimates allows the model to produce indicators of the levels of probability that would start to imply a shift in the initial strategy, and this can provide powerful insights, and support robust strategy decisions, even where the initial assumptions are quite crude.

A further issue is that decision trees can become very "bushy" because they encourage setting out all of the possible scenarios. However, modern software packages such as TreeAge facilitate the construction of decision trees through their replication facility (called 'cloning'). Such packages also allow the incorporation of simulations to calculate expected payoffs. Simulation addresses the problem of the "flaw-of-averages"[10]. It also enables the likely bounds of outcomes to be tested – for example to test the sensitivity of the conclusions to changes in cost assumptions or in the probability of factors beyond the control of the firm.

Another feature of decision trees is that they can lend themselves to starting simply and adding complexity if the analysis of the simpler representations suggests this would be cost effective. The above example illustrates this at quite a simple level. The initial decision tree (Figure 5) represented the resolution of uncertainty through a single uncertainty node and there was only one possible decision modelled – to build or do not to build. That simple model showed that uncertainty was relevant to strategy and that a reduction in uncertainty could be valuable – even if it entailed significant cost. Based on that, complexity was added Figure 7 in the form of a two-step reduction in uncertainty, requiring an additional level of uncertainty nodes. The analysis then showed the high value of reducing uncertainty – alongside the re-entry of significant risk.

It is also possible to build decision trees of different parts of a system, and then bring them together within a higher level tree, that can make calls on the component trees. This capability also favours starting small, for example testing how uncertainties and flexibilities might interact, and then adding detail if and as this appears worthwhile.

2.4 Comparison of approaches

Black-Scholes provided a valuable insight into option theory, however the strong assumptions needed to apply their formula renders the approach inappropriate for most real world projects. In particular, the formula applies to European options when most projects are more like American options (with the possibility of early exercise). Also Black-Scholes

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[10] The so-called "flaw of averages" dictates that a function of expected inputs will only equal expected output if there is a linear relationship between all variable inputs and output. Thus in general $\varepsilon[f(x)] \neq f(\varepsilon[x])$. This means that where there are variable inputs, a proper assessment of a project's NPV will often require a Monte-Carlo or similar simulation to derive the expected NPV (instead of using the expected values of each input). This expected NPV can then be compared with the value of the project after allowing for flexibility, to derive the value of the option. See Dixit and Pindyk (1994).

assumes continuous time movements and correlated markets. Indeed the Black-Scholes assumptions do not work well even for many financial derivatives – especially energy ones – because of the presence of negative prices and high kurtosis[11].

Where the analysis is concerned with project choices rather than valuations, or where there is the potential for major discrete changes in circumstances or knowledge, decision tree analysis is likely to prove the better approach. It is our experience that, in many cases, the construction of a standard decision tree, combined with appropriate sensitivity testing, will yield the key insights required for informed decision-making.

Binomial tees provide one method of introducing discrete rather than continuous movements in costs/prices but where, as with Black-Scholes, the uncertainties typically involve a rolling sequence of individually small price/cost variations, often without well-understood causal drivers. They can provide a powerful tool for the valuation of projects, however modern decision tree tools such as TreeAge provide a similar capability but with greater ability to incorporate detailed modelling of the costs and benefits to attach to individual nodes of the tree. These strengths are particularly apparent where there are a few major uncertainties with potential to induce large changes.

Monte Carlo simulation provides some guidance on the possible range of outcomes, given knowledge of the underlying distributions of key input parameters. However it provides little or no direct guidance on how best to structure decisions on the adaption of a project to minimise risk and to take best advantage of opportunities. It can support 'trial and error' simulation modelling of alternative decision strategies, and can be a powerful tool for probing the robustness of a strategy implied by decision tree, binomial tree or Black-Scholes analysis.

2.5 The choice of discount rate

The Black Scholes assumption of a continuously replicating portfolio allows the valuation of an option to be divorced from individuals' risk preferences. This assumption of a risk free portfolio implies that the risk free rate be used as the rate for discounting across time periods.

For infrastructure projects, however, the assumption of a risk free portfolio is unlikely to realistic. In particular, the portfolio cannot be traded continuously and it is not possible to lay off the specific risks involved. This raises the question of an appropriate discount rate.

The rate could be based on the standard weighted average cost of capital used for projects of similar risk. However, a real options approach serves to lower the amount of risk the project is exposed to, relative to the standard cost-benefit approach. If the adaptive decision process enables most of the risk to be eliminated before substantial expenditure commitments are made, then a rate close to the risk free rate may indeed be appropriate.

Often real options analysis will not eliminate all risk, although it does allow the risks to be better managed. If the risks reduce progressively over time, then it might be appropriate to use a discount rate that varies over time, or more specifically, as key uncertainties are reduced. This is likely to be most appropriate where there are distinct phases in the project, with very different risk profiles. One such example is a project involving exploration for oil,

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[11] Degree of peakedness of a probability distribution, with high kurtosis pointing to a greater propensity for 'extreme events' than is implied by a normal (Gaussian) distribution with the same variance.

followed by production if the field is successfully developed. The exploration task is subject to very high specific risks, suggesting that a high discount rate may be appropriate for the initial stages of the decision tree. However, once exploration has been undertaken and development of the field begun, the risks become much lower. Accordingly, the discount rate used within the decision tree should be lower for this stage in the project.

As the discussion in the Grimes paper indicates, the choice of a suitable discount requires significant judgement[12]. The major benefit of real options analysis lies in its ability to structure the way in which risk is handled: in other words it is often more about managing the risks than valuing the project. Nonetheless, projects will still require the choice of an appropriate cost of capital if the project is to be subject to assessment criteria, and/or if it is to be compared with other projects. In that case, one possibility would be to use the standard risk rate used for government projects. Alternatively the discount rate could be adjusted downwards, if the real options approach succeeds in reducing the project's risk profile significantly, potentially allowing lower cost funding to be accessed.

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[12] Grimes, A., 2010, The Economics of Infrastructure Investment: Beyond Simple Cost Benefit Analysis.

