Adaptive Investment Management
Using a real options approach in transport planning

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Ministry of Transport
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Ensuring our transport system helps New Zealand thrive

New Zealand Government

1. Introduction

Investment in long-lived transport infrastructure such as roads, railways or ports is subject to uncertainty[1], especially on the demand side. Failure to manage uncertainty can result in costly mistakes in either direction: white elephants or unacceptable levels of congestion. The real options approach helps deal with this problem.

Recent Ministry of Transport strategic work[2] has highlighted uncertainties that have implications for transport investments. For example, there are plausible scenarios that see car travel either increasing or decreasing.

Traditional techniques such as cost benefit analysis do not cope well with uncertainty[3]. High and low sensitivities around a forecast are essentially arbitrary. A higher discount rate just penalises long life projects, common in transport. These tweaks do not encourage the decision making process to adapt as events roll out and they do not help planners identify how best to invest in reducing uncertainty. Their common problem is that they rely on whatever information is available upfront; they produce a deterministic approach when some of the variables are not well determined.

The real options approach aims to encourage decision makers to consider uncertainty during option development and to incorporate flexibility in the investment decision-making process. It helps planners reduce risk of a worse-than-expected outcome and take advantage of upside opportunities as they emerge. It is conceptually simple and is a useful adaptive investment management tool.

An everyday example is house insurance – you buy the option to get your house rebuilt if it burns down (and forego the option to spend the premium payments on other things) but you hope not to exercise the option.

Real options in ancient times[4]

Alexander the Great and Julius Caesar both managed their armies in the field using real options principles – developing a diverse and flexible overall strategy for engagement with an enemy, 'investing' in additional information through the use of scouts and spies ahead of committing his forces to battle, and adapting the battleground strategy to information as it came in and to evolving threats and opportunities as their likelihoods changed. Calvary were held back, and often hidden, for the flexibility they offered to respond rapidly to an emerging threat or to capitalise on an emerging weakness in the enemy forces. These are classic examples of the acquisition and selective exercise of real options – with information and flexibility driving the adaptation to strategy, limiting downside risk and opening up greater access to the upside.

A transport example is a road serving a port whose fortunes may or may not improve as ship sizes increase. We could decide to build or not build an improved access road to the port, and later regret having either a white elephant or serious congestion. A real options approach points to preparing to build the road – e.g. planning, preservation of an easement, approvals – but delay the actual construction decision until demand information becomes firmer (in the meantime making small investments in chokepoints if necessary).

This summary report is largely based on a report by ACIL Allen Consulting[5]. The approach is explained in the next section. Section 3 explains how to carry out a real options analysis. The appendix has an illustrative example.

[1] "Risk" differs from "uncertainty" in that the former has an objective probability distribution and the latter does not. The terms are sometimes used interchangeably as real world examples are often in between. This summary report is mainly concerned with the unknown-probability type.
[2] *Future Demand* and *Economic Development and Transport*, on transport.govt.nz
[3] However broader forms of cost benefit analysis can embed the real options approach.
[4] Source ACIL Allen personal communication
[5] *Adaptive investment management – using a real options approach in transport planning,* ACIL Allen Consulting 26 June 2014.

2. What is the real options approach?

In the financial markets, a financial option gives the bearer the right, but not the obligation, to buy (a call option) or sell (a put option) a financial security at a fixed price during a pre-agreed time period in the future.

The real options approach applies this financial options theory to real investments such as roads. The real options approach allows decision makers to retain the right, but not the obligation, to exploit various 'go' and 'no go' opportunities in the future.

The rationale for the approach is that due to the presence of uncertainties, the value[6] (or payoff or net benefit) of a project can change before the project is completed. If the value goes down we would be worse off if the commitment cannot be altered.

A real options approach provides for future adaptation by creating and preserving flexibility, to deal with the uncertainty associated with an investment.