3 Illustrative application of real options to transport planning

3.1 Application of real options

The essence of the options approach lies in its structured way of exploring the design of strategy. It probes ways to add value through careful investments in flexibility and processes to be used in guiding the exercise of that flexibility. Real options analysis also ensures that comparisons between alternative strategies are made in ways that deal appropriately with the flexibility available to each strategy. It involves:

— Explicit recognition that there are uncertainties that are relevant to the best form of investment and the characterisation of what can be said about those uncertainties.

  – For example, demand uncertainty might reflect past volatility or might reflect the possibility of discrete changes in trends. It involves probing plausible departures of demand from expected paths.

  – Emerging technological and lifestyle trends can induce particular uncertainties that may not be well-reflected in past patterns, and that require consideration of plausible variations across possible future outcomes. The question whether some road systems are approaching a 'peak car' state as alternative transport and communications strategies bite is an example.

  – Sometimes this characterisation of uncertainty will recognise clear causal drivers of the uncertainty, in other cases it may be no more than a statement about the statistical properties of past variations.

— Careful consideration of how the uncertainties are relevant to strategy being considered.

  – If the uncertainties could be resolved before commitment to strategy, how would this influence the shape and value of the strategy? This goes well beyond the usual 'scenario planning' approach of probing whether the strategy could deal with certain outcomes, and instead looks at how the strategy could be shaped to take advantage of knowledge of these plausible outcomes.

— Careful consideration of whether a flexible, adaptive approach to the strategy might offer better prospects than a more deterministic, project-focused approach to planning

  – This involves not just identifying flexibility to adapt to changing information, but allows for the possibility of incurring additional up-front costs in building greater flexibility into the strategy – effectively as an insurance premium

— Using an appropriate set of tools to compare the alternatives and to select the preferred strategy – which will generally be some form of adaptive process, involving elements of up-front activity with the later evolution of the process as the uncertainties evolve.

  – These tools may include a range of ways of valuing individual options but this need not be the case. Preoccupation with the valuation capabilities of real options can be distracting, when its greatest value lies mainly in guiding the evolution of a robust, evolving strategy.

In the remainder of this section, we use the ports example raised in the RFT and subsequent discussion to illustrate how real options can be used to explore the uncertainties faced by MOT in its planning role, and the sorts of flexibilities that might be brought to bear.

3.2 Landside planning for ports in NZ (an illustrative example)

3.2.1 Background on NZ ports

Compared to other developed nations, NZ's economy is heavily orientated towards exports, including wood and timber products, dairy, coal, fruit, meat, iron and aluminium. Virtually all physical exports go through the ports, as well imports such as petroleum products, manufactured goods, textiles, fertiliser, and plastics.

Figure 9 shows the location of NZ's ports.

Figure 9   **Location of NZ's ports**
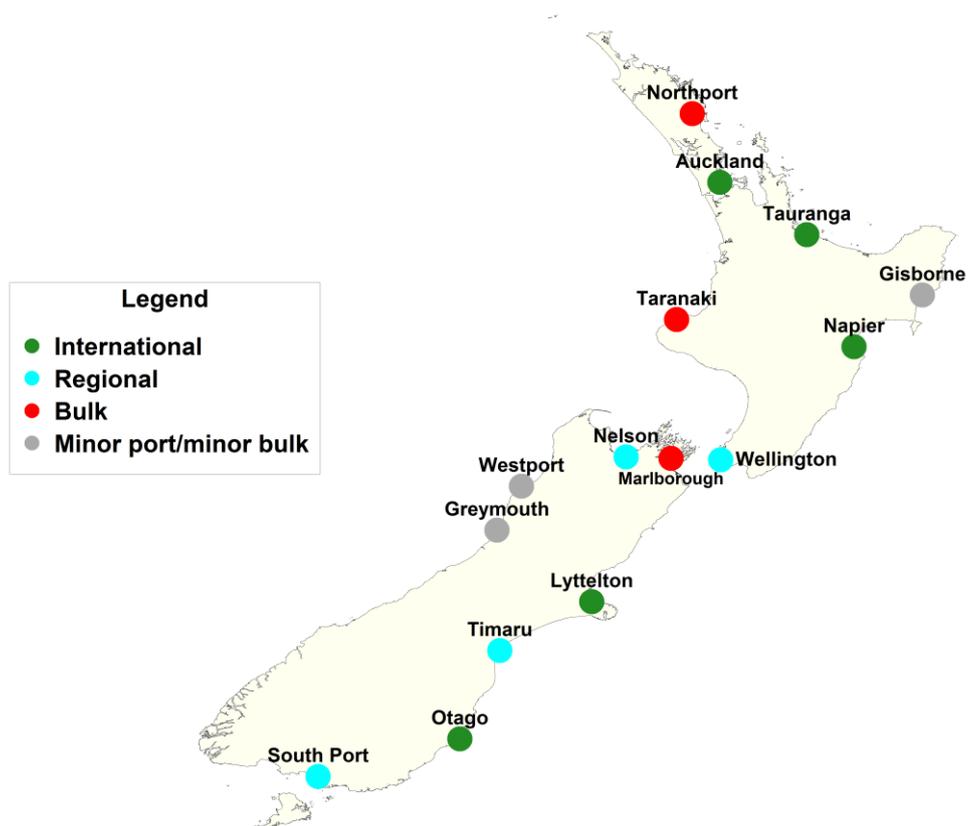
Source: ACIL Allen

Table 4 classifies the ports according to whether they are container based (international and regional), or bulk.

Table 4 **Classification of ports**

Port	Code	Commodity type
Ports of Auckland	AKL	International Container
Tauganga	TRG	International Container
Lyttelton	LYT	International Container
Port Otago	POE	International Container
Northport	NTH	Bulk
Taranaki	NPL	Bulk
Marlborough	MLB	Bulk
Timaru	TIU	Regional
Southport	BLU	Regional
Napier	NPE	International Container
CentrePort	WLG	Regional
Nelson	NSN	Regional
Gisbourne	GIS	Minor bulk
Westport	WST	Minor port
Greymouth	GRY	Minor port

International shipping lines used to stop at many of NZ's ports. However the global financial crisis (GFC) left the shipping lines suffering from massive over-capacity, leading to the laying up and accelerated scrapping of ships alongside very significant price discounting. To reduce their costs, shipping lines have been aggressive in seeking logistical efficiencies, including through larger ships making fewer port calls. Thus while international ships used to call at around 14 NZ ports, now there are five main international container ports: Auckland, Tauranga, Lyttelton, Port Otago and Napier.