Real options can take a number of forms:

- ***The option to expand or downsize a project in response to changing demand*** – a staged or modular approach creates options to expand or contract in the light of information emerging after commencement.
- ***The option to defer investment*** – If demand is uncertain the decision maker can exercise the option to defer the project until the uncertainty is resolved, to avoid committing to potentially redundant investment if demand turns out to be low.
- ***The option to abandon or temporarily shut down staged investment*** – If new information indicates lower demand than first thought, the decision maker can exercise the option to abandon or mothball future stages of the project
- ***The option to switch the way demand is met*** – It is worth trying to keep open the option of changing a project to take advantage of new technology or information that may become available.

Each of these options –expansion, downsizing, deferral, abandonment and modification – adds value to a project by allowing decision makers to exploit upside opportunities (e.g. project expansion) while limiting downside losses (e.g. abandon or downsize).

Examples of types of decisions where real options analysis can help

- the optimal time to invest in transport capacity, land development or resource extraction
- research and development, and related learning
- large versus gradual/scalable/modular capacity expansions
- investments that have multiple stages, creating continue/modify/delay/abandon options
- temporarily suspending operations; mothballing
- switching between different outputs or transport modes
- timing of asset replacement
- whether to preserve an easement for a future road or railway

Building in flexibility makes it easier to make the decision in the first place, because the effects of the 'worse case scenario' are recognised. Indeed, some projects that would fail an up-front cost benefit analysis may go ahead under real options, because the downside is managed, as shown in the following table.

[6] Usually expressed as a net present value.

Example of a project that fails a standard Cost Benefit Analysis and passes under real option analysis:

Standard CBA ignores flexibility					
A decision is made upfront and the full investment is made in the initial period. There are high and low revenue forecasts, each assumed to be equally likely. The result is an expected loss.					
Period	1	2	3	4	
Revenue Possibilities $m					Odds
High	2.5	4.0	4.0	4.0	50%
Low	2.5	1.0	1.0	1.0	50%
Capital costs $m	3.0				
Variable costs $m	2.0	2.0	2.0	2.0	
Expected cash flow $m	-2.5	0.5	0.5	0.5	
NVP (0 discount rate)	-1.0				

Value increased if incorporate flexibility					
Discover more information (wait to see if the price is high) and invest only if favourable					
Period	1	2	3	4	
Revenue possibilities $m					Odds
High		4.0	4.0	4.0	50%
Low		0.0	0.0	0.0	50%
Cost if high revenue $m					
Capital costs	0.0	3.0	0.0	0.0	
Variable costs	0.0	2.0	2.0	2.0	
Costs if low revenue $m	0.0	0.0	0.0	0.0	
Expected cash flow $m	0.0	-0.5	1.0	1.0	
NVP (0 discount rate)	1.5				

Another option may be to build in period 0 and mothball if prices fall - NVP = $0.5m

The real options approach is only useful where there is uncertainty and the opportunity to build in flexibility[7]. Its value is likely to be higher:

- for decisions with high uncertainty but where better information may become available
- for irreversible investment opportunities with longer horizons
- for projects that can be structured into multiple stages with opportunities after each stage to continue, alter or delay.

A real options approach does not eliminate the chance of downside risk. Rather, it seeks to minimise the cost of downside risk and maximise the value of upside opportunities.

[7] However real options may not help if the construction time is uncertain – it may then be wise to just start building the project.

3. How to carry out a real options analysis?

There are three key steps to identifying and creating real options in investment decisions:

- Determine the possible need for an investment
- Identify the nature and timing of the key uncertainties
- Probe the scope for adding value by building in or exploiting flexibility.