This consolidation into five hub ports has led to substantial transhipment, to collect goods for export and to distribute imports to the final destination. Transhipment can be undertaken by coastal shipping, road or rail freight. The future use of these different methods is not clear, and will be influenced by the quality of the road and rail links to different regions and the extent of double-handling costs across the different modes.

The use made of coastal shipping will depend also on the extent of any co-ordination between the ports. NZ's ports are either completely or majority owned by local councils, although they vary in terms of the extent of private sector participation in operations. As ownership is largely independent, the ports compete – not just as businesses in their own right, with a focus on port profits, but with the added role of being regional gateways, underpinning the competitiveness of regional enterprises.

However Tauranga recently bought Timaru's container operations, as well as owning 50% of Northport. It is possible that such joint ownership may encourage co-ordination in the form of increased use of coastal transhipping. Again, decisions made in relation to rail and road links are likely to influence the incentives for greater coordination.

Nor is it clear to what extent the trend towards larger ships will continue. Mega-ships are being introduced on Far East and European routes, which is likely to displace the existing large ships onto secondary routes such as NZ. On the other hand, ship size appears to have flattened out recently in NZ, so that it is possible that the trend towards bigger ships may have ceased or slowed temporarily.

The international ports differ in the depths of their channels, industrial relations records, capacity of landside links and distance from exporting and importing customers. Their relative strengths have been changing over time with dredging, road and rail improvements, and investments in "inland ports" and in port cross-shareholdings.

Thus different ports have different advantages across a range of features. Moreover, there are several uncertainties which are yet to play out, which may favour some ports over others. This raises questions regarding when and how to best invest in the expansion of the landside links that are needed to avoid congestion and ensure efficiency in NZ's port logistics chains. The following section illustrates how an options analysis might approach this question for a pair of hypothetical ports: Port X and Port Y.

3.2.2 Stage 1: Identifying the need

The Ministry of Transport is involved in decisions regarding the provision of all landside transport links, including road and rail infrastructure. Planning for future needs involves considerable uncertainty, given that new infrastructure typically involves sizeable projects which can be "lumpy" relative to the growth in demand. And where there is uncertainty, there is potential for later "regret" of decisions if demand does not turn out as expected. Similarly, changes in technology or supply conditions can result in projects turning out to be seriously constrained in their ability take advantage of the new technology or to adapt to new information, challenges or opportunities.

In the case of landside planning for ports, we would identify the need as being the cost-effective provision of land transport infrastructure, aimed at maximising the net benefits of NZ's international trade.

3.2.3 Stage 2: Identifying the nature and sequence of the key uncertainties

In its planning role, the Ministry faces a wide range of sources of uncertainty. These include uncertainty as to:

— The source and location of future growth in the NZ economy and hence the need for future improvement of regional road and rail links. Growth could follow past trends (being centred on Auckland), or agglomeration economics might lead to relatively fast growth in the northern triangle of Auckland-Hamilton-Tauranga. Recent strong growth in dairy farming in the South Island might continue, and/or growth could be led by new mineral or gas discoveries or new agricultural developments.

— Likely future change in the demand for urban passenger movements, and hence the need for enhanced road capacity. Of particular importance are potential "game changing" factors such as the possible advent of "peak car" usage, which could lead to the reversal of trends which have previously been reasonably stable. This potential makes the risk of regret particularly acute.

— Whether recent trends for larger international ships will continue, and whether this will continue the trend towards fewer port calls to a small number of "hub" ports. Freight to and from other origins and destinations needs to be transhipped, using rail, road or

coastal shipping, again leading to requirements for improved rail or road links to particular hub ports.

It is important also to recognise that decisions taken in relation to landside links – including decisions on policy – are likely to influence how these uncertainties play out. The nature of future links will influence the way that patterns of port demand evolve, by altering the relative economics of different patterns of evolution demands and usage. The Ministry needs to factor in the incentives it will change as decisions are made, especially if new or improved links are going to involve risks, or costs, being borne by the wider community.

This section provides an illustrative application of real options techniques to the third of these uncertainties: the future transport links needed by a potential hub. The aim is not to develop recommendations as to a preferred strategy. Rather it is to demonstrate the steps involved in real options analysis, the mechanics of the assessment, and the nature of the insights that it can yield.

To this end, we have employed a somewhat simplified structure for the uncertainties and decision points. A robust application of real options would involve workshopping the issues in detail, to identify the full range of uncertainties and their correlation with each other, the areas of flexibility, the options available to different players and their incentives in making decisions.

The choice of parameters, such as probabilities, costs and values, can be difficult. However this is an issue that needs to be addressed in any cost-benefit assessment. One advantage of real options analysis is that it facilitates testing the importance of particular assumptions, identifying thresholds beyond which optimal decisions would change and hence focussing attention on the areas where additional information on key parameters would be particularly valuable.

The starting point in developing a decision tree is to explore the key uncertainties and options. The key uncertainties facing the government in planning for landside transport links to NZ ports are:

— Will the trend of larger ships, fewer port calls and more transhipment continue?

– Will ship size continue to increase or has it plateaued? Will certain ports attract new and bigger ships once draughts are deepened?

– Does increased ship size necessarily mean fewer port calls?

– To what extent will transhipment be by coastal shipping, road or rail?

– Will bigger ships increase the peak loadings on the port? Will this carry any implications for the choice between improved road or rail links?

– To what extent does government wish to influence modal decisions by funding capacity of one form versus another?

— How will continued competition between individual ports play out?

– Will particular ports continue to gain market share?

– How will this be influenced by any change in mix in ship sizes between ports?

– To what extent will port and landside constraints affect the ability of particular ports to expand?