3.1 Determine the possible need for an investment

To determine whether there is a real need to invest, ask:

- ***Do we need the investment?*** This is part of a problem definition exercise. Do not make any assumptions about how a need should be met. Focusing on the problems or issues themselves will ensure that various cost-effective solutions, which may or may not involve investment, are considered. For example, do not just say you need more road capacity when your concern lies with congestion costs and travel times. Do not extinguish options before they are considered.
- ***What are the size and scope of the impacts of not investing?*** Answers to this question can help to assess investment need. It suffices to understand the order of magnitude rather than estimating the impacts precisely.
- ***Is the investment required now? Or in the future?*** This will help to understand whether the investment can be deferred. If investment is needed now, this will limit the options to be considered.
- ***Can the project be broken into a portfolio of projects?*** A modular design helps preserve flexibility – e.g. a road constructed in a way that is easy to widen. In energy a peaking plant (cheap to build, expensive to run) may be better than building more base-load capacity.

The answers to the above questions help to define investment needs as well as provide the information needed to design the real options available.

3.2 Identify key uncertainties

Uncertainties can be classified as those internal to the project and those external to it. Internal uncertainties include geological and hydrological conditions and construction cost escalation. External uncertainties include influences on demand and future energy prices.

When identifying the key uncertainties facing an investment decision, consider whether they can be resolved or reduced in a reasonable time. Consider also how the sequence of events may pan out. 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 definition, the need to invest and the real options available.

3.3 Build in and preserve flexibility

For projects with large sunk costs, the scope for later regret can often be minimised by building in or preserving flexibility.

Examples of flexible decisions include:

- Disaggregate the project into stages, the first of which (eg research, design, planning) buys both information and time and is usually cheap. This retains the option of construction and creates the options of allowing high cost elements to proceed later, more slowly or not at all should the anticipated demand not materialise.

- Embed a non-asset approach (such as research and development investments) in the process to allow more information to be collected to inform a future decision. This strategy can help with resolving uncertainties that are both internal and external to the project.

- Engineer the investment to accommodate future capacity expansion, rather than committing to high capacity up front. A variant is a modular or "scalable" approach

An example of scalable investment
A new road north of Perth was planned in the face of uncertainty about whether or not the iron ore industry would continue to boom. The road was therefore designed so extra lanes and interchanges would be easy to add. The iron ore industry later slowed down and unnecessary road expense was avoided.

A transport example that brings uncertainty and flexibility together is that of preserving easements for future road or railway lines. By preserving the easement, the option of constructing the road or railway is maintained and the risk of much higher tunnelling costs (under whatever would have been constructed on the easement) is avoided. But the preservation is not costless – it destroys the options of making other use of the land, in extreme cases having a "blight" effect (e.g. houses falling into disrepair along the easement for the extension of the Wellington motorway south of the Terrace tunnels). The alternative use in rural areas may have low value but in urban areas may have a high opportunity cost. A halfway house is to allow construction on the easement of cheap limited-life buildings of the "shed" type with the title stipulating possible resumption of the land any time after x years. Allowing full residential or commercial construction would make resumption economically and politically difficult.