These questions raise a series of issues when planning any necessary reinforcement of transport links

— At what point should government commit to augmenting the transport links for any particular port

- What lead times are required to avoid inefficient congestion on roads?

- Given that government and taxpayers, rather than the ports themselves, bear the risks of overinvestment in landside links.

— Can government build in additional flexibility in order to delay the time when a decision has to be made, to allow additional information about the level of traffic arriving at a given port and the extent of peak loading.

- Such flexibility would guard against the risk of underinvestment in roadside links, while allowing the collection of additional information as to the scale of augmentation needed.

— Does government wish to pre-empt commercial decisions by improving the transport links in advance of expansion requirements? Are there other issues, such as externalities or policy positions that favour one mode above the others?

The deepening of the draught at any particular port has the potential to trigger significant changes in the pattern of ports usage across NZ and hence the pattern of freight transfers. Government will want to limit the risk that it gets the scale of any upgrade to landside links wrong, which implies considerable benefit in waiting until the work in deepening the draught is completed and resultant traffic patterns are clearer.

However simply waiting carries a risk of underinvestment – in particular the possibility that the growth in freight traffic around a particular port contributes to congestion and a decline in NZ's international competitiveness.

3.2.4 Stage 3: Probing the scope for adding value by building in or exploiting flexibility

This section illustrates how options analysis could be used to explore the optimal timing and type of investment in landside links for NZ ports. As above, the analysis is intended to be illustrative only – thus it is highly stylised and does not cover the full set of uncertainties, choices and interdependencies involved. The Ministry would need much closer involvement in the development of an authoritative model of this type before it could to be used to guide strategy.

Suppose the government is considering in investing in improved road links for Port X. Our starting point is to assume that there will be continued increase in overseas trade, with benefits of $1,000m to the NZ economy. Against these benefits need to be set the cost of additional road and rail links, as well the cost of additional congestion if links are not reinforced as required.

We have characterised the key uncertainties as involving:

— Whether there will be a further increase in ship sizes

- If yes, whether this will imply more transhipment

- If no, whether transhipment will increase anyway

— Whether there will be any re-balancing of transhipment traffic between rail and road, assuming no growth in coastal shipping

— Whether another port will gain traffic at the expense of Port X

We assume that additional rail freight requires some additional expansion of rail line capacity, and that this is more expensive for Port Y than Port X. To begin with, we assume

that no upfront investment is made in road links, so we also include congestion costs when the additional transhipping takes place by road rather than by rail.

Figure 10 in Appendix A sets out a structure for these uncertainties and attaches probabilities to them. The bottom set of branches uses the TreeAge feature of "cloning" discussed earlier. This allows the structure and parameters of a "master" set of branches to be replicated elsewhere in the diagram, which can greatly simplify the complexity of large trees.

Rolling back the tree gives a total expected net value of $715m, which reflects the benefits of trade, less the costs expected to be incurred on reinforcing rail links and as a result of increased congestion.

Alternatively, a decision could be make an upfront investment in improved road links, to pre-empt the likely increase in road congestion around Port X and the costs this would impose on importers and exporters. Given our assumptions regarding the road build cost and the avoided congestion costs, rolling back the decision tree shown in Figure 11 yields a net value of just $655m. This indicates that the upfront investment in road links is a less valuable option than doing nothing, given the range of possible outcomes in terms of freight movements.

However, this result is dependent on the structure of the uncertainties modelled and the parameters chosen. If for example the cost of road congestion was significantly greater, then investing in the initial road link could become the more valuable option.

Options thinking looks also looks for ways to relax the constraints being faced by decision-makers – in this case the need to decide on an investment in advance of information as to how movements in traffic will play out. Thus it is worth considering whether there are any strategies available which might avoid the potential build-up of congestion while gaining the additional information needed for a robust decision to be made. One strategy might be to reduce the build-up by investment in small chokepoints, another might be to work with the logistics industry to spread peak truck demands and another, discussed in the appendix, could be to subsidise coastal shipping.

Further investigation might yield alternative ways of lessening the constraints – typically this is done by finding different mixes of fixed/sunk costs and operating costs. High fixed costs can allow size economies to be tapped, thus lowering the forward unit costs if significant extra capacity is needed. However, investments that involve higher unit operating costs combined with lower fixed costs and greater scope to modify output can be dramatically more valuable under a real options paradigm. This can apply indefinitely – as shown by the value of flexible electricity generation and water factory production capability. Or like our example above, it can apply during an early phase of adaptive investment management when information about likely levels of forward demand is improving rapidly. In that circumstance, a low capital cost option affords powerful insurance against potentially excessive or inappropriate patterns of investment.

Sometimes, this can suggest looking at very different approaches to addressing a problem – with the early stages of an adaptive strategy sometimes seeming counterintuitive when viewed through a traditional analysis lens.

Our ports example shows that it may be efficient to allow road congestion to grow to a level that might be judged excessive under traditional assessment methods, if this allows delay in commitment to very high cost infrastructure when there is uncertainty about the appropriate configuration. The options generated by the delay include options to improve the design of

later expenditure – they are not simply options to delay capital expenditure. The value of such options need to be taken into account when judging how much congestion is optimal.

Of course, the decision trees explored above only covered decisions about initial timings. Further sets of decisions would be needed about when and whether to invest in different types of landside links. Such decisions would need to be based on sensible risk weighted assessment of benefits and costs, taking into account the additional information then available, and using real options to factor in the value of remaining flexibilities.

3.3   Linkages to other models

In the examples above, variable values and formulae have been programmed directly into the decision tree. For simple, illustrative models this can work quite well. Once done, it is straightforward to use the sensitivity analysis capabilities within TreeAge to explore combinations of parameter assumptions that would imply a shift in strategy. Additional stochastic elements can be introduced, including quite powerful Monte Carlo capabilities.

However, large infrastructure investment programs often involve large and complex financial models, often developed within Excel. Instead of programming parameter estimates directly into the decision tree, it is also possible to define and alter parameter/cost and benefit estimates within Excel which can be fed through to different nodes. This combination of Excel and TreeAge provides powerful analytical tools which are capable of handling real-world complexities. Thus this type of decision tree modelling can actually be built as a layer over the top of existing financial and cost benefit-models. In addition, sophisticated macro capabilities, using a Visual Basic-like environment, are available within TreeAge or can be used in Excel through dynamic links.