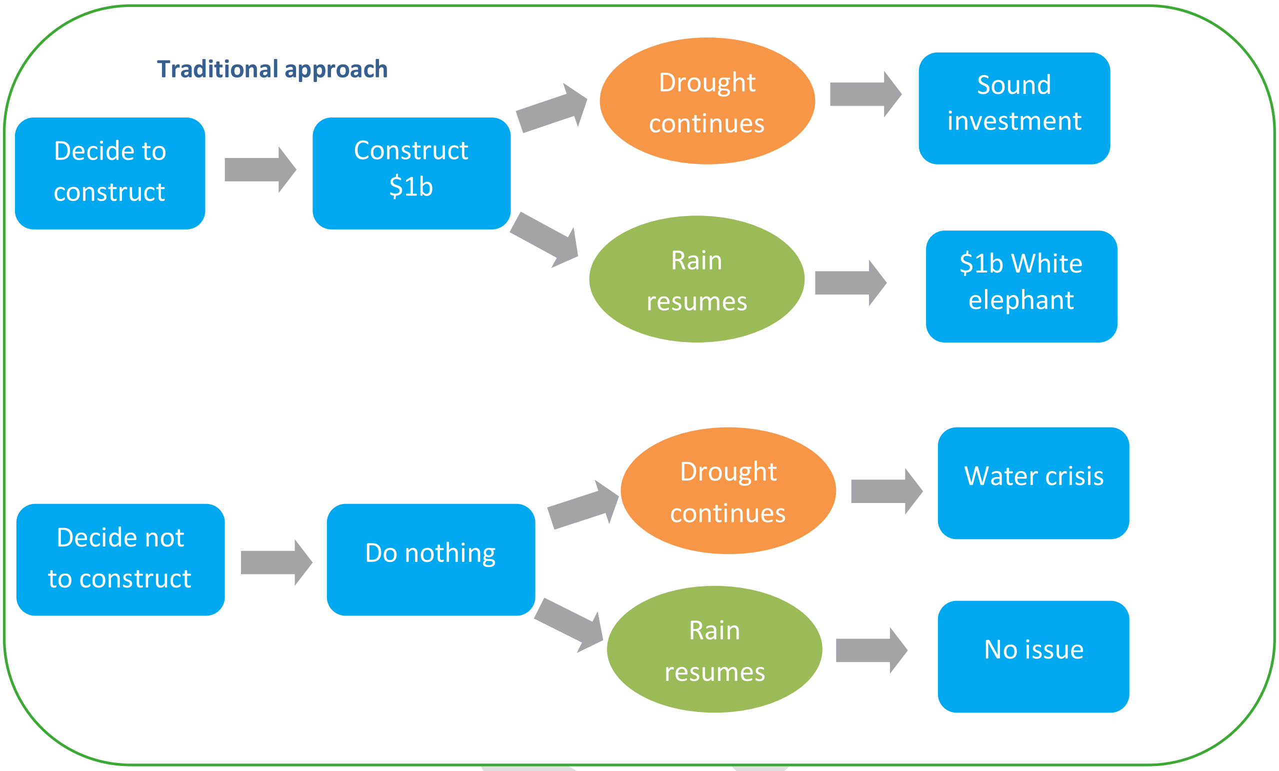
Other transport examples are:

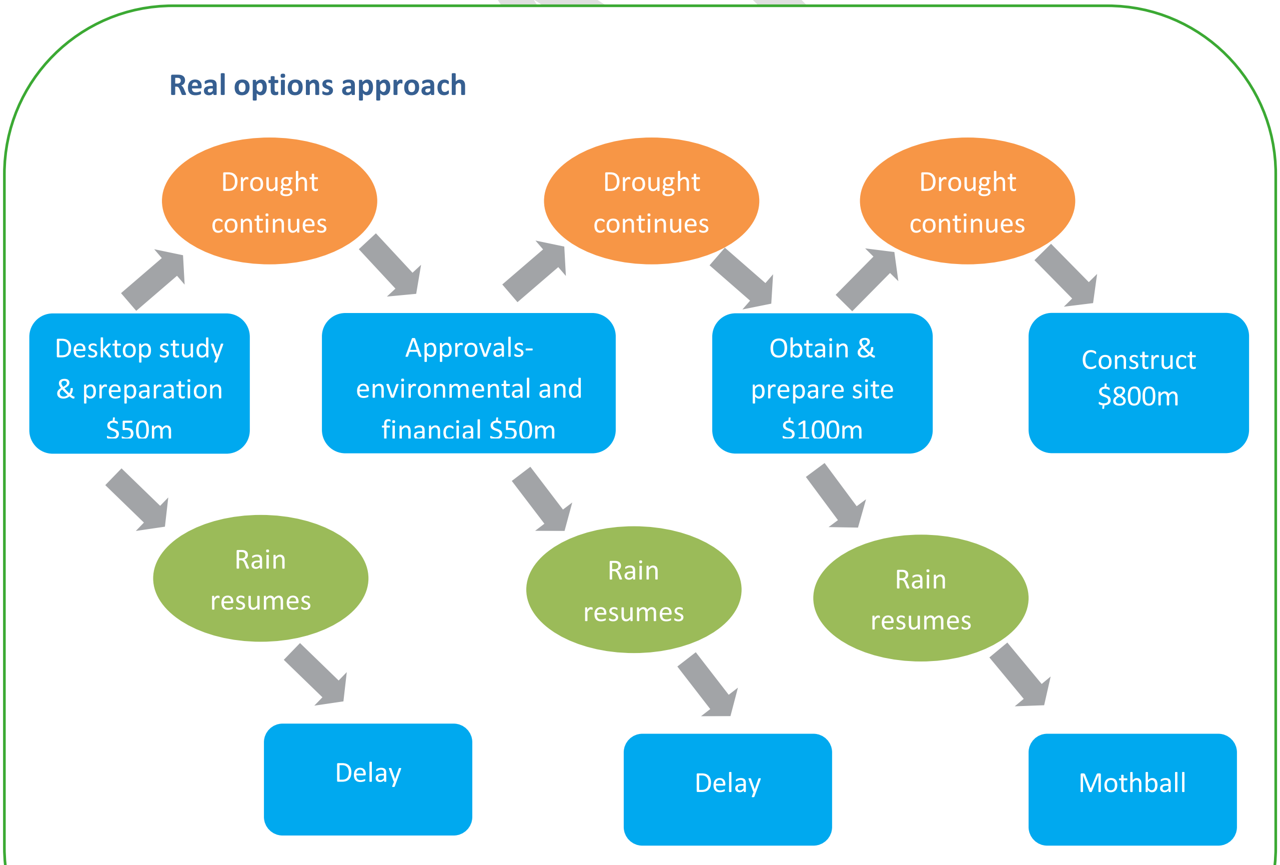
- To prepare for lengthening or shortening of an airport runway, but delay construction but delay construction until there us greater certainty about airline demand.
- To prepare for urban road improvements but delay construction to see how much uptake there is of vehicle sharing (and other traffic reducing) apps.

The full report by ACIL Allen Consulting contains several other transport and non-transport examples such as oil field development, metropolitan water strategy, electricity markets and landside planning for ports in New Zealand.

The following page shows an example of applying staged approach to the water sector during a prolonged drought. Desalinisation plants offer a way to get more drinkable water from the sea but are expensive to construct and operate. The first box shows that a decision to build one could prove to be a waste of money, while a decision not to build could result in severe water restrictions. The second box shows a staged approach which builds in the flexibility to choose the best option as new rainfall information comes in.

Water Desalinisation Plant example





Retains the option to construct and the option to potentially avoid spending $800 to $950 million on a white elephant.

3.4 Putting it together

There are three commonly used techniques for carrying out a real options analysis:

- ***Decision trees*** – these map the sequence of decisions that define the project together with the sources of uncertainty. They start with the initial proposition, such as a proposed project, and branch out into a succession of "nodes" as more information becomes available and decisions are made between the options that emerge. Each decision node[8] in the tree represents a possible price of the underlying asset at a given point in time. An example is given in the appendix.

  The option value (payoff or net benefit) is calculated iteratively, starting from the final nodes (which show the value of each outcome), and then working backwards through the tree towards the first node.

  The key steps of a decision tree approach are to:

  - create the decision tree
  - find the option value at each final node
  - find the option value at earlier nodes

  To calculate the option value at the final and earlier nodes, it is necessary to determine the probability of occurrence. However usually there is no need to value the option. It suffices to determine that a strategy with the option is worth more than one without. This requires a capacity to rank, not value – and can often be achieved by working with lower and upper bounds on probabilities. These can be modified as new information comes in.

  Once all of the potential options are identified other tools, such as net present value calculations, can be used to evaluate the potential outcomes of each option.

  Although this approach is relatively simple to use conceptually, it can handle complex decisions that can be challenging using other approaches.

- ***Simulation*** – This is a technique[9] to estimate the distribution of possible outcomes. However, it is not straightforward to determine the policies that maximise statistical expected value given the information available at the time. Simulation is a useful tool for determining the expected value or payoff of the real options.