In principle, the same comments can be made in relation to other approaches to implementing real options. Decision trees are especially well suited where decisions and uncertainties are big and lumpy – or can be reasonably approximated as such. Where uncertainties are more continuous time variations, often without a good understanding of causes, other methods may prove useful.

4 Other applications of real options

4.1 Some real world examples

4.1.1 Oil field development

Much of the early development of option theory was undertaken in the context of oil exploration. The licensing, exploration, appraisal and development process falls into stages, each of which can be pursued or abandoned according to the results of the previous stage. Hence licensing delivers an option over the subsequent stages. Further, the initial exploration can be regarded as a learning option, whereby the decision to proceed with full development of the field, on what scale and in what form, is made after additional information is gained from initial exploration and the monitoring of market conditions. The option value of the additional information is compared to the cost of obtaining the information in deciding whether to exercise the learning option – in this case undertake the exploration, during which time additional market information may become available.

Market-based risk has a significant influence on exploration decisions, in a form that makes it particularly well suited to options analysis. Instead of valuing the field on the basis of what it would be worth if development started immediately, the oil field is valued on the basis of its value as an opportunity to develop in the future, given variability in the estimated price of oil and the potential for new technologies to increase the size of the recoverable reserves. The several stages in oil exploration, each of which "purchases" an option to continue with the following stage, make it a good example of a compound option.

Similarly the decision to abandon a field can be examined in terms of the option value of keeping the field open and possibly benefiting from the development of new technologies. For example, the satellite unmanned gas platforms in the southern North Sea now make it possible to use processing capacity that would otherwise have become surplus as soon as the original reservoirs were exhausted.

4.1.2 Sydney metropolitan water strategy

Real options reasoning was brought to bear a few years back in work done by ACIL Tasman as an advisor to the Sydney Metropolitan Water Strategy, and then built into the planning process involving a wide range of experts. The introduction of a real options approach resulted in dramatic revision to the water strategy, with a political commitment that had been made to build and operate continuously a large desalination plant being changed to a decision to delay the build (once it was shown that this could safely be done), and then to build a smaller, scalable plant capable of intermittent operation. The cost savings from this shift to an adaptive management strategy opened up opportunities for very large cost savings, and for significant allaying of concerns regarding the potential environmental impact of the large desalination plant.

The changed strategy relied on much more complex and detailed modelling than that shown above, but the modelling was feasible based on existing hydrology models and data. It proved relatively straightforward to demonstrate that there was an adaptive strategy that

offered substantially lower expected costs, and at least the same level of water security, as could be provided by the deterministic approach that had been announced.

The main benefits flowed not from any refinement of the value of an investment in greater water supply capability, but instead from the way that the real options approach led to a different question being asked, and pointers to very different ways of meeting demands more cost effectively. The big gains came from the approach allowing a differently designed strategy to emerge from the planning process, and to be assessed as a viable and cost effective alternative. This is despite the fact that the Sydney water supply system was already designed for adaptive management, with sophisticated triggers guiding the management of usage restrictions and new investments in capacity. The big change came when a different investment assessment paradigm was applied to the comparison of alternatives.

4.1.3   Electricity markets

Electricity demand is volatile, demand trends are somewhat uncertain and market share for any given generator can be quite uncertain. Unplanned, short-lived and extended outages of individual generators can occur. The system has responded to these challenges using a portfolio of real and financial options. System capacity normally, for good commercial as well as social reasons, exceeds 'expected' demand almost all the time. This affords both insurance against the downside risk of having demand unmet in the event of a demand spike, or a system outage, but also affords individual generators insurance against the risk of seeing a large rise in market prices, but being unable to capitalise on these due to inadequate 'spare' capacity. Options can provide insurance against either or both of these downside risks, and risks of being unable to seize upside opportunities.

The same generators typically enter into financial options contracts with electricity retailers, substantially locking in prices provided that supply can be maintained. To secure their capacity to deliver on these options contracts, it is common for generators to maintain substantial peaking capacity that sits idle most of the time. That peaking capacity offers real options – a physical hedge against their own financial exposure to price spikes and protection for the system against demand surges and outages. System integrity and company financial performance can both be protected by this investment in extra, highly responsive, generation capacity. In the same vein, operators of hydro plants can sell options for very rapid response to system volatility – much faster than can be achieved by firing up a gas fired plant. The market ends up with access to a mix of complementary options to ensure its capacity can maintain system services and to allow the costs of such insurance to be passed through to market participants.

The opening up of electricity markets in Australia from the late 1980s revealed a different type of option inherent in the small (compared to traditional, usually coal-fired baseload) generation plants that had dominated generation in Australia. Where traditional planning by effectively monopoly providers had typically brought in new generation in very large chunks, creating surplus capacity for many years as demand gradually 'caught up, competing commercial firms have revealed greater sensitivity to the risks of investing in what may become stranded assets. While big baseload plants may offer the cheapest electricity, measured on a per kilowatt basis, they do not necessarily offer the cheapest insurance against supply shortfalls, given the major uncertainties in relation to demand trends, a company's share of the market and price outcomes. In recent years, these large plants have also carried significant risk in relation to plausible developments in relation to carbon pricing.

The market response has been to shift more strongly into smaller, intermediate and peak load facilities, commonly gas fired. This response, while entailing higher unit prices for electricity generated, offers greater value and better risk management in a competitive market setting. Uncertainty about forward demand trends are managed because the smaller units can more closely track actual growth in demand – with less need to bring in large blocks of what is initially overcapacity (entailing underutilised capacity and risks that demand does not grow fast enough to justify the costs). The gas fired units offer far greater flexibility to adapt to short-term changes in demand or system outages. The use of gas brings in reduced exposure to forward risks in relation to carbon costs. Overall flexibility is much greater. While unit costs of generation are elevated, so is the capacity to avoid incurring the costs of generation except at those times when the price of electricity is high enough to justify the elevated generation costs.

All the major participants in the electricity market are actively managing portfolios of options – both financial and physical (real) options. Failure to do so would certainly entail much greater risks.

4.2   Commentary on NZ papers

This section of the paper provides some brief comments on the NZ real options papers provided by the Ministry: a paper by Arthur Grimes (2010) and a presentation by Grimes (2011)

4.2.1   Grimes paper on cost-benefit analysis

The paper by Grimes takes a wider perspective than our paper: it provides quite a wide-ranging critique of cost-benefit analysis generally, one aspect of which is the inability of standard CBA to handle uncertainty and option value. The paper starts by identifying a number of well-recognised deficiencies of cost-benefit analysis, before focusing on four particular circumstances when the standard analysis can be deficient:

⎯ When there are network benefits or interactions, and issues of resource availability
⎯ When there are intangible benefits involved
⎯ When the project is servicing the international sector
⎯ When projects create option value

The discussion of real options covers similar issues of principle as our paper: thus it discusses the value of delay if delay can resolve uncertainty, and the benefits of breaking down a project into sequential stages if that can increase the information available to decision-makers. While the paper illustrates the principles with some simple numerical examples, it does not employ any decision tree analysis. Grimes' paper does refer to some additional complications not addressed by our paper, in particular when the benefits accrue to someone other than the initial investor, and when delay can result in the loss of first-mover benefits.

Grimes' paper also contains a thoughtful discussion of discount rates, which discusses the implications of using a social opportunity cost of capital, the social rate of time preference or the standard CAPM weighted average cost of capital. This discussion focusses on the difficulties that arise where there are intangible benefits, which concern problems of time inconsistency and inter-personal welfare comparisons.

4.2.2 Grimes presentation on treating a new bridge as a real option

The set of slides, and associated paper Grimes (2011b), provides some examples of the application of real options analysis in transport, namely the provision of the Auckland Harbour Bridge and the northern motorway extension. The presentation provides some background on the decision to build the bridge despite the uncertainties, and the manner in which traffic flows vastly exceeded expectations. It uses the motorway extension to demonstrate that option value can be very high – equal to the sum of all other CBA calculated benefits.

The presentation then works through two example applications of options analysis: the option value of waiting to resolve uncertainty and a two stage investment project (the first stage of which is a public investment and the second stage is a private investment). The slides show how a standard CBA can give the decision not to invest in the first (public) stage of the project, whereas an options analysis would conclude the project should go ahead because of its option value. In doing this, its perspective is very similar to our report.

Appendix A   Ports example decision trees

The following figures show the construction of the decisions trees for our ports example.

As discussed in Section 3.2, we consider the NZ government's decision on whether to invest in improved road links for a given port (Post X). Our assumptions are:

— Potential benefits from international trade of $1,000m

— A cost of building improved road links around Port X of $200m, which avoid road congestion costs of $300m in the vicinity of the port

— The cost of road congestion varies according to a number of factors, including whether transhipment increases, the extent of rebalancing between road and rail transhipment, and whether another port gains freight at the expense of Port X

— The cost of augmenting rail links on an incremental basis varies according to the extent of increased traffic on rail, between $200m and $400m

— The uncertainties are characterised as:

  – Whether there will be a further increase in ship sizes (with probabilities yes 70%, no 30%)

    〉 If yes, whether this will imply more transhipment (yes 80%, no 20%)

    〉 If no, whether transhipment will increase anyway (yes 20%, no 80%)

  – Whether there will be any re-balancing of transhipment traffic between rail and road (towards road 70%, towards rail 30%)[13]. (For the moment we are assuming no growth in coastal shipping).

 – Whether another port will gain traffic at the expense of Port X (yes 50%, no 50%).

Figure 10 shows the structure of uncertainties and outcomes if no road is built initially for Port X. Rolling back the decision tree shows a value of $715m, being the benefits of trade less the costs of increased road congestion and incremental rail expenditure.

Figure 11 considers the alternative option of investing in improved links for Port X up front. Rolling back the tree shows a net value of $655m, which indicates that the additional road expenditure is not warranted given the expected reduction in congestion it would allow.

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[13] Our assumption is very simplified, in that we have assumed that the increased transhipment will be handled by one or other of mode. In practice it is likely that a combination of modes would be used to meet the extra traffic.