- ***A Valuation model*** – This is based on a formula developed for valuing financial options (the Black-Scholes model). The parameters of the financial options formula are replaced by their real options equivalents – the present value of the expected payoff (i.e. share price); the investment required (i.e. exercise price); the value lost by delay (i.e. dividend); variability of benefit and cost streams of the project (i.e. the variance of share price) and the period for which the investment opportunity is available (i.e. time to expiry).

  If information is available, the application of the Black-Scholes formula is straightforward, but It is built on assumption that may not apply to transport.[10]

Considering the relative strengths and weaknesses of each approach, the decision tree approach is by far the most flexible and powerful if there are a small number of major uncertainties, and is conceptually simple to apply. In the appendix, a simple example is used to illustrate its application. In more complex cases decision tree software and simulations are useful.

[8] There are two types of node: a chance node, which identifies where an external event will influence the project and sets out the probabilities of different outcomes or branches eventuating; and the decision node, where the value of the assets at that point can be assessed taking on board the relevant uncertainties.
[9] Monte Carlo simulation, a problem solving technique used to approximate the probability of certain outcomes by running multiple trial runs, called simulations, using random variables.(www.investopedia.com)
[10]This model assumes a continuously replicable portfolio and that the pricing of the underlying asset satisfies a range of constraints, including that prices move continuously. In practice, many of the important risks facing transport investment decisions are discrete in nature.

4. Conclusion

There is much to be uncertain about with the future of transport – e.g. new vehicle technologies, the exploiting of "big data" for traffic management and journey planning, changing social attitudes by young people to cars and biking, larger and more efficient trucks and ships. Alternative plausible scenarios point to different future demand patterns. It has become imprudent to make decisions about investment in transport infrastructure, which typically has a long life, on the basis of existing information and simplistic projections of past trends.

The real options approach deals with the uncertainty problem by preserving the option to construct something that turns out to be needed while avoiding most of the cost of constructing something that turns out to be a white elephant. It maintains the upside while managing the downside. It works by building flexibility into the investment decision-making process so that it is possible to change course as new information comes in.

Real options are particularly relevant to investments in road, rail and port infrastructure. They are also relevant to decisions about preserving future opportunities and to deciding whether to mothball redundant facilities. They offer the potential to achieve good transport outcomes while spending substantially less than with the classic approach that is limited by the information available at the outset.

Appendix - An illustrative example: buying a house

The following example is inspired by Dobes (2008)[11].

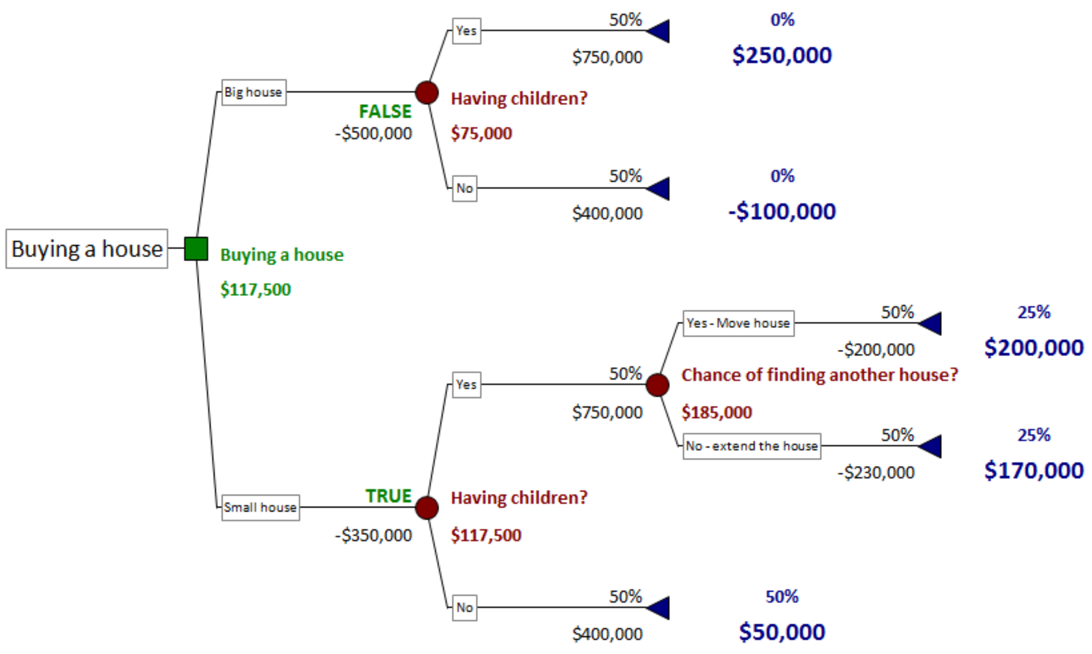
A newly-wed couple is contemplating buying a house, but uncertain about when, or if, they will have children, or how many children. Buying a large house immediately could be unnecessarily costly if they remain childless, or if they delay starting a family for a significant time. But they could buy a smaller, cheaper house on a suitable block of land and extend it later or move, as required. The smaller house in effect 'embeds' an option to extend or move, but there is no obligation to do so if the family remains small. The couple is buying the option of a big house while retaining the option of a small one. If instead they decided upfront, they could end up stuck with the wrong size of house.