Figure 10   **No initial road investment**
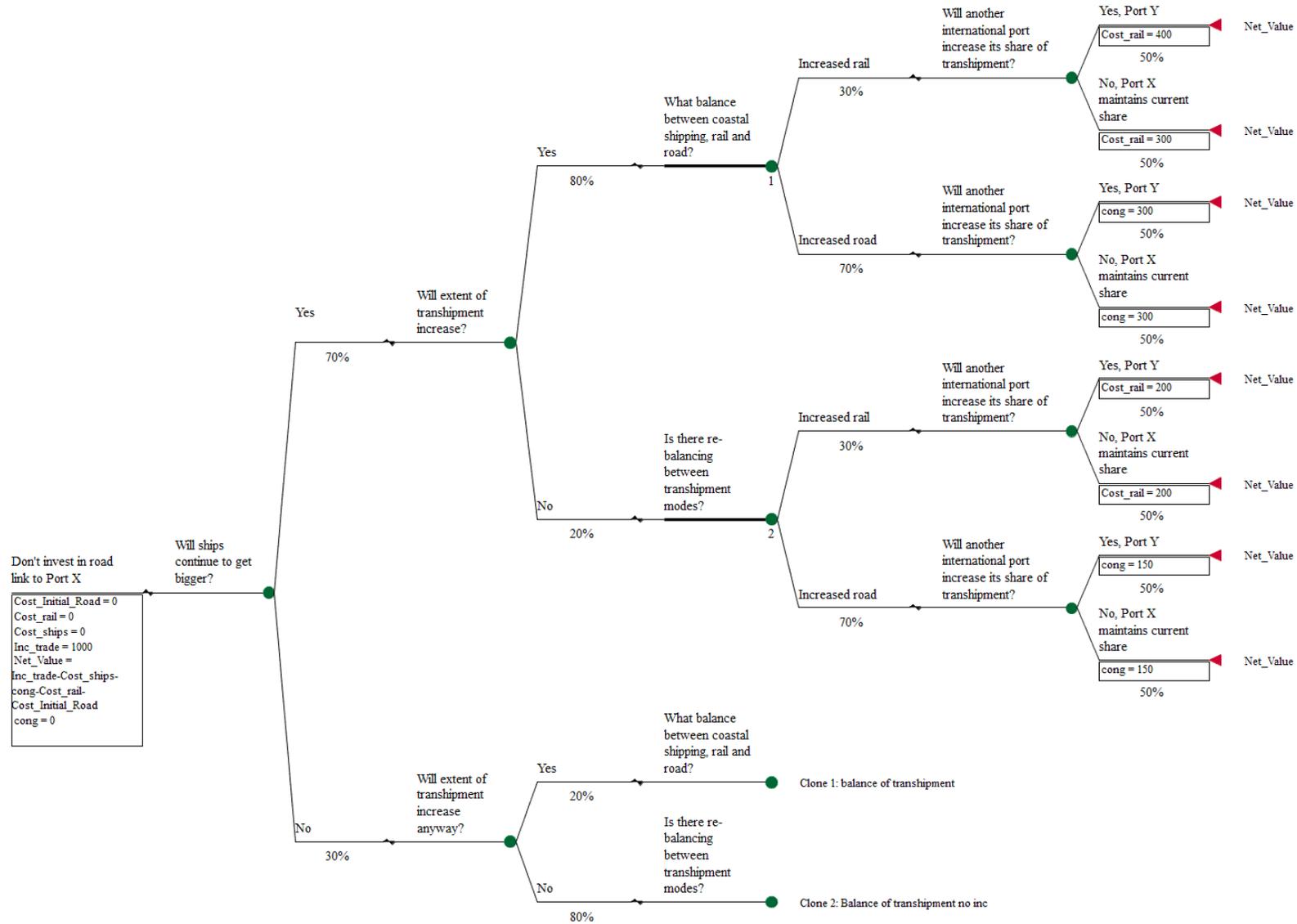
**Figure 11** **Initial investment in road links**
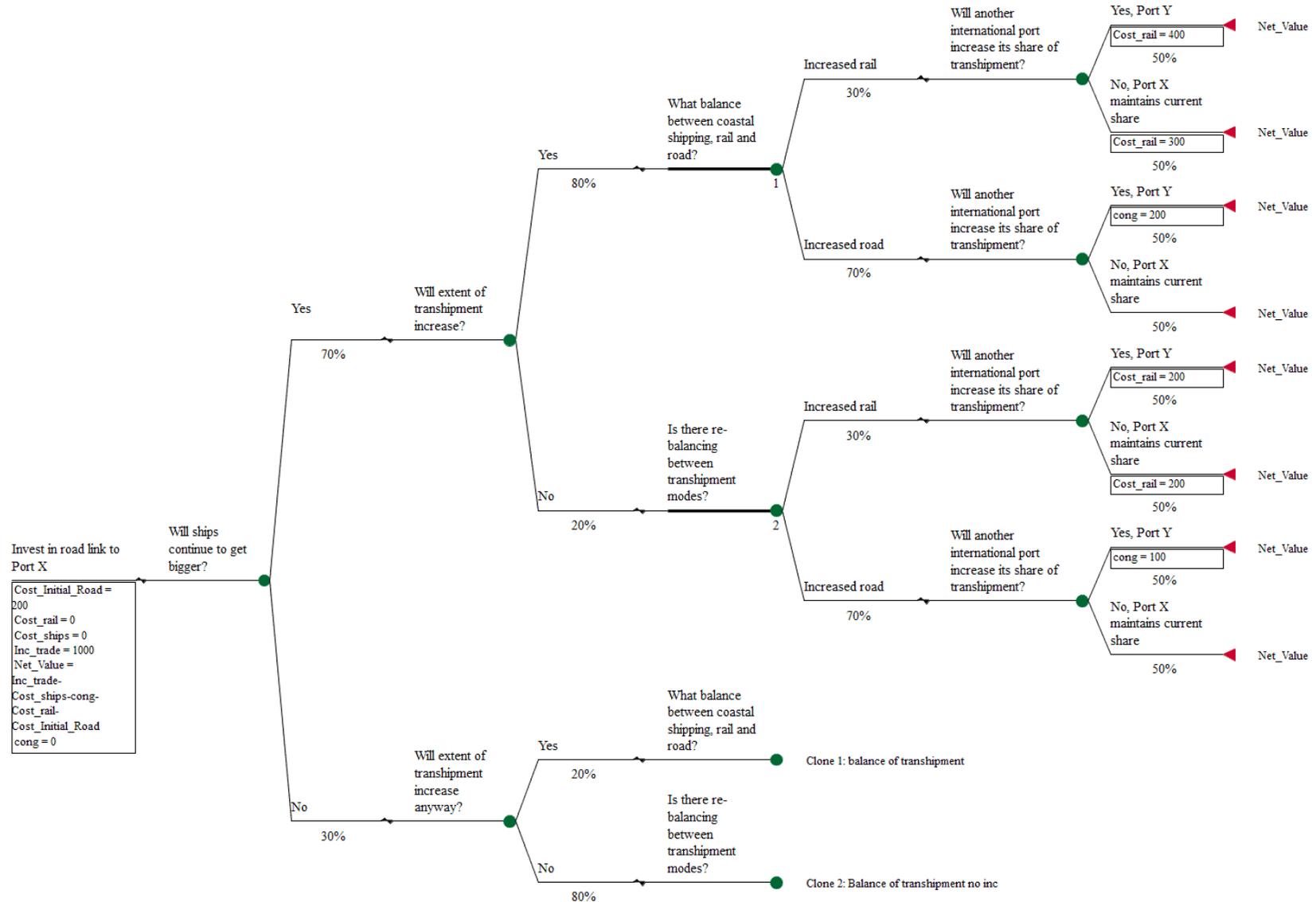
Figure 12 starts to explore the possibility of using shipping subsidies as one strategy to mitigate the expected costs of road congestion. Thus one possible option would be for government to encourage coastal shipping, as a temporary alternative to increased road/rail capacity while future traffic patterns emerge . Such a strategy could involve a low commitment to sunk capital costs, which allows the additional information to emerge at low risk. In other words, it represents an investment in insurance which allows the creation of real data and allows the decision on landside links to be optimised.

Such a strategy could be undertaken by temporarily subsidising the lease of additional coastal ships, in an attempt to mimic the cost structures that would apply in the future were a major link to be built . The introduction of subsidies may not at first sight be attractive. However, such subsidies should be seen in the context of providing an option to hedge against the risk of very much larger subsidies being provided to exporters and importers via overinvestment in road and rail links. Since the latter risk would be borne largely by the community, then a 'testing' strategy that generates new information options might be defensible.

Whether subsidies to encourage coastal shipping would be cost effective depends on whether the reduction in the risk of inappropriate investment in landside links more than compensates for the amount of subsidy involved. The objective of the subsidy would be to ensure that the user cost of transhipment by coastal shipping is comparable to the other modes that would be viable if the link were built. Such a subsidy would not be permanent: it provides insurance against underinvestment and excessive congestion, while the additional information is gained to enable the better investment decisions to be made on landside links.

Figure 12 starts to explore the flexibilities opened up by such as strategy, and in particular the benefit of using shipping subsidies to reduce the expected congestion cost of under-investing. This would allow subsequent investment in landside links to be better targeted towards meeting future freight flows. The figure is more complex than the previous trees, as it introduces the choice of coastal shipping as an additional transhipment mode.

The tree assumes that the subsidy for shipping costs $200m, and that this results in a 50% probability that any increase in transhipment will take place by shipping rather than rail or road. Rolling back the decision tree gives a net value of $811m. This is better than the other options, since it avoids much of the congestions costs but with a smaller commitment to upfront costs. Note that this decision tree is applying similar reasoning to the earlier stylised tree shown in Figure 7 (the partial reduction in uncertainty case). The general point is that any reduction of uncertainty in advance of locking into substantial fixed costs can have considerable value.

Figure 12 No initial investment but with shipping subsidy
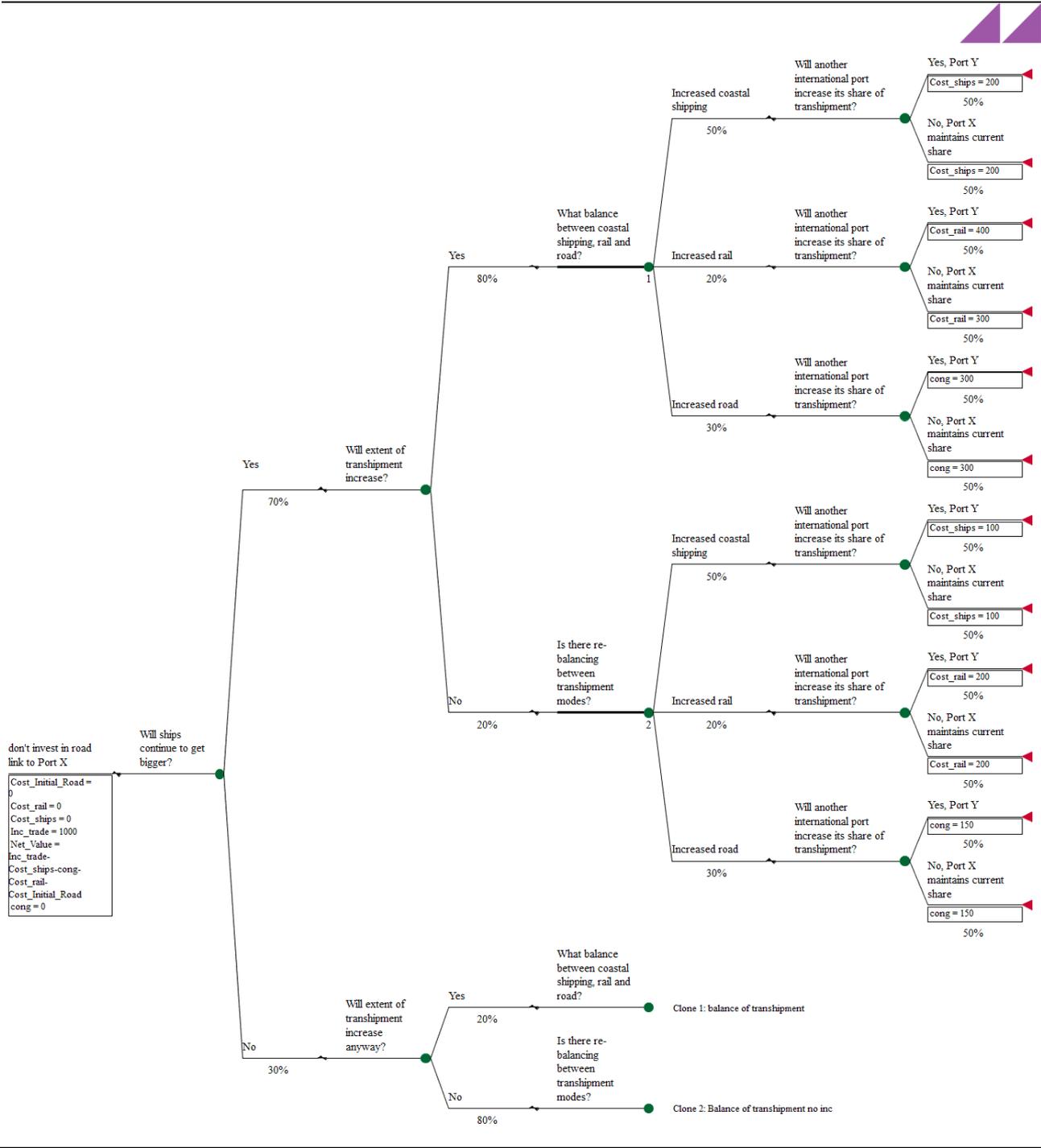
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