Assume the following expected costs and benefits (both in present values):

- Investment cost of a bigger house is $500,000 and a smaller house is $350,000.
- If the couple has children, they can look for a bigger house and move at a cost of $200,000. If they do not find the right house, they could extend the house at a cost of $230,000. The probability of whether the couple will find the right house is 50:50.
- The expected benefit from owning a house and having children is $750,000. The expected benefit from owning a house without children is $400,000.
- The probability of whether the couple will have children is 50:50.

Figure 1 shows the decision tree for this example. Final expected payoffs are illustrated in blue; expected costs or benefits are illustrated in black and the expected payoffs at decision nodes are illustrated in red.

Figure 1: Decision tree analysis of whether to buy a house



Key for dollar values:
Blue = expected final payoffs
Black = expected costs (-) or benefits (+) for each branch
Red = expected payoffs at chance nodes
Green = expected payoff of the overall decision

[11] Dobes, L (2008), "Getting real about adapting to climate change: Using 'real options' to address uncertainties".

From the first branch of the tree (buying a big house at a cost of $500,000), the final nodes are the expected benefits of having or not having children ($750,000 versus $400,000). The expected final payoffs (expected benefits less costs) are $250,000 (if the couple have children, being $750,000 - $500,000) or -$100,000 (if the couple doesn't have children). Based on a 50% probability of having children, the expected payoff from buying a big house is therefore $75,000 (being 0.50 * $250,000 + 0.50 * -$100,000).

For illustrative purposes, in this example the uncertainty and benefits of having children are the same irrespective of the size of the house. Therefore, the second branch of the tree (buying a small house at $350,000) has the same expected benefits from having children as in the case of buying a big house. However, in this case, the final nodes of the second branch are different because once the couple find out whether they are having children they need to either move or extend the house.

Working backwards, this second branch has expected payoffs of $170,000 (if they have children and decide to extend the house, being $750,000-$350,000-$230,000), $200,000 (if they have children and move, being $750,000-$350,000-$200,000) or $50,000 (if the couple is not having children and stay the same house, being $400,000-$350,000). Based on a 50% probability of having the house extended instead of moving, the expected payoff from having children with house extension/move is therefore $185,000 (being 0.5 * $170,000 + 0.5 * $200,000). Further, based on a 50% probability of having children, the expected payoffs of buying a small house is therefore $117,500 (being 0.50* $185,000 + 0.50 * $50,000).

Comparing the expected payoff of buying a big house of $75,000 and that of buying a small house of $117,500, the best strategy would be to buy a small house and wait for the uncertainty about whether to have children to resolve before deciding whether to extend the house or move.